NATURAL RESOURCES JOURNAL

Volume 10
Issue 4 *Fall 1970*

Fall 1970

Environmental Quality Management

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natural resources journal

Published four times a year by The University of New Mexico School of Law

Vol. 10 October 1970 No. 4

ENVIRONMENTAL QUALITY MANAGEMENT

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> We are immersed in an overwhelmingly complex system; we sense that our health and well-being are becoming ever more dependent on the successful management of the quality of our environment.[1]

> As we lengthen and elaborate the chain of technology that intervenes between us and the natural world, we forget that we become steadily more vulnerable to even the slightest failure in that chain.[2]

> To state categorically that changes in the environment should be prevented at all costs is to fail to recognize the value of resources invested for other purposes or to fail to recognize the multitude of adjustments that can be and are made when some resources are over-used. Moreover, there is no justification to place a higher value on the degree of risk or uncertainty found in estimating ecological changes than in any other similarly risky or uncertain investment. There undoubtedly will be times when degradation in the environment is worth the benefits that accrue from the new technology or the other conditions that caused it. Moreover, there have been very few times in history where adjustments to environmental degradation could not be accommodated.[3]

Any attempt to define environmental quality to the satisfaction of any individual other than the one who is formulating the definition will probably be doomed to failure. Even attempting to define the converse, environmental pollution, would presumably fare no better. Very broadly, environmental quality refers to the conditions and circumstances which surround man in his multifaceted activities. The "total" environment consists of a myriad of components, including the characteristics of: the natural environment (air quality, water

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1. 2 Environmental Sci. & Tech., cover (August, 1968).
2. Porter, The Place No One Knew, Glen Canyon on the Colorado (Sierra Club No. 50, 1963).
3. Carlson, *How Much Environmental Quality Should We Buy*, 6 Industrial Engineering 20 (May, 1969).

quality, aesthetics of the landscape); the man-made environment (buildings, transportation systems, the "cityscape"); and the sociological environment (inter-relations among individuals and groups in society). Environmental quality often has been equated with environmental health. However, environmental health traditionally has included not only problems relating to air and water pollution and solid wastes disposal, but problems relating to food sanitation, vector control, personal health and nutrition, housing, social stratification, motor vehicle accident prevention, and occupational health or industrial hygiene.[4]

It does not appear operational to include such problems as housing, social stratification, and motor vehicle accident prevention under the rubric of environmental pollution. The exclusion of such problems does not imply they are unimportant. Rather, the reason for exclusion is to enable focusing on a set of closely related problems, amenable to analysis within a coherent framework. Thus the focus of this symposium is primarily on those aspects of environmental quality–characteristics, parameters, indicators, variables–which are affected by the material and energy residuals generated in man's activities, and secondarily, on those aspects of environmental quality which are directly affected by production and consumption activities, that is, where no residuals are involved. Examples of the latter include the impacts of the design and location of energy transmission lines, billboards, highways and other transportation facilities on the aesthetic appearance of the landscape; the elimination of unique historical and scenic resources by man's activities, such as reservoir construction; and those problems traditionally within the purview of urban design, that is, the impact on perceived environmental quality of the juxtaposition of building in space.

I
RESIDUALS-ENVIRONMENTAL QUALITY MANAGEMENT SYSTEM

To provide a basis for discussion of the primary concern of this symposium, a residuals-environmental quality management system is described herein as consisting of two major subsystems: (1) the economic-technologic-ecologic subsystem; and (2) the information-response-institution-management subsystem. This is shown schematically in Figure 1. The elements of the system include: the factors which affect the generation of residuals, including the nature

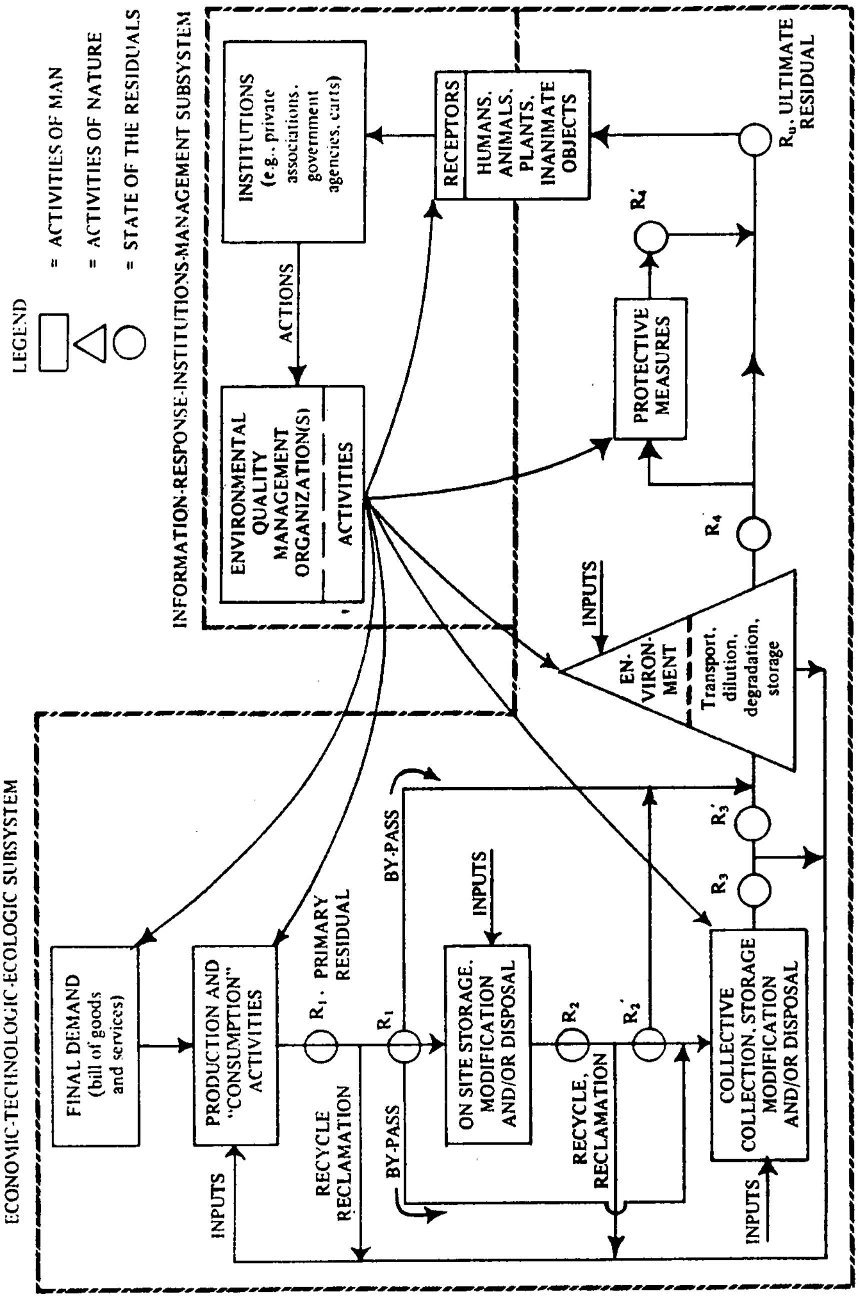
4. Occupational health refers to problems relating to the impacts of residuals on individuals *within* the work plant, office, or residence.

of goods and services (final demand) desired by society; the methods for handling residuals after generation but prior to discharge into the environment, including transformation into other forms of residuals; the mechanisms affecting residuals in the natural environment, which result in time and spatial patterns of ambient concentrations; the impacts of those time and spatial patterns of environmental quality on receptors (humans, animals, plants, inanimate objects); and the complex configuration of human responses to perceptions of environmental quality. The last of these elements is essentially the information-response-institutional-management subsystem, which produces a strategy (set of activities affecting one or more points in the system) for residuals-environmental quality management. The elements of the system are tied together by three types of flows: (1) material; (2) energy; and (3) information. The first two comprise the two classes of residuals, material and energy. Material residuals have three forms: solid, liquid, and gaseous. Energy residuals are exemplified by light, heat, vibrations, sound and radioactive particles. Both material and energy residuals may be transported through, or deposited in or on, the three environmental media: air, water, land.

The economic-technologic-ecologic subsystem may be visualized as a myriad of residuals generators, some moving, some stationary, located at various points in space, each of which produces a vector of primary residuals, R_1, of n elements or characteristics, according to some specified time pattern. (See Figure 1.) Prior to discharge to the natural environment, these residual vectors may be modified by recycling and/or treatment at either or both on-site and collective facilities and/or storage units, as indicated by R_2, R_2', R_3, and R_3'. After discharge into the environment, residuals can undergo only three basic mechanisms or processes: (1) transport; (2) transformation or modification, that is, physical, chemical, or biological conversion from one mix of residual characteristics to another; and (3) storage or accumulation, i.e., in the atmosphere, in water courses, on the land, and in the food chain.

Superimposed on the same area is an array of receptors, such as humans, animals, plants, and inanimate objects. These receptors are exposed to ultimate residuals, R_u, as reflected in concentrations of those residuals. These concentrations may be identical with the ambient concentrations in the environment, R_4 in Figure 1, or may be equal to the residuals vectors indicated by R_4', where some types of final protective measures are inserted between the ambient concentrations in the environment and the receptors. Examples of such devices are water intake treatment, soundproofing of buildings, and air filters.

Figure 1
GENERALIZED CONCEPTION OF RESIDUALS
ENVIRONMENTAL QUALITY MANAGEMENT SYSTEM



A. Residuals Generation

Final demand, that is, the set of goods and services desired, is the "driving force" behind residuals generation in society. Final demand itself is affected by population, standard of living, and social values. Considering a production function–including provision of services and household activities–as some combination of raw materials, processes and operations, operating rate or conditions, and specified characteristics of the product outputs or services, then for any set of goods and services desired, the type, quantity, and time pattern of residuals generated is a function of the production function and of the environmental controls imposed upon the production unit. For example, the residuals generated in producing a ton of paper of specified characteristics are dependent upon type of wood, method of wood preparation, pulping process, bleaching process, paper making operation, plus the environmental controls imposed. The gaseous residuals generated in internal combustion engines in vehicles are a function of the design of the engine, the age of the vehicle, the operating conditions, and the nature and quality of the fuel used. The residuals generated in producing a particular crop in an agricultural operation depend on the cultivation practices, variety of seed used, method of application or pesticides and fertilizers, slope of the land with respect to erosion potential, and irrigation practices.

Because of the number of variables involved in these relationships, there is a wide range in the magnitude and character of residuals generated even in a single type of activity. In addition, the generation of residuals from a single operation in many cases, varies over time–diurnally, weekly, seasonally, and from year to year. These time fluctuations in residuals generation stem from variations at the individual operation in: demand, the quality of raw material inputs, and climate. Of course, residuals generation varies from region to region depending on the mix and spatial pattern of economic activities.

B. The Natural Environment

The natural environment has a capacity to assimilate in some degree, all forms and types of residuals through the mechanisms of transport, transformation, and storage. In effect, the environment acts as a buffer between the discharger and the receptor, that is, it dissipates, absorbs, dilutes, and degrades or modifies residuals. However, the capacity of the environment to assimilate residuals varies from place to place and from time to time, depending both upon local conditions and upon the stochastic nature of some components of the environment, such as streamflow, temperature, and sunlight.

From the point of view of residuals-environmental quality management, it is necessary to be able to translate a specified time and location pattern of residuals discharges into the resulting time and spatial pattern of ambient concentrations, including the cumulative and long-run effects through the food chain. There are many complicating factors which affect the transport, modification, and accumulation of residuals in the environment, including synergistic and antagonistic effects and the complicated paths through the ecological system. Another complication is represented by the interactions in the environment among forms of material residuals and between material residuals and energy residuals.

Perhaps the most difficult aspect of the analysis of the interrelationship between residuals discharged and resulting environmental quality, is the differential time rates and spatial extent involved. Some discharges into the environment have an immediate effect on environmental quality, at least in a local area. Thus, the change in environmental quality per unit of time is large. At the other end of the continuum, there are residuals whose discharges have an imperceptible effect on environmental quality in the short-run, but over time may have a large impact. The impact may not be large in terms of change in the ambient concentration, but rather with respect to the result of even that small environmental quality change. In effect, the change in quality per unit of time is very small and the spatial area involved may be very large, such as the entire atmosphere with respect to the change in concentration of carbon dioxide in the atmosphere.

C. Receptors

Four basic categories of receptors which may be affected by the discharge of residuals are: (1) humans; (2) animals; (3) plants; and (4) inanimate objects, such as buildings, clothing, and vehicles. The problem is to translate the time and spatial patterns of ambient environmental quality into the short-run (acute) and long-run (chronic and mutagenic) physiological and psychological effects, and in turn, to translate those effects into economic effects on receptors. The impacts on the last three categories of receptors are important through their impacts on the first. That is, it is the reaction of individuals and society to the impacts of DDT on the bald eagle which is the response of relevance for residuals-environmental quality management.

As in the case of the impacts of residuals discharge on environmental quality, there is a wide variation in the time response of receptors to ambient environmental quality concentrations. That is, the change in damage per unit of time is large in cases of acute impacts, such as eye irritating smog. The changes in damage per unit of time are very small in the case of mutagenic effects.

There are other complicating factors in determining impacts on receptors. These include: the additive or mitigating effects of meteorological conditions; the synergistic or antagonistic effects of the simultaneous exposure to several different residuals, including exposure through more than one medium, (for example, intake via air, water, and foods);[5] and the distribution of effects among population groups stemming from differential exposure and/or differential susceptibility. The response of humans, plants, and animals to environmental quality conditions is not distributed evenly. Both exposure and susceptibility to adverse conditions vary substantially among different groups. Exposure of humans is a function of the combination of exposures in the three primary environments in which the individual operates–residence, work place, and transport from residence to work and return. Susceptibility varies with such factors as physiological condition and age. For example, the response to air quality is conditioned by diet and the use of drugs. The response to aircraft noise is greater, that is, more adverse, among older segments of the population than among younger segments.

II
IMPROVING AND/OR MAINTAINING ENVIRONMENTAL QUALITY

The pervasiveness of residuals in society has been amply and ably described.[6] Essentially all of man's activities result in the generation of residuals and entail some use of the assimilative capacity of the environment, a common property resource.[7] This pervasiveness logically leads to a consideration of the physical or technological methods by which environmental quality can be improved and maintained, in the context of residuals management. Such is the primary focus of the symposium. These methods can be classified into four basic types: (1) reduction in nature, magnitude and/or time pattern of residuals *generation;* (2) modification of residuals after generation;

5. It should be emphasized that residuals are imbibed through several processes for example, injection, inhalation, absorption, and radiation.

6. *See* Ayres & Kneese, *Production, Consumption, and Externalities,* 59 American Economic Review, No. 3, 282-297 (1969), and Kneese & d'Arge, *Pervasive External Costs and the Response of Society,* in The Analysis and Evaluation of Public Expenditures: The PPB System, A Compendium of papers submitted to the Subcommittee on Economy in Government of the Joint Economic Committee, 91st Cong., 1st Sess., 87-115 (1969).

7. For an extended discussion of the environment as a common property resource, *See* Kneese, Ayres, & d'Arge, Economics and the Environment: A Materials Balance Approach, Resources for the Future, forthcoming.

(3) modification or better utilization of the assimilative capacity of the environment; and (4) application of final protective measures.

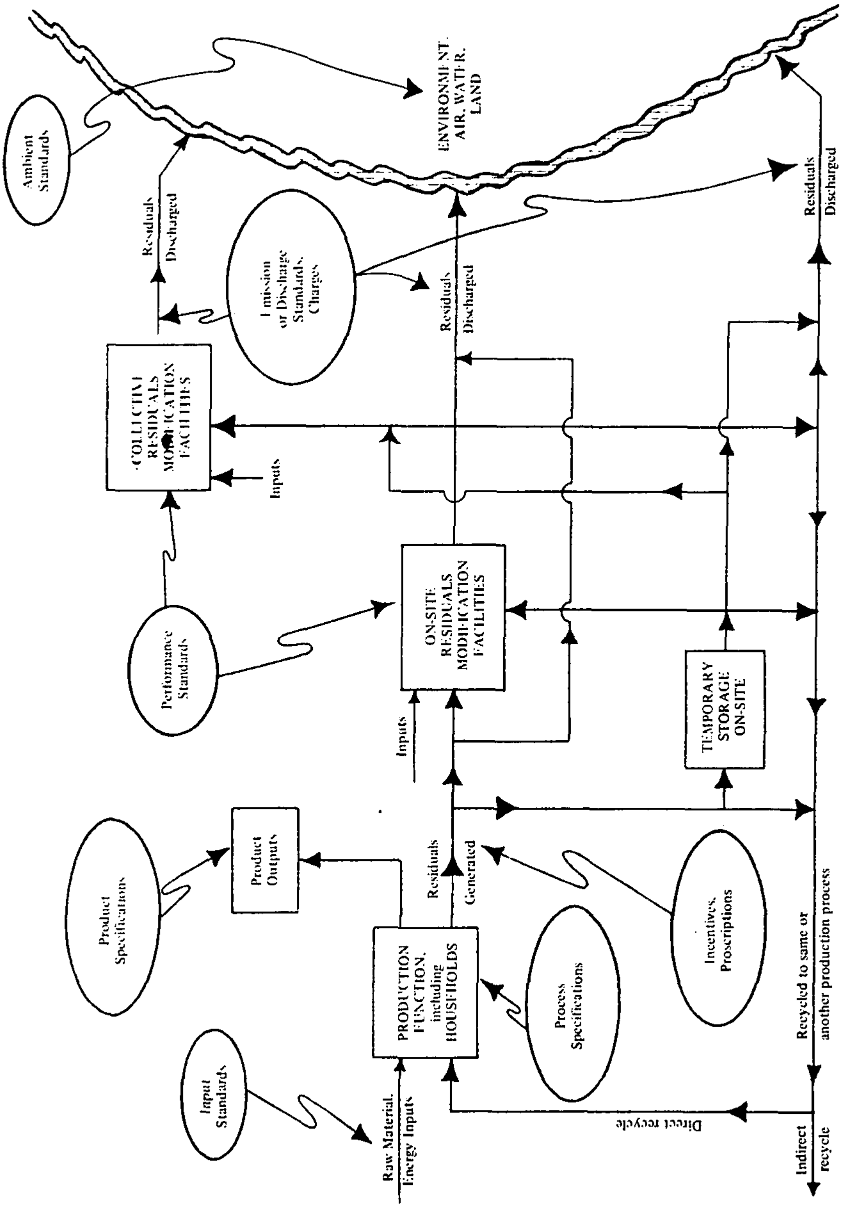
Reduction in residuals generation can be accomplished by some combination of changes in: the nature of raw material inputs; production processes and operations; the nature of final products or product output specifications; and scheduling of activities. After residuals have been generated in an activity, residuals can be modified before discharge into the environment by materials recovery or direct recycle, byproduct production, reclamation, and what has been traditionally called "treatment." (The first three can be subsumed under the general term, "reuse".) Direct recycle is defined as the return of materials and/or energy directly into the same production function at the same site. This is in contrast to by-product production which is termed indirect recycle, because the residual is utilized as an input to a different production function, either at the same or another site. Reclamation of residuals is differentiated from direct and indirect recycle by the intervention of one or more activities, including storage in the environment, between the locus of generation and the locus of reuse. For example, abandoned vehicles are often "stored" in the environment, city street or rural countryside, prior to collection, transport, and processing for reuse. Waste newspaper generated in households is not returned directly to an industrial operation to which it comprises a raw material input. Rather, it may be collected by a scout troop for delivery to and processing by a waste paper broker. The differentiation among types of residuals reuse is made because of the important policy, legal, and institutional problems involved. Finally, residuals modification after generation by treatment encompasses such activities as sewage treatment plants, electrostatic precipitators, sanitary landfills, and deep well disposal of liquid residuals. It should be emphasized that additional residuals may be generated in the production functions involving the processing of residuals generated in the first place. Such processing itself requires inputs. Treatment does not reduce the weight of total residuals, but rather modifies their form and/or time and spatial pattern of occurrence.

The third basic method of improving and maintaining environmental quality involves making better use of and/or modifying the assimilative capacity of the environment. Examples include: (1) regulating the time pattern of generation and/or discharge of residuals to coincide more completely with available assimilative capacity; (2) redistributing effluents downstream, to other river basins, or outside of a particular airshed where the assimilative capacity is larger, or building higher effluent stacks; (3) modifying the assimilative capacity of the environment itself, such as by instream aeration and increasing low flows through releases of water from surface and/or groundwater reservoirs during periods of low flow; and (4) regulating land use, either, or both, with respect to residuals generators and residuals receptors. Another possibility, which can be considered to fall in this third category, is to expand the scope of analysis of the decision unit. For example, if the problem involves deterioration of water quality stemming from residuals discharges from tomato canning, changing the boundaries of the residuals-environmental quality management system from just the cannery itself to encompass all activities from tomato production in the field through canning, enables consideration of other possible alternatives and tradeoffs. Obviously, expansion of the areal scope should not result simply in trading off an environmental quality problem in one location for the same or a different type of environmental quality problem in another location. Similarly, it should be emphasized that the fundamental interrelationships among the three types of material residuals and between the material and energy residuals require that strategies for improving water or air quality, and other environmental factors must consider all residuals simultaneously.

The preceding three types of measures result in ambient concentrations of the various environmental quality indicators or variables of concern (R_4 in Figure 1). Since the receptor is the basic concern of residuals-environmental quality management, the fourth category involves the application of final protective measures between the ambient concentrations and the receptors, at least for humans, and for animals, plants, and inanimate objects within man-made structures. Soundproofing and air conditioning (with respect to temperature and other characteristics) of buildings, intake water treatment, and washing of fruits and vegetables in the home to reduce or eliminate pesticide and other residuals, are examples of such measures.

The alternatives indicated above are the basic physical or technological methods for residuals-environmental quality management. Application of these methods is accomplished through the policy instruments adopted via the information-response-institutions-management subsystem, which includes not only the governmental agencies directly responsible for residuals-environmental quality management, but also the general levels of government and the courts. Figure 2 illustrates the possible loci of controls to affect residuals discharges into the environment. However, it is limited to controls which might be imposed on the generators-dischargers. As indicated previously, an efficient strategy for residuals-environmental quality management is also likely to include measures which modify or

Figure 2
RESIDUALS-ENVIRONMENTAL QUALITY MANAGEMENT:
POSSIBLE LOCI OF CONTROLS



better utilize the assimilative capacity of the environment and "final protective" measures between the ambient environmental concentrations and the receptors.

Strategies for residuals-environmental quality management involve different time and spatial contexts. One possible taxonomy of these contexts is shown in Table 1.

Table 1
TIME-SPATIAL CONTEXTS OF
RESIDUALS-ENVIRONMENTAL QUALITY PROBLEMS

TIME DIMENSION / SPACE DIMENSION	SHORT-RUN	LONG-RUN
LOCAL		
REGIONAL		
NATIONAL		
GLOBAL		

Different strategies may well be appropriate depending on the time-space context (or contexts) involved. This is particularly important in terms of the uncertainties associated with impacts of various types of residuals discharges to the environment, uncertainties with respect to both impacts on environmental quality and impacts of the resulting quality on receptors. For example, what are the long range ecological effects of the widespread discharge and distribution of persistent pesticides? What effect will a long term increase in atmospheric carbon dioxide have on climate? Will the reflection of light energy from the sun caused by particulate residuals in the atmosphere have a significant impact on the temperature of the biosphere? What are the impacts on human health of low-level, long-term exposure to various types of residuals? Despite the uncertainties surrounding these and other questions, the problems they reflect are integral parts of residuals-environmental quality management. One of the most difficult problems is to determine how to incorporate such long-run problems of uncertain importance in the day-to-day decisions of environmental quality management agencies.

Whatever the context, selecting a strategy for residuals-environmental quality management involves four basic questions. These are:

1. What level(s) of environmental quality are desired what portion(s) of the time?
2. What is the least cost means of achieving any desired level of quality with a specified degree of certainty?
3. What are the distribution of benefits from, and the distribution of costs associated with, the environmental quality improvement (or maintenance) program?
4. What kinds of management institutions can be devised which will enable achieving the desired quality and certainty level(s) most efficiently?

All of these questions are interrelated. The first cannot be answered in isolation from the second, because the level and certainty of quality desired will to some extent be a function of the costs of achieving that level of quality with the specified degree of certainty. But the costs in turn will depend on the management agency available and the policy instruments used, for example, uniform reduction at all discharge points in contrast to an effluent charge. The strategy selected will also depend on the desired distribution of costs and benefits, as determined politically.

Although the primary focus herein is on environmental quality as related to residuals, the importance of the class of environmental quality problems *not* involving residuals should be reiterated. Many of these latter problems are characterized by "preservation vs. development" controversies. The issues pertaining thereto have been delineated by Krutilla.[8] Just as with residuals problems, (1) the driving force is final demand; (2) there is a wide range of technological alternatives available, both in space and in time; and (3) the

8. Krutilla, *Conservation Reconsidered*, 57 American Economic Review, No. 3, 777-786 (1967).

selection of a strategy involves a complex information-response-institution-management subsystem.

The present and subsequent papers in this symposium will deal with one or more elements of the residuals-environmental quality management system or with a particular type of residual. Anderson is concerned with governmental organization for residuals management on the regional level. Edwards, Headley and Langham analyze the problems of pesticide use, both benefits and externalities stemming therefrom. Bragdon describes some of the dimensions involved in the noise problem. Grad and Rockett look at the implications for environmental quality management of recent environmental litigation.