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Do Variations in Urban Form Affect Environmental Quality?

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Executive Summary of the Final Report of Project No. R-801419, "Land Use Forms and the Environment," completed for the Environmental Protection Agency by a research group at the University of Chicago.

F O R E W O R D

Ways in which the demand for energy and other basic resources can be lessened by more appropriate urban design are developing as a continuing theme of IIASA's Project on the Management of Urban and Regional Systems. It is a theme which cross-cuts and integrates many of the other concerns of the Institute, and from comments received from national member organizations, it is of considerable interest to persons charged with the formulation and implementation of urban plans.

As the first formal fruit of our developing cooperation with other research groups sharing these interests, we are pleased indeed to present this summary and synthesis of work on the relation between urban land use and environmental quality carried out by a team under the direction of Professor Brian J. L. Berry at the University of Chicago. Professor Berry, who is both Chairman of the Geography Department and Director of the Center for Urban Studies at Chicago, also finds time to serve as a member of the International Advisory Committee on IIASA's urban work.

Harry Swain
Project Leader

CONTENTS

List of Figures

List of Tables

I. CONCLUSIONS

The principal finding of this study is that urban form plays a significant role in translating basic city characteristics, such as size, economic base and income levels, into land use, and that the land use pattern is directly related to the nature and intensity of environmental pollution. Hence, urban form is a significant variable in pollution relationships, viz:

(1) After taking into account, size, density, economic functions, etc. a core-oriented radially-structured urban form reduces pollution levels, while a dispersed pattern of low-density urban sprawl increases them.

But the study also shows that:

(2) The net benefits of urban life, as indexed by aggregate property values and therefore including agglomeration economies and net of negative externalities, are greater in more dispersed urban regions.

The resulting land use policy problem is that the urban forms that are emerging are responses to the greater aggregate net benefits of the more dispersed forms. Decentralization is therefore continuing apace, but with the obvious consequence of increasing the nation's environmental quality problems. There is a fundamental conflict, therefore, between an economically-desirable urban form as indicated by the aggregate choices of individual Americans and that form which might be most desirable from the viewpoint of the environment.

II. PREFACE

A few words of background are important. Under the provisions of Project No.R-801419, "Land Use Forms and the Environment," undertaken for the 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 will be 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, 144 tables, 107 figures, references). It was felt by the Agency staff that the report was too long for wide circulation within the Agency with any likelihood of being read in detail, and so a much briefer "executive summary" was requested highlighting 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 written and Agency--to which we could turn for reasonably compact 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 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 basis of the standards. As might have been expected, the search was in vain. No agency has the responsibility for drawing together what is known and thus none does; nor, with a few notable exceptions, have professionals done the job.

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 will not be reviewed in this summary.

Instead, this document focusses on the original findings of the research group, comprising faculty members and students in The Department of Geography and/or 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 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 effort 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 involve 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 feelings should be known at the outset: collection of data on environmental quality is in a primitive state at this time. Gaps and inconsistencies abound. The nation's environmental data banks use the monitoring networks now available selectively and incompletely (as in the case of the National Air Surveillance Network) or they assemble all available data, regardless of source, completeness or quality into a poorly-functioning data bank (as in the case of the STORET system for water quality). In other cases, comparative nationwide information is totally lacking (solid wastes and noise), or is at a scale that does not permit detailed investigation of the effects of different urban forms on environmental quality (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 have significant incremental effects on environmental quality.

III. CONCEPTS AND DATA

The finding that urban form does have significant incremental effects on environmental quality is to be understood within the framework of a conceptual schema that was used to structure the research, and a body of data that was used to assess the validity of the concepts.

Conceptual Background

Figure 1 details one of the overarching concepts, and Figure 2 the second. We believed there to be substantial reason in urban economic theory for arguing that the key elements of an urban region's economic base are determined by the ecoı

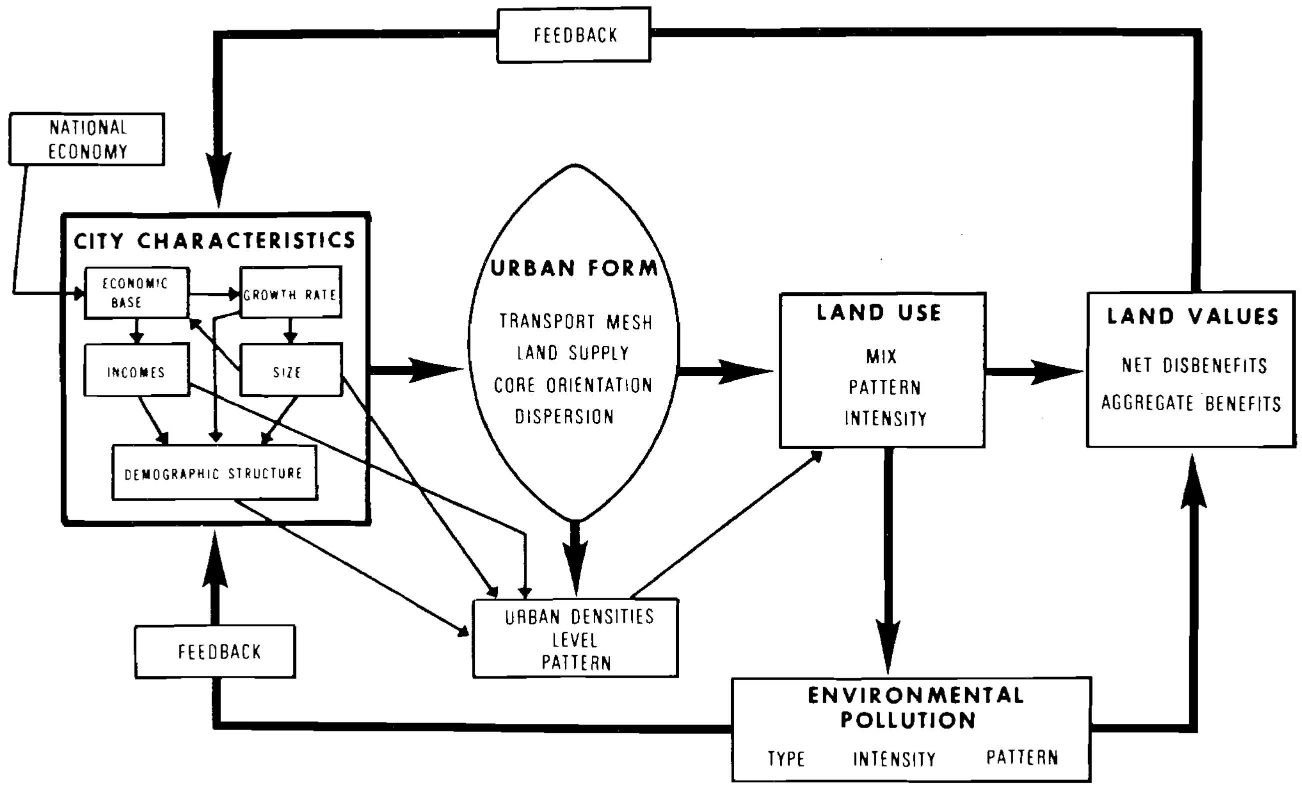
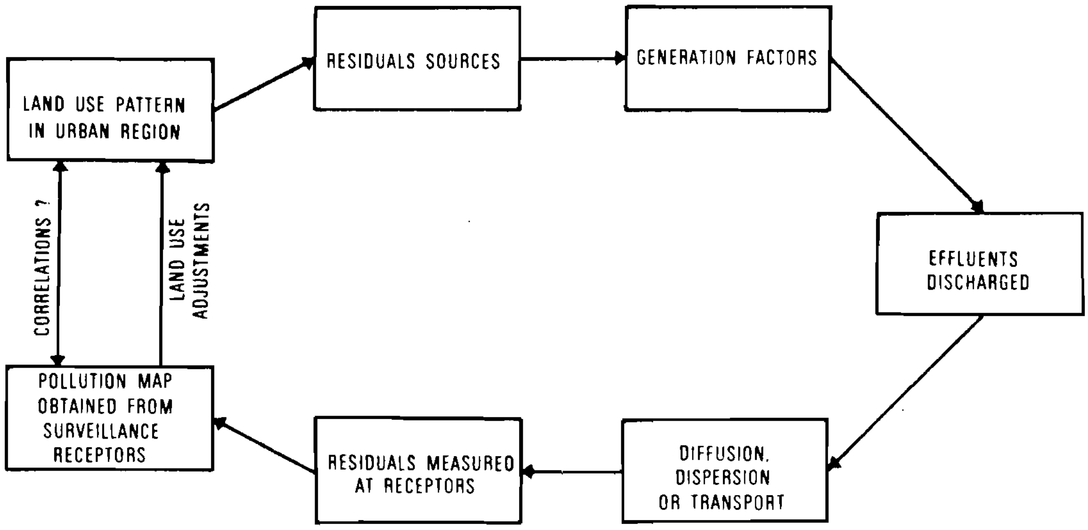


FIGURE 1

THE LINKS BETWEEN THE URBAN ECONOMY,
LAND USE AND ENVIRONMENTAL POLLUTION

FIGURE 2

PATHS LINKING LAND USE AND ENVIRONMENTAL POLLUTION,
AND RESEMBLING CORRELATIONS OF THE TWO MAPS



omic role played by the urban region in the nation's economy. The economic base, in turn, determines the metropolitan growth rate, size, income levels, demographic structure, and the level and pattern of urban population densities. We also felt it to be obvious that <u>within</u> urban regions, land uses are the sources of effluents and that, knowing locations of land uses and generation factors, patterns of residuals discharges can be charted and, via diffusion, dispersion or transport mechanisms, related to the pollution patterns observed by a surveillance network.

Urban form was conceived as playing an important role in <u>translating</u> city characteristics into land use. The transport network, for example, helps determine the location of economic activities and residences. Whether or not the inherited urban structure is highly concentrated or dispersed determines the land supply, and whether, at any given level of aggregate demand, land is used intensively or extensively. Concentration and dispersion, in turn, both result from and help determine the transportation patterns and modal mixes 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 determines land values, and others have shown that environmental pollution reduces these values, for--given well-functioning markets--the price of land and the capital assets located on it will equal the present value of the anticipated future stream of net benefits expected to flow over the useful life of the assets. If this is true for individual properties, it should also be true of all properties within an urban region: aggregate land values should include the agglomeration economies of large urban complexes, and should be the net of disbenefits such as the negative externalities imposed by discharge of pollutants into the urban environment. Further, high values should accrue to the comparative advantage of the urban region in the national economy, while low values resulting from higher levels of environmental pollution should detract from this comparative advantage.

The overall conceptual model depicted in Figure 1 thus postulates that metropolitan characteristics are the determinants of land use, with an intervening role played by urban form. 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 at the aggregate level of the metropolitan region, and the determinant--as shown in Figure 2--of the pollution map that prescribes where, and on whom, the incidence of negative externalities is greatest within each metropolitan area. 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, densities, income levels, etc.

(ii) Land values as a function of city characteristics, urban form and environmental pollution, to see 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 are related to details of the pollution map on a case-study basis. Only in the case of air pollution were comparisons of several metropolitan areas possible.

A Nationwide Data Set

We attempted to assemble the best data set possible. After much exploration, it was found that 76 was the greatest possible number of metropolitan regions that could be included in the study, because of limited availability of air quality data, viz:

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

These 76 metropolitan areas are located in Figure 3. For as many of these regions as possible, the data listed in Table 1 were collected. Details will be found in the main report.

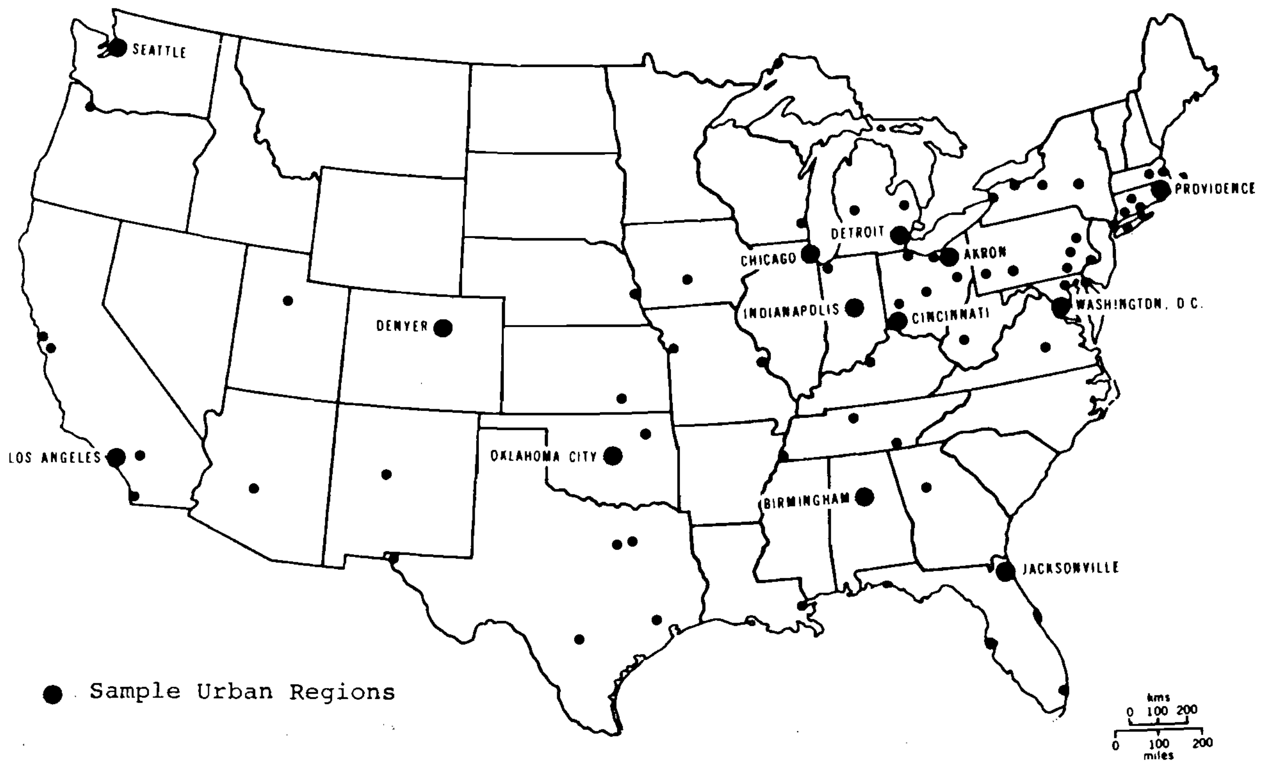


FIGURE 3

MASTER SET OF METROPOLITAN AREAS

TABLE 1

LIST OF VARIABLES WITH UNITS OF MEASUREMENT

Variable		Unit of Measurement
	1. CITY CHARACTERISTICS	
1970	City Population	1000's
	SMSA Population	1000's
	City Density	Pop./sq/mile
	SMSA Density	Pop./sq/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	sq. miles
	Land Area, SMSA	sq. miles
1967	Total Value of Real Estate, SMSA	$1,000,000's
	2. URBAN FORM INDICATORS	
Degrees of Arc of SMSA around CBD		0° to 360°
Density Ratio		(SMSA density/city density? x 100
Transportation Radials, SMSA		number
Transportation Circumferentials, SMSA		number
	3. AIR POLLUTANTS	
Sulfur Dioxide		(a) Annual Mean ($\mu g/m^3$)
		(b) Annual Maximum ($\mu g/m^3$)
Total Suspended Particulates		(a) Annual Mean ($\mu g/m^3$)
		(b) Annual Maximum ($\mu g/m^3$)
	4. AIR QUALITY INDEXES	
Mitre Air Quality Index (MAQI):		
(a) SO_2		index numbers
(b) TSP		index numbers
(c) NO_2		index numbers
(d) All pollutants		index numbers

TABLE 1 (cont'd)

Variable	Unit of Measurement
4. AIR QUALITY INDEXES (cont'd)	
Extreme Value Index	
(a) SO_2	index numbers
(b) TSP	index numbers
(c) All Pollutants	index numbers
5. WATER CHARACTERISTICS	
Temperature	^{o}F
Color (Platinun-Cobalt Units)	P-C units
Turbidity	JTU's
pH	pH values
Fecal Coliform Bacteria	MPN/100 ml.
Total Dissolved Solid	ppm (residue at 180^{o} C.)
Suspended Solids	ppm
Total Nitrogen	ppm
Alkalinity (as CaC))	ppm
Hardness (Ca, Mg)	ppm
Chlorides	ppm
Total Iron and Manganese	ppm
Sulfate	ppm
Dissolved Oxygen	ppm
6. WATER QUALITY INDEXES	
Water Quality Index, Drinking Use (PI_1)	index numbers
Water Quality Index, Recreation Use (PI^2)	index numbers
Water Quality Index, Industrial Use (PI_3)	index numbers
Mean Water Quality Index (of above 3)	index numbers
7. SOLID WASTE ESTIMATES	
Single-Family Source Units, SMSA	1000's
Multi-Family Source Units, SMSA	1000's
Manufacturing Employees, SMSA	1000's
Total Solid Waste in Tons per Year:	
Single-Family (S.F.S.U. x 2858 lbs/year)	1000's tons/year
Multi-Family (M.F.S.U. x 1315 lbs/year)	1000's tons/year
Commercial (SMSA Pop x 3.5 lbs/cap/day)	1000's tons/year
Manufacturing (MFG emp x 7.6 tons/year)	1000's tons/year

TABLE 1 (cont'd)

Variable	Unit of Measurement
7. SOLID WASTE ESTIMATES (cont'd)	
Demolition and Construction (500 lbs/cap/year)	1000's tons/year
Sewage (SMSA Pop x 87.1 lbs/cap/year)	1000's tons/year
Simple Solid Waste Generation Figure	lbs/cap/day
Total calculated from simple solid waste generation figure	1000's tons/year
Total calculated from summation of generation figures for specific uses	1000's tons/year
Same as above, but omitting manufacturing	1000's tons/year
8. SURROGATES FOR NOISE	
Automobile Traffic Volume	No. of workers using private automobiles in commutation to work, SMSA
Air Traffic Volume	No. of scheduled aircraft arrivals and departures, SMSA
9. PESTICIDES	
DDT	ppm
DDE	ppm
TDE	ppm
DIELDRIN	ppm
HEPTACHLOR EPOXIDE	ppm
BHC	ppm
Total Bromides	ppm
Lindane	ppm
Kelthane	ppm
10. RADIATION	
Gross Beta Radioactivity, Max.	pci/m^2
Gross Beta Radioactivity, Ave.	pci/m^2
Beta Radioactivity Deposition	mci/m^2
11. LAND USE	
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

This data set was used for the metropolitan scale analysis.

We also attempted to insure that the detailed intra-metropolitan studies would be undertaken for a series of cases representative of the universe of 76 regions. Therefore, a factor analysis procedure was used to classify the 76 regions into subsets, each of which contained a group of cities with relatively similar pollution problems, viz:

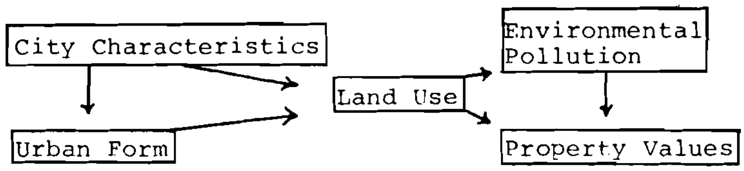
Factor		
1+	Atlanta	New Orleans
	Boston	New York
	Columbus	San Antonio
	Dallas	San Diego
	Detroit	San Francisco
	Fort Worth	San Jose
	Houston	Seattle
	Miami	Tampa-St. Petersburg
1-	Birmingham	Johnstown
	Charleston	Nashville
	Chattanooga	Omaha
	Dayton	Reading
	Des Moines	Utica-Rome
	Gary-Hammond	Worcester
2+	Chicago	Pittsburgh
	Milwaukee	Portland
	Minneapolis	St. Louis
	Philadelphia	
2-	Albuquerque	Phoenix
	El Paso	Tulsa
	Oklahoma City	Wichita
3+	Bridgeport	New Haven
	Cleveland	Newark
	Hartford	Providence

3-	Cincinnati Jersey City Kansas City	San Bernadino Syracuse Wilmington
4+	Baltimore Buffalo Indianapolis	Los Angeles Washington, D.C.
4-	Denver	Salt Lake City
5+	Akron Allentown-Bethlehem Canton	Rochester Youngstown York
5-	Honolulu	Memphis
6+	Flint Grand Rapids Jacksonville Louisville	Norfolk Patterson Richmond Toledo

Sample cases were selected from each of the groups, both to prepare land use estimates for that part of the metropolitan-wide analysis, and for the more detailed intra-metropolitan inquiries. These cases are underlined in the grouping (above) and are identified in Figure 3.

IV. THE ROLE OF URBAN FORM AT METROPOLITAN SCALE

The conceptual flow in Figure 1 reduces to the following:



Land Use Related to City Characteristics and Urban Form

We first investigated the relationships of land use to city characteristics and urban form using multiple regression analysis, with the results noted in Table 2. The proportion of land use of each type in the metropolitan areas was regressed first upon city characteristics alone, and then upon city characteristics plus the measures selected as indexes of urban form. In all cases except two the coefficient of determination doubled when the urban form variables 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 and utilities (TCU). In economic models, it is commonly assumed that industrial location is determined exogenously by the role played by a city in the national economy, and that TCU represents a key instrument variable that may be used to pattern land use, i. e. that

TABLE 2

LAND USE AS A FUNCTION OF CITY CHARACTERISTICS

INDEPENDENT VARIABLES	DEPENDENT VARIABLES (7x2 REGRESSION EQUATIONS) LOG RESIDENTIAL		LOG COMMERCIAL		LOG INDUSTRIAL		LOG EXTRACTIVE		LOG PUBLIC USES		LOG T.C.U.		LOG OPEN SPACE	
LOG SMSA	.232[1]	.608*	.160	.756*	.576*	.621	.688	.975	.592*	.367	-.349	-.372	-.057	-.124*
POPULATION	(1.350)[2]	(2.798)	(.851)	(3.431)	(2.554)	(1.304)	(1.529)	(1.489)	(2.455)	(.798)	(-1.245)	(-.672)	(-1.396)	(-2.674)
LOG DENSITY	-.105	-.092	-.002	-.020	-.312	-.329	-.899*	-.826*	-.007	-.056	-.005	-.085	.243	.025
RATIO	(-.735)	(-.894)	(-.014)	(.189)	(-1.673)	(-1.460)	(-2.415)	(-2.663)	(-.329)	(-.259)	(-.201)	(-.325)	(.717)	(1.142)
LOG MEDIAN	-.218	-2.134*	.674	-1.628	-2.642	-3.960	-2.378	-2.039	-.626	.493	.799	-1.335	.180	.710*
FAMILY INCOME	(-.172)	(-1.754)*	(.486)	(-1.320)	(-1.590)	(-1.486)	(-.717)	(-.556)	(-.352)	(.191)	(.307)	(-.431)	(.596)	(2.741)
LOG PERCENT	.179	.921	.120	-.135	-.042	-.001	.769	.860	-.319	-.132	.028	.152	-.018	-.014*
MANUFACTURING	(1.037)	(.568)	(.638)	(-.822)	(-.184)	(-.002)	(1.760)	(1.760)	(-1.317)	-.385	(.100)	(.369)	(-.428)	(-.413)
DEGREES OF		.002*		.002		-.000		.007*		.802		-.001		-.000
ABC		(1.828)		(1.554)		-.093		(2.253)		(.695)		(-.295)		-1.450
RADIAL		-.001		-.161*		.004		-.018		.086		.037		.011
HIGHWAYS		(-1.470)		(-2.880)		(.336)		(-.108)		(.739)		(.266)		(.943)
CIRCUMFERENTIAL		.212*		.287*		.122		-.040		-.149		.183		-.054*
HIGHWAYS		(2.431)		(3.237)		(.635)		(-.154)		(-.806)		(.824)		(-2.895)
INTERCEPT	2.397	17.524		10.487		8.792	15.970	8.792		-6.756		16.202	3.070	-1.285
	(.213)	(1.634)		(.965)		(.272)	(.544)	(.272)		-.298		(.593)	(1.147)	(-.565)
COEFFICIENT OF DETERMINATION	.420	.817	.318	.815	.540	.852	.647	.852	.597	.711	.202	.383	.300	.823

NOTES: 1. Regression coefficient
2. t-statistic

*Significant at .05 level

industry and transportation are determinants of urban structure rather than being determined by it. The regression results confirm this common assumption.

As for the other land uses, the important intervening role of urban form in determining the urban land use mix is clear. For example, the percentage of land used for residential purposes varies 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 is borne out by the inverse relationship that exists between the residential percentage and the density ratio: the percentage of residential land increases as the density ratio falls. 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). In other words, higher central city densities produce more intensive land use and a relatively lower residential percent.

The greatest elasticity of residential land use is with respect to median incomes; a 1.0 percent increase in incomes is associated with a 2.1 percentage point decrease in residential land use. Looking at the other equations, the compensating factor is open space: 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 reveals the specific mechanics of translation of city characteristics into land use. A positive relationship is seen between the residential percentage and the degrees of arc of a city. The higher the degrees of arc, 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 radials. 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 along the fingers. The inverse relationship shown here supports this argument, as does the positive relationship of the residential percentage to the number of circumferential highways. An increased number of circumferentials promotes residential sprawl.

What are the mechanics of these urban form relationships? What is indicated is that the demand for urban land is determined exogenously by the role that the city plays in the national economy. From such exogenous relationships arise the industry mix, growth rate, size, and income levels of the urban region. Urban form controls the supply 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.

Environmental Pollution Related to Land Use

The next link in the conceptual diagram that was explored was between environmental pollution and land use. Several air pollution measures were regressed twice on a series of land use percentage variables, the difference between the models in each pair being the elimination of the extractive land use percentage and the addition of open space in the second equation. See Table 3. That the power of the model does not differ in the two versions and the lack of significance of the open space variable is indicative of the fact that presence of open space per se does not reduce environmental pollution; it is the type of land use that determines pollution levels. That the power of all of the models is substantial indicates that land use does indeed play the important immediate role in producing environmental pollution.

That land use is indeed a key intervening variable was confirmed by regressing each of 14 different air and water pollution variables directly on city characteristics and urban form variables, skipping land use. In all cases, the results were quite poor. Coefficients of determination ranged from 0.16 to 0.37 in regressions on the city characteristics alone,

TABLE 3

AIR POLLUTION AS A FUNCTION OF LAND USE MIX

INDEPENDENT VARIABLES	DEPENDENT VARIABLES (4x2 REGRESSION EQUATIONS) LOG SO2 AVE		LOG SO2 MAX		LOG TSP AVE		LOG TSP MAX	
LOG RESIDENTIAL PERCENTAGE	-.251[1] (-.187)[2]	-.957 (-.187)	-.209 (-.177)	-.533 (-.118)	.781 (1.494)	.257 (.306)	1.079* (2.666)	.430 (.503)
LOG COMMERCIAL PERCENTAGE	2.727* (2.415)	2.880* (1.821)	3.181* (3.202)	3.253* (2.333)	-.587 (-1.360)	-.488 (-1.302)	-1.066* (-3.192)	-.786* (-2.065)
LOG INDUSTRIAL PERCENTAGE	-1.176* (-2.078)	-1.379 (-.921)	-1.510 (-3.032)	-1.602 (-1.215)	.294 (1.045)	.131 (.365)	.935* (4.301)	(.752)* (2.065)
LOG EXTRACTIVE PERCENTAGE	.020 (.073)		.006 (.023)		-.041 (-.393)		-.135 (-1.685)	
LOG PUBLIC USE PERCENTAGE	.940* (1.843)	.853 (1.074)	1.440* (3.208)	1.400* (2.000)	.017 (.083)	-.054 (-.250)	-.285* (-1.672)	-.369 (-1.665)
LOG T.C.U. PERCENTAGE	-1.364 (-1.580)	-1.973 (-.499)	-1.208 (-1.591)	-1.476 (-.423)	.007 (.041)	-.163 (-.484)	.207 (1.672)	.084 (.245)
LOG OPEN SPACE PERCENTAGE		-4.995 (-.155)		-2.211 (-.078)		-2.626 (-.529)		-1.424 (-.282
INTERCEPT	5.730 (1.649)	30.232 (.189)	6.159 (2.014)	17.033 (.121)	2.744 (1.947)	15.751 (.660)	2.710 (2.485)	10.820 (.446)
COEFFICIENT OF DETERMINATION	.762	.763	.873	.873	.688	.697	.906	.842

NOTES: 1. Regression coefficient
2. t-statistic

*Significant at .05 level.

and increased only to 0.18 to 0.43 when the urban form variables were added, revealing that urban forms are expressed in environmental pollution only 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 air pollution. There were also some indications in the research materials assembled that the same was true for water pollution, noise and solid wastes.

Property Value Relationships

A somewhat more structured approach was taken in relating aggregate metropolitan property values to agglomeration economies and to negative externalities produced by environmental pollution, because a previous research group at Harvard University led by J. R. Harris and D. Wheeler had produced results that could be used as a point of departure. Harris and Wheeler had pointed out 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 larger cities. 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. 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 to 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.

If this is so, then one question that arises is whether, since 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 <u>diseconomies</u> 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 range, property values will increase more than proportionally with population.

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

(4) Assuming that aggregate property values increase in an S-shaped logistic pattern with respect to population, it should then be possible to identify that point at which average land value per person is maximized, the population size which is optimal 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 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.

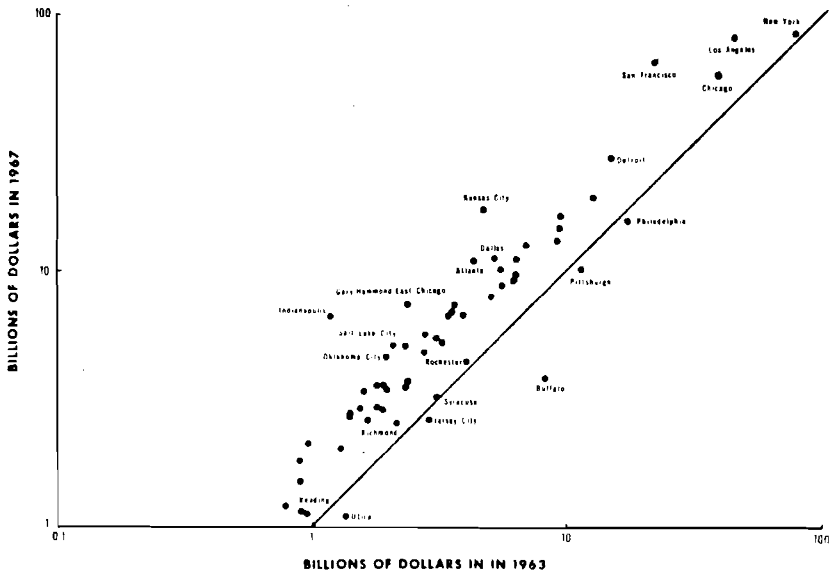
In testing the first four propositions, a measure of aggregate property values was derived by Harris and Wheeler from assessment data in the Census of Governments, adjusting them toward true market value using the assessment ratios available in that publication. Aggregate property values were then regressed on a variety of city characteristics to find the partial relationship between city size and property values. The analytic results were consistent with the idea that there are increasing and then decreasing economies of agglomeration over a range of population up to about three million. It seemed reasonable to Harris and Wheeler to argue that the assembling of a large labor pool coupled with scale economies in the provision of some public services explained the zone of net agglomeration economies, while diseconomies of scale in services and related congestion-pollution phenomena explained the zone of diseconomies of scale.

We repeated and extended the Harris-Wheeler analysis by including variables relating to urban form and environmental pollution. The dependent variable, total property values, was derived in the same manner as the Harris-Wheeler measure, but from the later 1967 Census of Governments. Figure 4 shows that the two measures are consistent, with a constant rate of change apparent over the whole set of cities. On the leading edge, with more rapid growth of property values than the nation, are such metropolitan areas as San Francisco, Kansas City and Indianapolis. On the other hand, in Philadelphia, Pittsburgh, Buffalo, Jersey City and Utica, they actually declined.

The independent variables are those used in the analysis reported in the previous sections. Figure 5 plots the observed property values against metropolitan population. Our interest centers on the partial nature of this relationship, holding constant a variety of factors, and on the possible contributions of urban form and environmental pollution to the variance.

FIGURE 4

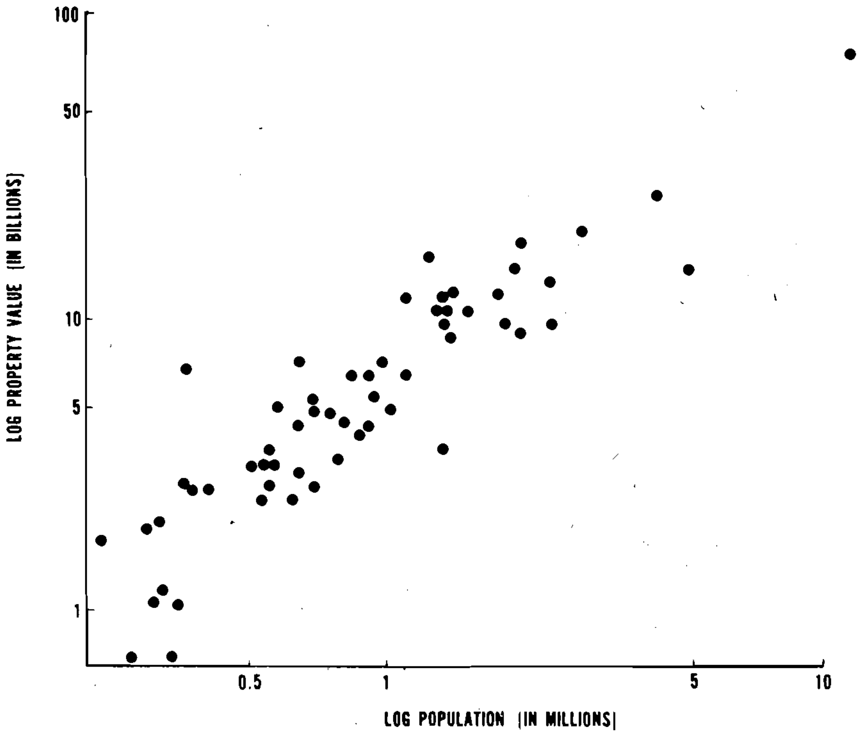
AGGREGATE PROPERTY VALUES OF SAMPLE SMSA's
IN 1963 AND 1967



Source of Data: 1963 and 1967 Census of Governments

FIGURE 5

AGGREGATE PROPERTY VALUES RELATED TO
SMSA POPULATION



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

Table 4 records the first series of regression relationships, and clearly bears out propositions (1) and (5): aggregate property values and total population move systematically together, with property values depressed by manufacturing concentrations and assuming much higher levels in higher income communities. Harris and Wheeler believed 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 earlier results belie this supposition; environmental quality, at least, is much better in higher- than in lower-income communities.

Surprisingly, inclusion of the urban form variables does not significantly affect the power of the model, however, and thus proposition (6) is called into question. Three of the signs are in the right direction if property values are lower in the dispersed city (degrees of arc radial highways +, and circumferential highways -) but the density ratio has the wrong sign (+), and none of these variables is statistically significant.

Nor, for that matter, are the environmental variables significant. If, for example, the environmental quality indicators are regressed in turn on the property value residuals from the

TABLE 4

REAL PROPERTY VALUES RELATED TO SELECTED CITY CHARACTERISTICS AND TO LAND USE MIX

Independent Variables[a]	Regression Coefficients and t-Statistics			
Population of SMSA	0.892* (13.59)		0.852* (8.18)	
Density Ratio--SMSA/C. City	0.109* (1.73)		0.070 (0.91)	
Median Family Income	2.143* (3.94)		2.335* (4.01)	
Percent Employment in Manufacturing	-0.375* (-2.82)		-0.381* (-2.75)	
Degrees of Arc of Urban Area			-0.000 (-0.15)	
Radial Highways in SMSA			0.010 (0.73)	
Circumferential Highways			-0.056 (-1.40)	
Residential Percentage		0.465 (0.301)		2.094 (0.835)
Commercial Percentage		0.031 (0.633)		0.664 (0.601)
Industrial Percentage		-0.222 (-0.343)		0.122 (0.229)
Extractive Percentage		0.063 (0.202)		
Public Uses Percentage		0.780 (1.654)		0.960 (1.808)
T.C.U. Percentage		-0.604 (-1.242)		0.066 (-.609)
Open Space Percentage				0.668 (0.629)
Intercept	-16.228 (-3.50)	8.728 (2.142)	-17.638 (-3.48)	-33.851 (-0.507)
Coefficient of Determination	0.875	0.708	0.879	0.724
F-Statistic	(4, 53) 92.531	(6, 6) 2.422	(7, 50) 52.165	(6, 6) 2.623

*Significant at .05 level
a All variables transformed to natural logarithms.

second equation in Table 4, the results reported in Table 5 emerge. The incremental effect of environmental pollution on aggregate property values, holding constant the pollution effects arising directly from size, manufacturing concentrations, and income, is statistically insignificant.

Inclusion of the different subsets of environmental variables into the basic equations, as in Table 6, provides no further insights. The power of the model is scarcely affected by their inclusion, even though the environmental variables are statistically significant. In the third model property values do appear to be marginally lower where SO_2 concentrations are greater, but for TSP concentrations the sign of the coefficient is in the opposite direction: property values are greater where particulate concentrations are higher.

It thus follows that any effects on urban property values of environmental pollution are contained within the direct relationships between the city characteristics themselves and property values; pollution effects are built into the parameters relating size (etc.) to the stream of net urban benefits.

The questions posed in postulates (2)-(4) then arise. Table 7 and Figure 6 show that different city-size classes do indeed appear to display different relationships between

TABLE 5

R^2 OF POLLUTION VARIABLES REGRESSED ON RESIDUALS FROM TABLE 4, EQUATION (2)

	Pollution Variables	Coefficient of Determination
1	MAQI	0.024
2	EVI	0.028
3	SO_2 AVE.	0.017
4	SO_2 MAX.	0.027
5	SO_2 MAQI	0.018
6	NO_2 MAQI	0.001
7	TSP AVE.	0.055
8	TSP MAX.	0.023
9	TSP MAQI	0.046
10	TSP EVI	0.030
11	WPI 1	0.000
12	WPI 2	0.011
13	WPI 3	0.020
14	WPI 4	0.004

TABLE 6

ENVIRONMENTAL VARIABLES INCLUDED IN BASIC REGRESSIONS

	Model 1			Model 2			Model 3		
	Regression Coefficients	Standard Errors	t Statistics	Regression Coefficients	Standard Errors	t Statistics	Regression Coefficients	Standard Errors	t Statistics
Population of SMSA	0.847*	0.194	8.10	0.860*	0.101	8.51	0.873*	0.097	8.93
Density Ratio - SMSA/City	0.115	0.083	1.38	0.155*	0.082	1.88	0.170*	0.079	2.13
Median Family Income	2.617*	0.641	4.08	2.767*	0.603	4.58	2.821*	0.578	4.88
% Employment in Manufacturing	-0.478*	0.151	-3.15	-0.369*	0.153	-2.39	-0.376*	0.150	-2.49
Degrees of Arc	-0.000	0.000	-0.12	-0.000	0.000	-0.33	-0.000	0.000	-0.66
Radial Highways in SMSA	0.005	0.027	0.22	0.002	0.026	0.09	0.001	0.025	0.05
Circumferential Highways	-0.044	0.041	-1.08	-0.030	0.040	-0.76	-0.018	0.039	-0.46
MAQI	0.193	0.380	0.50						
EVI	0.058	0.099	0.58						
SO_2 MAQI				-0.130*	0.073	-1.76			
NO_2 MAQI				0.199	0.178	1.11			
TSP MAQI				0.474*	0.217	2.18			
SO_2 AVE							-0.163*	0.077	-2.12
TSP AVE.							0.732*	0.264	2.76
INTERCEPT	-20.210	5.727	-3.52	-22.399	5.328	-4.20	-24.24	5.553	-4.54
COEFFICIENT OF DETERMINATION	0.885			0.895			0.899		

*Significant at .05 level

TABLE 7

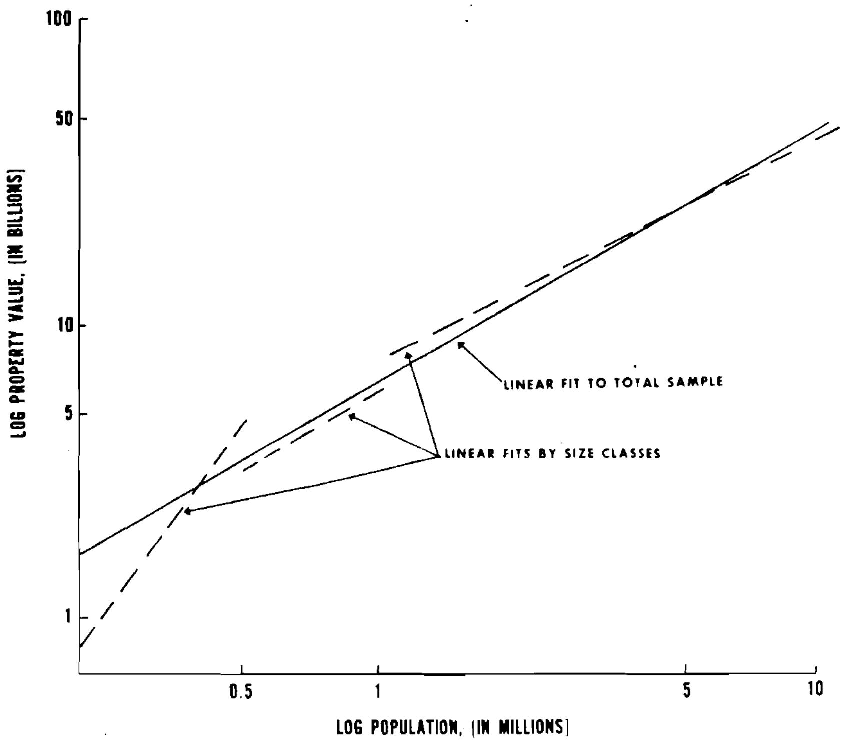
REAL PROPERTY VALUES REGRESSED ON CITY CHARACTERISTICS
FOR THREE CITY SIZE CLASSES

	SMSA Population 200,000 to 500,000			SMSA Population 200,000 to 500,000			SMSA Population 200,000 to 500,000		
Independent Variables[a]	Regression Coefficient	Standard Errors	t Statistics	Regression Coefficient	Standard Errors	t Statistics	Regression Coefficient	Standard Errors	t Statistics
Log SMSA Population	2.063*	0.839	2.46	0.890*	0.249	3.57	0.768*	0.183	4.30
Log Density - SMSA/City	0.440*	0.188	2.34	0.158*	0.082	1.94	0.128	0.117	1.10
Log Median Family Income	0.984	1.861	0.53	2.013*	0.724	2.78	3.157*	1.080	2.92
Log % Employed in Manufacturing	-0.712*	0.326	-2.19	0.002	0.190	0.01	-0.988*	0.387	-2.56
Log SO_2 AVE.	0.338	0.266	1.27	-0.201*	0.095	-2.11	-0.191	0.118	-1.61
Log TSP AVE.	0.122	1.047	0.17	0.661*	0.277	2.39	0.739	0.476	1.55
INTERCEPT	-13.480	17.976	-0.75	-18.818*	7.190	-2.62	-25.637*	10.033	-2.56
Coefficient of Determination		0.833			0.665			0.810	
Durbin-Watson Statistic		1.875			2.572			2.484	

a All variables transformed to natural logarithms
*Significant at .05 level

FIGURE 6

RELATIONSHIPS OF PROPERTY VALUES AND POPULATION
FOR THREE CITY SIZE CLASSES



property values and population size, with a zone of agglomeration economies in the smaller size ranges, and net diseconomies setting in at larger metropolitan sizes.

Even within size classes, city size remains an important determinant of property values, and manufacturing concentrations depress them. In the smallest cities, property values are greater, the greater the dispersion of the urban form (high SMSA/City density ratio), although this effect drops out in larger urban regions while income levels become progressively more significant in larger places. The two air quality variables included in Table 7 are statistically significant in the middle size-class, but again the signs of the coefficients raise more questions than they answer.

Table 8 and Figure 7 extend the argument a little further. Marginal improvements in fit emerge, moving from the linear through the quadratic to the cubic formulations of the property value-population relationship. In each case, there are significant partial effects of income and manufacturing employment. The density ratio is significant throughout with a positive sign, indicating that holding other variables constant, property values are greater in the dispersed rather than the core-directed city. This would, of course, be the situation when the demand for land of any given level of accessibility is relatively elastic, and indicates that, the predilections of urban planners notwithstanding, urban

TABLE 8

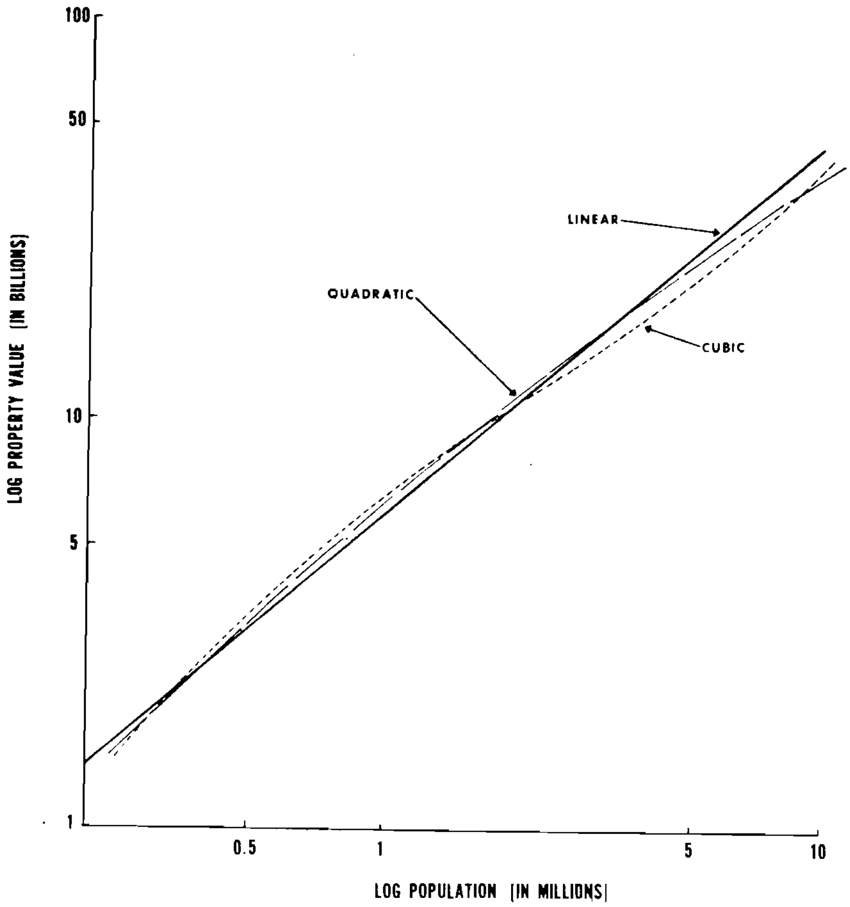
PROPERTY VALUES REGRESSED ON CITY CHARACTERISTICS AND LINEAR, QUADRATIC AND CUBIC EXPRESSIONS OF POPULATION

	Model 1			Model 2			Model 3		
Independent Variables[a]	Regression Coefficient	Standard Errors	t Statistics	Regression Coefficient	Standard Errors	t Statistics	Regression Coefficient	Standard Errors	t Statistics
Log Density Ratio - SMSA/City	0.191*	0.063	3.03	0.188*	0.063	2.97	0.172*	0.064	2.69
Log Median Family Income	2.683*	0.533	5.03	2.662*	0.533	5.00	2.723*	0.533	5.11
Log % Employed in Manufacturing	-0.366*	0.147	-2.49	-0.401*	0.150	-2.67	-0.426*	0.151	-2.82
Log SO_2 AVE.	-0.163*	0.071	-2.29	-0.140*	0.074	-1.90	-0.127	0.075	-1.71
Log TSP AVE.	0.722*	0.240	3.00	0.784*	0.246	3.18	0.811*	0.246	3.29
Log SMSA Population	0.887*	0.065	13.64	1.635*	0.684	2.39	9.498	6.737	1.41
$(\text{Log SMSA Population})^2$				-0.053	0.048	-1.10	-1.144	0.931	-1.23
$(\text{Log SMSA Population})^3$							0.049	0.042	1.17
INTERCEPT	-24.216	4.996	-4.85	-26.828	5.524	-4.86	-46.067	17.297	-2.66
COEFFICIENT OF DETERMINATION		0.898			0.900			0.903	
DURBIN-WATSON STATISTIC		1.931			2.918			2.005	

a All variables transformed to natural logarithms
*Significant at .05 level

FIGURE 7

LINEAR, QUADRATIC AND CUBIC RELATIONSHIPS OF
PROPERTY VALUES TO CITY SIZE



sprawl produces the greatest stream of net benefits of urban growth, despite the greater pollution levels of the dispersed city noted earlier (which helps explain the statistically-significant pollution variables with nonsensical signs in Table 8).

Most of the results in Table 8 are consistent with those of Harris and Wheeler (Table 9). However, in contrast to the Harris-Wheeler results, we find no point at which there is an absolute decrease of property values with increasing size.

In the quadratic model, property values are greater than in the linear case in the range between 185,000 and 2,400,000 population. In the cubic formulation, the lower inflection point is at 720,000 population (this is the point at which the marginal increment in land value from population increase is maximized) and the upper inflection point is at 6,600,000 population. Average land value per person is maximized at 1,070,000 population, beneath which size there are increasing returns to urban scale, and beyond which relative diseconomies of increasing set in. These diseconomies must, however, be those of congestion, crime, etc., because the effects of environmental pollution are partialed out by the independent variables included in the equation.

TABLE 9

PARTIAL EFFECT OF POPULATION SIZE ON AGGREGATE PROPERTY VALUE

Regressions by Size Classes	Harris and Wheeler		Present Study		
	Sign	Statistic	Sign	Statistic	
50,000-250,000	+	7.7			
250,000-500,000	+	4.2	+	2.5	230,000-500,000
500,000-1,000,000	+	1.1	+	3.6	500,000-1,000,000
1,000,000-10,000,000	-	-1.4	+	4.3	1,000,000-11,600,000

Cubic Equation on Total Sample	Harris and Wheeler		Present Study		
	Sign	Statistic	Sign	Statistic	
Pop	+	1.1	+	1.4	Log Pop
$(Pop)^2$	-	-0.9	-	-1.2	$(Log\ Pop)^2$
$(Pop)^3$	+	3.9	+	1.2	$(Log\ Pop)^3$

V. SELECTED RELATIONSHIPS WITHIN METROPOLITAN REGIONS

A variety of exploratory and experimental studies of land use-environmental pollution relationships 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. 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) systematic density relations; and (b) patterns of water quality in a complex hydrologic situation.

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.

Further, at each of the last censuses, both the density gradient and central densities have been related to city size (smaller cities have a steeper gradient than larger cities; larger cities have greater central densities) but the form of this relationship has changed as decentralization has proceeded and urban forms have become more disposed:

$$B_{1950} = -0.799 + 0.042 \ln P_s \qquad R = 0.41$$

$$B_{1960} = -0.923 + 0.052 \ln P_s \qquad R = 0.55$$

$$B_{1970} = -0.935 + 0.053 \ln P_s \qquad R = 0.63$$

$$D_{c,1950} = -172{,}000 + 13{,}553 \ln P_s \qquad R = 0.76$$

$$D_{c,1960} = -111{,}600 + 8{,}790 \ln P_s \qquad R = 0.62$$

$$D_{c,1970} = -105{,}600 + 8{,}348 \ln P_s \qquad R = 0.83$$

Clearly, density-gradient relationships are one powerful way of examining urban form. What of relationships between population densities and environmental pollution? First, the typical air pollution map (Figure 8) yields the negative exponential relationship (Figure 9). Data obtained from the National Air Surveillance Network enabled the relationship to be generalized for particulates in seven of the sample cases

FIGURE 8

AVERAGE ANNUAL SO_3 RATES IN THE DETROIT-WINDSOR AREA

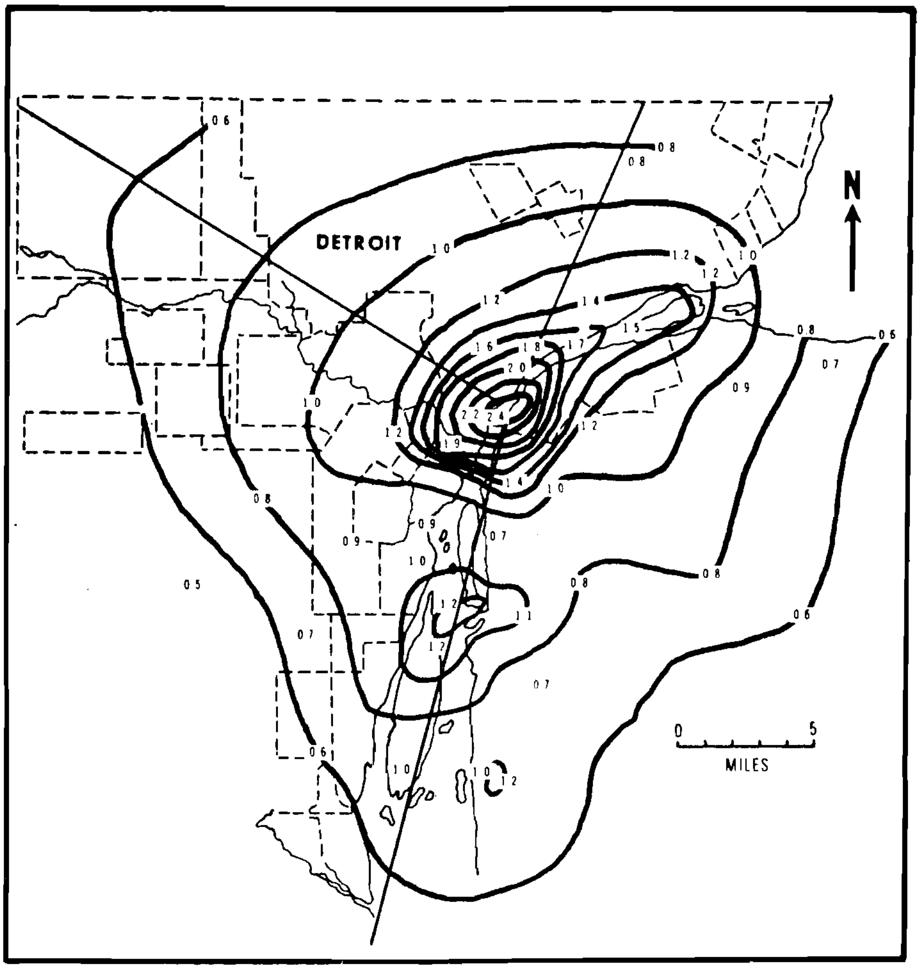
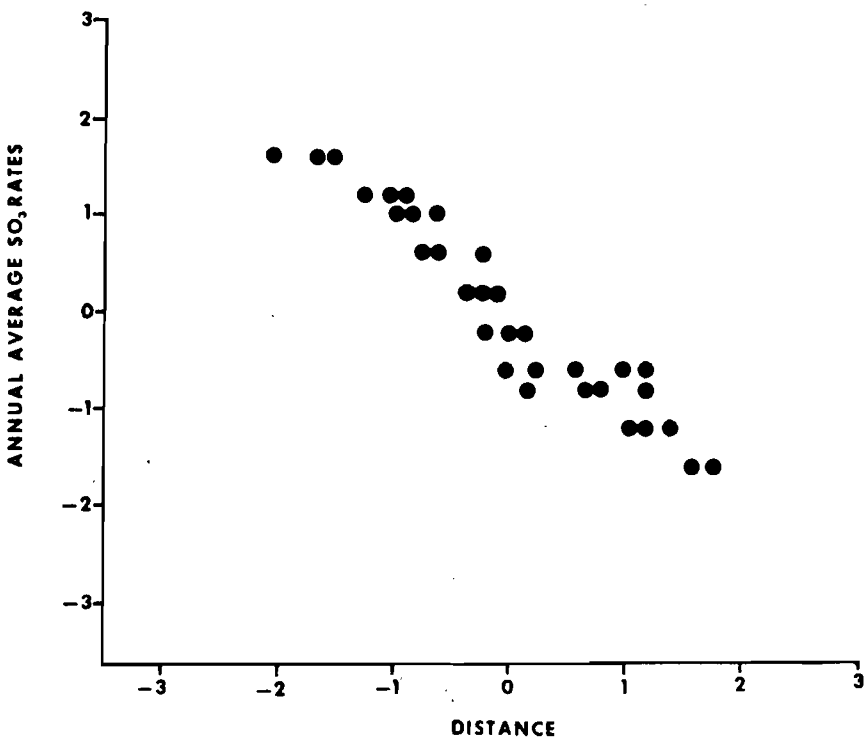


FIGURE 9

SO_3-DISTANCE RELATIONS IN DETROIT



	MEAN	STD. DEV.
VERT. VAR.	1.49375	.554127
HORIZ. VAR.	1.17769	.946041

(Table 10). Where B_x is the particulate pollution density gradient and B_p is the population density gradient:

$$B_x = 0.94 + 20.1\ B_p \quad , \qquad R = 0.611 \quad ,$$

which implies that the particulate density gradient should have changed from approximately

$$B_p = -.0087 + 0.0021 \ln \text{(city size)}$$

in 1950 to a 1970 gradient of

$$B_p = -.094 + 0.0027 \ln \text{(city size)} \quad .$$

Similar relationships were suggested for noise and for solid wastes.

Water Quality on a Complex Hydrologic Net

The difficulties that beset comparative metropolitan analysis of water quality because of the uniqueness of the hydrologic net and locations of discharges were illustrated in a case study of the Seattle-Everett SMSA. Several factors were thought to make Seattle an ideal test case:

TABLE 10

COMPARATIVE POPULATION DENSITY
AND POLLUTION INTENSITY-DATA

	Population Density			Pollution Level: Particulates		
	Central City	Suburban	Ratio	Central City	Suburban	Ratio
Birmingham	3,786.16	165.815	22.83	160.875	122.073	1.383
Chicago	15,107.00	1,032.48	14.63	32.858	23.289	1.411
Cincinnati	5,787.45	450.318	12.85	96.462	86.328	1.117
Denver	5,409.66	200.01	27.05	131.493	88.079	1.493
Oklahoma City	1,227.01	148.64	8.26	106.673	55.304	1.929
Seattle	5,181.58	203.35	25.08	53.757	42.357	1.269
Washington, D.C.	12,312.70	918.97	13.39	62.046	51.470	1.594

1) There are three major drainage basins which are located entirely within the SMSA.

2) There is much physical diversity within the region, ranging from mountainous headwaters to alluvial lowlands.

3) Location on Puget Sound provides an excellent opportunity for applying a general water quality index to marine waters. Heretofore, such indexes have only been applied to rivers or lakes.

4) The City of Seattle contains a heavily-industrialized estuary, a CBD on a bay, the largest freshwater lake within a metropolitan area and numerous rivers.

5) The area east of Lake Washington is expanding and is expected to continue to do so, presenting a problem in water resource planning.

6) Waters from the mountains reach the lowlands in unpolluted condition. There are no major SMSAs upstream from Seattle-Everett.

7) There is adequate cooperation and transfer of data between all agencies which monitor water quality in the region (i.e. Department of Ecology, EPA, METRO and U.S. Geological Survey).

8) The City of Seattle has experienced and reversed serious degradation of its waters.

First, permissible water quality standards were derived from State of Washington regulations for three use groupings for both fresh and marine waters (Tables 11, 12 and 13). Next, data were obtained from the EPA STORET system through the Region X office in Seattle. A PGM-INVENT request was made for all stations within the general boundaries of the Seattle-Everett SMSA for all data recorded between 1970-1972.

TABLE 11

MULTIPLE USE GROUPINGS FOR FRESH AND MARINE WATERS

Use Grouping	Fresh Waters	Marine Waters
Human Consumption and Direct Contact Uses (j=1)	Drinking use Swimming and water skiing (direct recreational use) Beverage manufacturing, Industrial food preparation } eventual human consumption	Human water contact use--swimming and water skiing Food fish canning and preparation
Wildlife Habitat and Indirect Contact Uses (j=2)	Fish and shellfish reproduction, rearing and harvest Agricultural use (irrigation and stock watering) Wildlife habitat	Salmon rearing Other food fish Shellfish Wildlife habitat
Recreational and Industrial Remote Contact Uses (j=3)	Aesthetic and recreational (picnicking, hiking, fishing, boating and plain visitation) Commerce and navigation Power production Fish passage Industrial cooling water Industrial process use Log storage and rafting Liquid waste transport	Fish passage Aesthetics (environmental) Recreational (boating, picnicking, hiking and plain visitation) Commercial fishing and fish passage Industrial water use Navigation Log storage and rafting Liquid waste transport

TABLE 12

PERMISSIBLE QUALITY LEVELS FOR VARIOUS FRESHWATER USES IN THE STATE OF WASHINGTON

Use	Parameters													
	1	2	3	4	5	6	7	8	9	10	11	12	13	14
(A) j-1	18.5	5	5	6.5-8.5	240	500	5	10	150	100	250	.35	250	8.0
(B) j-2	21.0	10	10	6.5-8.5	1000	500	10	10	150	125	250	.35	250	6.5
(C) j-3	24.0	10	10	6.0-9.0	1000	500	10	45	75	100	250	.11	250	5.0

Parameters:

	Parameter	Units	STORET Number
1	Temperature	°C	00010
2	Color	Platinum-Cobalt Units	00040
3	Turbidity	Jackson Turbidity Units	00070
4	pH	Standard Units	00400, 00403
5	Total Coliform Bacteria	/100 ml	31501, 31504
6	Total Dissolved Solids	mg/l	70300, 70301
7	Suspended Solids	mg/l	00530
8	Total Nitrogen	mg/l	00605, 00610, 00615, 00620, 71080
9	Total Alkalinity	mg/l	00410
10	Total Hardness	mg/l	00900
11	Chloride	mg/l	00940
12	Total Iron and Manganese	mg/l	01045, 01055
13	Sulfate	mg/l	00945
14	Dissolved Oxygen	mg/l	00300

TABLE 13

PERMISSIBLE QUALITY LEVELS FOR VARIOUS
MARINE WATER USES IN THE STATE OF WASHINGTON

Use	Parameters				
	1	3	4	5	14
(A) j-1	16.0	5	7.8-8.5	70	6.8
(B) j-2	19.0	10	7.8-8.5	1000	5.0
(C) j-3	24.0	10	6.0-9.0	1000	4.0

Source for parameters 1, 3, 4, 5, 14: Water Pollution Control Commission, State of Washington, "A Regulation Relating to Water Quality Standards for Interstate and Coastal Waters of the State of Washington and a Plan for Implementation and Enforcement of Such Standards," 1967.

Remaining criteria derived from the following:

a) American Water Works Association, "Water Quality and Treatment," 1950.

b) Eugene Brown, M. W. Skougstad and M. J. Fishman, "Methods for Collection and Analysis of Water Samples for Dissolved Minerals and Gasses," U.S. Geological Survey Techniques of Water-Resources Investigation, 1970.

c) California State Water Pollution Control Board, 1952.

d) California State Water Quality Control Board, Water Quality Criteria, 1963.

e) John D. Hem, "Study and Interpretation of the Chemical Characteristics of Natural Water," 1970.

f) R. O. Sylvester and Carl A. Ranbow, Methodology in Establishing Water-Quality Standards in Water Resources Management and Public Policy, 1968.

g) U.S. Federal Water Pollution Control Administration, Committee on Water Quality Criteria, 1968.

h) U.S. Public Health Service, "Drinking Water Standards," 1962.

Enough information was provided to enable the water quality indexes to be computed for a sampling network of 160 nations. However, no source listed the locations of the stations, and much effort had to be expended to be able to locate them (Figure 10). Likewise, information on the known pollutant discharges in the metropolitan area had to be hand pulled to complement a RAPP retrieval requested from the EPA STORET system for the year 1971. Detailed information was obtained for all industries which had filed an application for a permit to discharge effluent into the waterways within the EPA region. Only a portion of the total discharge is accounted for by the retrieved information but it was sufficient to elucidate the concentrations of industry. Figure 11 shows the locations of pipes discharging effluent into the region's waterways. The heaviest grouping of industrial discharges is at the mouth of the Duwamish River.

Finally, the water quality indexes were computed (Table 14), indexes exceeding 1.0 indicating substandard water. Clearly, Seattle has been able to achieve significant water quality for all purposes except in specific land-use related clusters: on the Snoqualmie River and in Everett to the north, in the Duwamish River industrial area of Seattle, and adjacent to Tacoma's industrial complex to the south--and then only for drinking use! While certain obvious generalizations can be made, the results indicate that each metropolitan

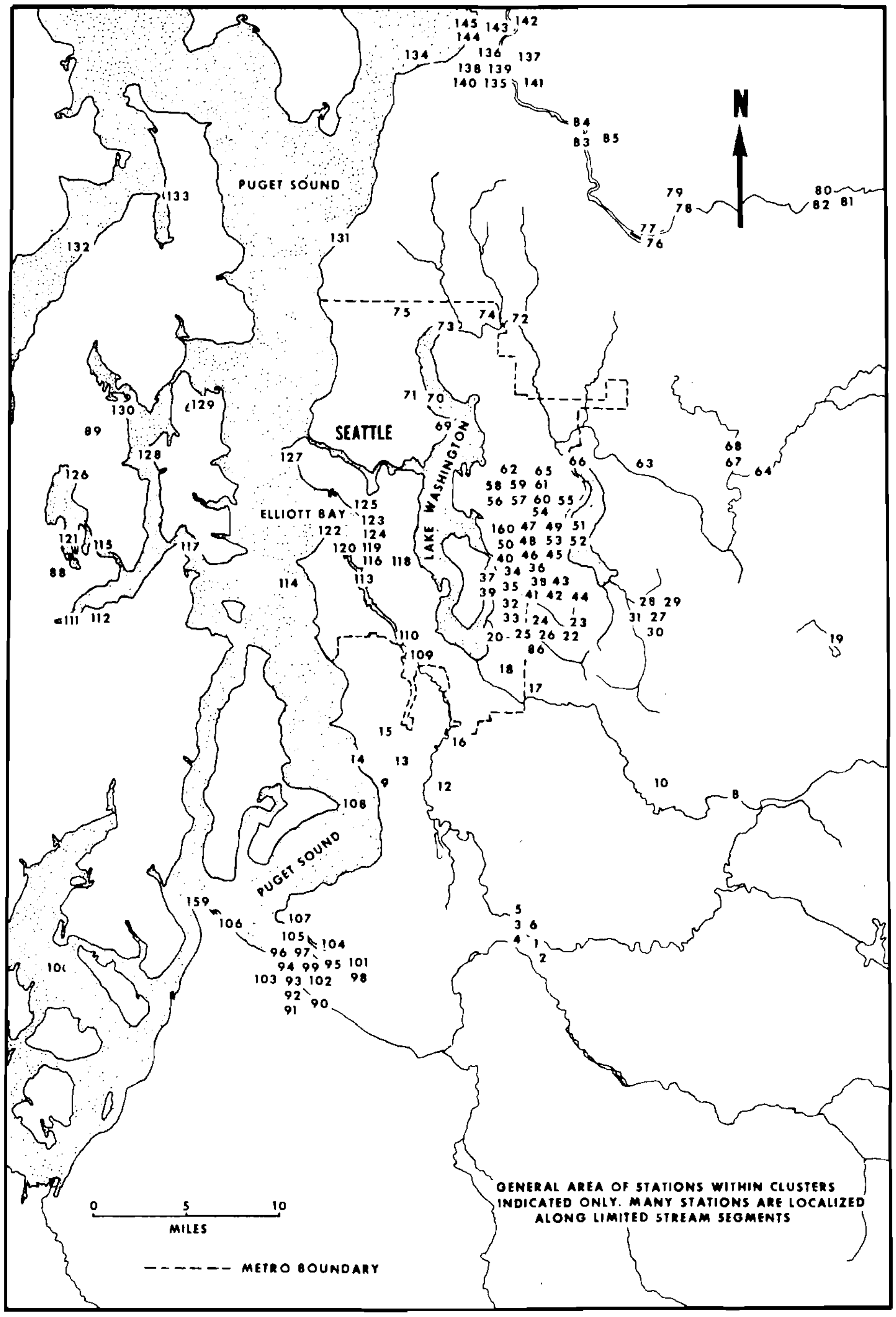


FIGURE 10

THE SAMPLING NETWORK OF 160 STATIONS

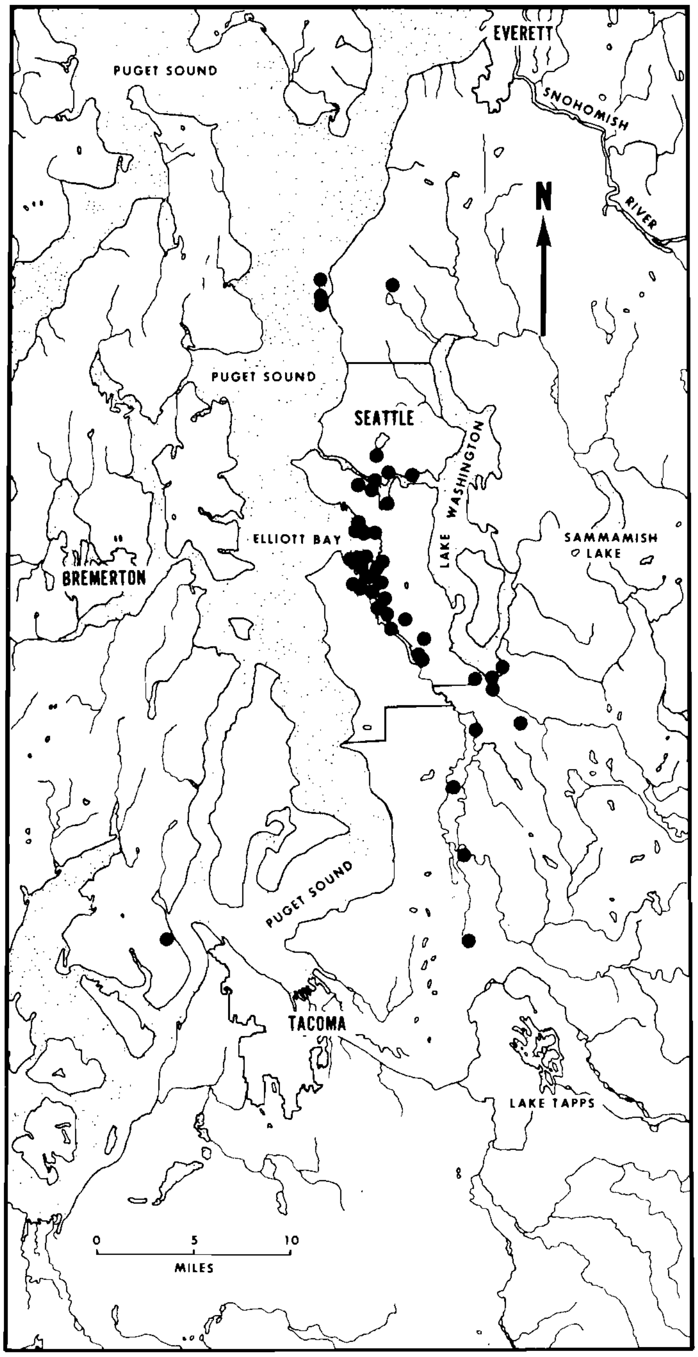


FIGURE 11

LOCATION OF DISCHARGES

TABLE 14

WATER QUALITY INDEXES FOR
SEATTLE MONITORING STATIONS

Freshwater Stations

Obs. No.	PI_1	PI_2	PI_3	Overall PI
1	0.6165	0.5985	0.3463	0.5204
2	0.6923	0.5978	0.3488	0.5253
3	0.7285	0.6172	0.4937	0.6131
4	0.7199	0.6165	0.3910	0.5758
5	0.5517	0.6205	0.5096	0.5873
6	0.7065	0.6108	0.3781	0.5651
7	0.6943	0.6105	0.4366	0.5804
8	0.4450	0.5853	0.2279	0.4194
9	0.9077	0.6257	0.5670	0.7001
10	0.4487	0.5907	0.2227	0.4207
11	0.5066	0.7033	0.6936	0.6345
12	0.5068	0.7034	0.6937	0.6346
13	1.0174	0.6311	0.3095	0.6527
14	1.2974	0.8548	0.3099	0.8207
15	1.4354	0.9921	0.3078	0.9118
16	0.5689	0.6221	0.4936	0.5615
17	0.4709	0.6021	0.3230	0.4653
18	0.5578	0.5956	0.3063	0.4866
19	0.4964	0.7174	0.7079	0.6406
20	0.8067	0.6162	0.4652	0.6294
21	0.5901	0.5923	0.3875	0.5233
22	0.6985	0.6191	0.6881	0.6752
23	0.7880	0.7094	0.7239	0.7404
24	0.5097	0.6254	0.4343	0.5231
25	0.7419	0.6322	0.3772	0.5818
26	0.5403	0.6403	0.7228	0.6345
27	0.6519	0.6530	0.4357	0.5802
28	0.7300	0.6101	0.3570	0.5657
29	0.6030	0.6030	0.4792	0.5301
30	0.5803	0.5951	0.3449	0.5047
31	0.7404	0.6179	0.4114	0.5899
32	0.5584	0.6303	0.4232	0.5373
33	0.6830	0.6322	0.5771	0.6308
34	0.6128	0.7100	0.6954	0.6727
35	0.6956	0.7082	0.6954	0.6997
36	0.6835	0.6346	0.5757	0.6313
37	0.5304	0.6320	0.4023	0.5215
38	0.5599	0.6376	0.6288	0.6088
39	0.6506	0.6587	0.6468	0.6521
40	0.6547	0.6439	0.6344	0.6414
41	0.5764	0.6470	0.6711	0.6315
42	0.6098	0.6654	0.5587	0.6113
43	0.9605	0.7461	0.4427	0.7265
44	0.6984	0.7482	0.7321	0.7262
45	0.6166	0.6439	0.7047	0.6551
46	0.6907	0.6571	0.4895	0.5854
47	0.9549	0.7411	0.3558	0.6340
48	0.6274	0.6449	0.5907	0.6210
49	0.7266	0.6579	0.7255	0.7033
50	0.7307	0.6702	0.6825	0.6945
51	0.6706	0.6972	0.5391	0.6356
52	0.6323	0.6804	0.5995	0.6374
53	0.6753	0.6513	0.6015	0.6427
54	0.6358	0.6475	0.5711	0.6188
55	0.6794	0.6651	0.5664	0.6370
56	0.6564	0.6318	0.5739	0.6207
57	1.0337	0.8124	0.3313	0.7258
58	0.6367	0.6446	0.5793	0.6202
59	0.6485	0.6501	0.5776	0.6264
60	0.6284	0.6724	0.6708	0.6572

61	1.2252	0.7858	0.3219	0.7776
62	0.5191	0.6205	0.6047	0.5814
63	0.7389	0.7274	0.4850	0.6504
64	0.4965	0.6000	0.3487	0.4817
65	0.5659	0.6459	0.6036	0.6052
66	0.7171	0.6096	0.3637	0.5635
67	0.5120	0.6016	0.4032	0.5056
68	0.6844	0.6022	0.3409	0.5425
69	1.1996	0.7687	0.4848	0.8177
70	0.9426	0.6292	0.3631	0.6449
71	1.0999	0.6571	0.3406	0.6992
72	0.7679	0.6375	0.4330	0.6130
73	0.9928	0.6273	0.4699	0.6967
74	0.7782	0.6270	0.3559	0.5870
75	0.7491	0.6787	0.6620	0.6956
76	0.6358	0.6013	0.4276	0.5549
77	0.4678	0.6201	0.4684	0.5183
78	0.5315	0.5911	0.2636	0.4621
79	1.0086	0.6272	0.3615	0.6659
80	0.5821	0.5908	0.2697	0.4809
81	0.5069	0.6007	0.3065	0.4714
82	0.5059	0.6005	0.3042	0.4702
83	0.4778	0.7019	0.6916	0.6230
84	0.5080	0.6674	0.6550	0.6101
85	0.6788	0.6875	0.6747	0.6903
86	0.7337	0.7280	0.3262	0.5940
87	0.7185	0.7156	0.2885	0.5742
88	0.7219	0.7180	0.4887	0.6428
89	0.7280	0.7232	0.4479	0.6330

Marine Stations

Obs. No.	PI_1	PI_2	PI_3	PI_4
90	1.3241	0.6390	0.3047	0.7559
91	1.7162	0.8969	0.3526	0.9886
92	1.3198	0.6436	0.3170	0.7669
93	1.4147	0.6652	0.3465	0.8089
94	0.8041	0.6775	0.6641	0.7152
95	0.7288	0.7296	0.4070	0.6218
96	1.0975	0.7251	0.3350	0.7192
97	1.0888	0.6684	0.3234	0.6935
98	0.8376	0.7385	0.7117	0.7626
99	0.8523	0.6591	0.3293	0.6136
100	0.6362	0.6523	0.3215	0.5367
101	0.7339	0.7240	0.3634	0.6074
102	0.7379	0.7264	0.3535	0.6059
103	0.7297	0.7228	0.3327	0.5951
104	0.6822	0.6673	0.3342	0.5679
105	0.7357	0.7254	0.3526	0.6045
106	0.7234	0.7210	0.3340	0.5928
107	0.7271	0.7218	0.3707	0.6086
108	0.7231	0.7798	0.3214	0.5881
109	1.4385	0.6347	0.3293	0.8008
110	1.5588	0.7407	0.3489	0.8828
111	0.6501	0.6623	0.3881	0.5669
112	0.6525	0.4419	0.3706	0.5550
113	1.5820	0.7781	0.6564	1.0055
114	0.6404	0.6541	0.3326	0.5424
115	0.6767	0.6411	0.3762	0.5647
116	2.1275	1.3083	0.3497	1.2618
117	0.6268	0.6425	0.3523	0.5405
118	2.4527	1.6400	0.5459	1.5462
119	1.4259	0.7351	0.4591	0.0733
120	0.7790	0.6665	0.5846	0.6767

121	0.6472	0.6561	0.3806	0.5613
122	0.6357	0.6563	0.4325	0.5748
123	2.2215	1.4082	0.4193	1.3497
124	1.9817	1.1622	0.3590	1.1676
125	1.6804	0.8608	0.3655	0.9689
126	0.6293	0.6405	0.3830	0.5510
127	0.6647	0.6511	0.3405	0.5521
128	0.6186	0.6376	0.3679	0.5413
129	0.6297	0.6452	0.3514	0.5421
130	0.6364	0.6570	0.5051	0.5995
131	0.6264	0.6508	0.3517	0.5463
132	0.6474	0.6598	0.3412	0.5495
133	0.6399	0.6547	0.3283	0.5410
134	0.7300	0.7230	0.3301	0.5944
135	0.7615	0.7170	0.7059	0.7281
136	1.2517	0.6795	0.4097	0.7803
137	1.2000	0.6480	0.3222	0.7234
138	1.3260	0.6815	0.3396	0.7824
139	1.3884	0.6830	0.3401	0.8038
140	1.4275	0.6885	0.3518	0.8226
141	1.0154	0.6442	0.3038	0.6545
142	1.4004	0.6856	0.3441	0.8101
143	0.9979	0.6680	0.5990	0.7550
144	1.2542	0.6934	0.3561	0.7679
145	1.1047	0.6768	0.6633	0.8149
146	1.1371	0.6612	0.3347	0.7110
147	0.7318	0.7239	0.3396	0.5985
148	1.0025	0.6499	0.3298	0.6674
149	1.1054	0.6549	0.3470	0.7024
150	0.6590	0.6693	0.3071	0.5452
151	0.7265	0.7210	0.3311	0.5929
152	0.7760	0.6658	0.5917	0.6779
153	0.6555	0.6648	0.3028	0.5410
154	0.6503	0.6605	0.3442	0.5517
155	0.6881	0.6694	0.3385	0.5653
156	0.6604	0.6675	0.2949	0.5409
157	0.6608	0.6705	0.2779	0.5364
158	0.5490	0.6585	0.3100	0.5392
159	0.6513	0.6625	0.3032	0.5390
160	0.7440	0.6623	0.6543	0.6869

hydrologic network creates a unique situation demanding repetition of any analysis on a detailed basis, rather than application of any generalized model.

VI. POLLUTION RELATIONSHIPS AND URBAN DYNAMICS

To summarize, there appears clear evidence that urban form plays a significant role in translating basic city characteristics (size, density and the economic base) into land use, and that the land use pattern is in turn directly related to the nature and intensity of environmental pollution. Most importantly, holding constant the effects of city size and manufacturing concentrations, and controlling for an inverse relationship between income levels and pollution, we find that:

1) The core-oriented urban region with a radial transportation network and a steep density gradient--
   a) displays greater intensity of land use, a lower percentage of land developed and used for residential and commercial purposes, and more open space, and
   b) as a consequence of this land use mix and pattern, has incrementally superior air and water quality.
2) The dispersed urban region, which has a less focussed transport network and lower, more uniform population densities. This urban form--
   a) displays urban sprawl, with a higher percentage of residential and commercial land use and less open space than in the core-oriented case, and
   b) as a consequence of this land use mix, has incrementally inferior air and water quality.

In what ways are these circumstances of environmental pollution reflected in levels of welfare? It has been shown that properly-structured economic models of property values can be given a direct interpretation in terms of the individual's willingness to pay for environmental quality. Does the same relationship hold between the aggregate property values of an urban region and the levels of environmental pollution in that region? If aggregate property values do express streams of net benefits accruing to land uses within an urban area, taking into account all benefits and costs, including agglomeration economies and negative externalities, then properly-structured economic models should be capable of interpretation in terms of the aggregate willingness of urban residents to pay for whatever advantages their urban region has to offer.

In fact, we have found that the aggregate property values of urban regions vary directly with their population size (the elasticity lying between 0.85 and 0.89) and median income levels (elasticity between 2.14 and 2.33), and inversely with manufacturing concentrations (elasticity between -0.37 and -0.48). A cubic relationship to city size reveals that net agglomeration economies are 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, that net diseconomies of greater size take their toll between 2.5 and 6.0 millions, and that increasing returns are found once again in the largest urban regions. Most importantly, variables representing levels of environmental pollution add no explanation to the model not already provided by size, economic base and income levels. Any depressing effects of pollution, congestion and crime on the quality of urban life are expressed in the fact that the elasticity of property values with respect to population size is less than one, that the coefficient attached to manufacturing concentrations is negative, and that there is a self-selectivity reflected in the fact that the relationship to income levels is positive and large.

To complicate matters, the levels of aggregate property values associated with different urban forms are exactly reverse of what might be predicted from levels of pollution. Controlling for the basic city characteristics once again, aggregate property values are greater in the lower-density dispersed urban region than in the high-density, core-oriented urban center. This means either that there are certain real advantages of dispersion that, in balance, offset the greater pollution levels associated with this urban form or that there are other negative externalities present in the core-oriented cities of the U.S. that offset any positive effects on property values imbued by their relatively superior levels of environmental quality. Whichever of these reasons is correct, the rapid continuing decentralization of American urban regions (which is documented in some new ways in the main report) is consistent with adjustments to urban form in response to the net benefits of dispersion, while carrying with it the probability that environmental quality will, as a result, worsen.

Urban dynamics, then, all point in the same direction: increasing size, increasing dispersion and increasing automobile usage are producing the very urban forms and land use patterns that will increase rather than decrease environmental pollution.

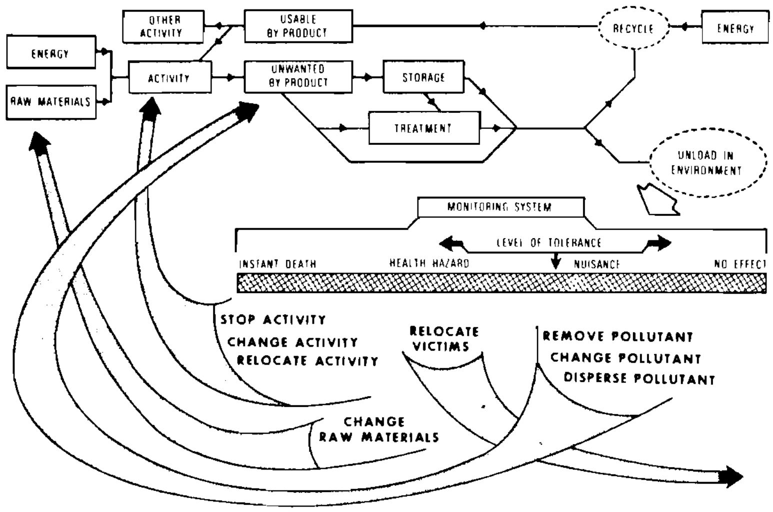
Figure 12 provides a picture of the policy alternatives that arise. One can change pollution by:

1) Removing, changing and dispersing pollutants produced by existing activities.
2) Changing the nature of these activities.
3) Changing urban forms through relocation of people and activities.

Currently, EPA's regulatory approaches focus on the first of these alternatives. Much of today's ecoactivism is directed

FIGURE 12

POLICY ALTERNATIVES



(after Grava, 1969)

to the second. What is suggested by the results of this study, and supported by the work of others, is that the third represents an alternative worthy of consideration.

The urban form variable is, of course, quite complex. It can be specified microscopically in terms of the detailed locations of jobs, residences, commercial areas, recreation areas, and vacant, non-urban land, with particular attention to the location of heavy polluting facilities (power stations, for example). At a higher level of generalization, it can be specified in terms of its density (areal intensity of activities and elements), the mixture or separatedness of uses, type and structure of the transportation network and the time dimension of the utilization of its space. Or, at the most generalized level, urban form may be approached in terms of plausible spatial configurations: compact versus dispersed, single nuclei versus multiple nuclei, those which adapt to growth as contrasted with those which have predetermined size.

Findings at all levels complement our own. At least three studies have shown that core-oriented, radically-structured urban forms could reduce pollution:

> Hartford. Air quality would be improved by corridor development rather than sprawl.
>
> Chicago. Significant air quality improvements would result from a radial finger plan.
>
> Seattle. Emissions would be reduced by corridor development.

The dilemma in these findings is this: if environmental pollution is to be changed by changing urban form, nothing less than reversal of present urban development directions must be achieved. But to state this is to highlight the nation's current land use and urban policy problem, which is that there is no national land use or urban policy except to accept the consequences of current developments (which, admittedly, do produce the greatest returns). The lack of national will in this regard was highlighted no more clearly than in President Nixon's Report on National Growth 1972 (pp. 30-1), in which it was stated:

> Patterns of growth are influenced by countless decisions made by individuals, families and businesses. These decisions are aimed at achieving the personal goals of those who make them, and reflect healthy free choices in our society. Locational shifts by individuals reflect, in part, a search for better job opportunities or for a better climate, while businessmen relocate where they can operate most effectively and therefore make the most profit.
>
> The factors that influence these decisions may be susceptible to changes that will alter the emerging growth patterns, but, in a Nation that values freedom in the private sector and democratic choice in the public, the decisions themselves cannot be dictated...It is not feasible for the highest level of government to design policies for development that can operate successfully in all parts of the Nation. [Emphasis added].

What, then, are "the factors that...may be susceptible to change"? In the words of the Nixon report, they include "local tax levies; the location of public facilities and roads; the extension of sewer, water, electric, and gas services; specific zoning and building regulations; and the approval of development plans." Even to make changes with respect to these factors at a local level will demand that the present limits of land use planning be extended in at least three ways as defined, for instance, by (Kaiser et al., 1973):

1) By redefining comprehensive planning to reflect environmental objectives.

2) By including environmental system information, concern for physical processes operating in the biosphere, and related evaluation criteria, in the land use planning process.

3) Through development of an adequate land use guidance system, involving use of public facility decisions to control the spatial locations and timing of development.

But, to achieve these extensions so that new urban development can be cast into more desirable urban forms will demand that land use planning decisions be made and policing power be applied effectively at their currently weakest level, that of the metropolis, so that reasonable closure be achieved with respect to the land use system whose development path it is hoped to redirect. The fact that most land development decisions remain private today, reflecting the prevailing attitude that land is a private commodity rather than a public resource, combined with a balkanization of available land guidance techniques among competing local governments, serve to produce our urban future by incremental drift. Radical changes in attitudes are required, involving nothing less than a new land ethic under which prevailing systems of values are shifted radically, if national environmental policy is to be promoted by changed directions of urban development.