J. ENVIRONMENTAL SYSTEMS, Vol. 8(2), 1978-79

A RESIDUALS MANAGEMENT MODEL FOR REGIONAL ENVIRONMENTAL QUALITY

RANGESAN NARAYANAN
Research Assistant Professor
Department of Economics
BRUCE BISHOP
Professor
Department of Civil Engineering

Utah State University

ABSTRACT

Due to uncertainties in the development of the energy industry, the growing Utah economy is faced with alternative futures. Using an economic and demographic model, the population and level of economic activities have been forecast by the office of the State Planning Coordinators. Based on these projections, the amount of various residuals (solids, water-borne and air-borne) were estimated. A residuals management model is developed to investigate the feasibility of alternative treatment technologies incorporating residual transformation possibilities. A set of cost minimizing residual modification processes at each outfall is selected to meet prescribed environmental standards at specified receptor points using linear programming. The effectiveness of alternate environmental policies such as effluent charges and standards were analyzed using parametric programming. Solution to institutional and legal problems due to treatment technologies is demonstrated.

Residuals generated by the society through its production and consumption activities are discharged to the water, air and land resulting in the degradation of environmental quality. This problem stems from the divergence between private and social costs leading to overproduction and consumption and hence resource misallocation in the economy [1—3]. Most economic analyses of environmental

doi: 10.2190/313W-EJHH-2KXT-BFM4
http://baywood.com

problems have been confined to resolving externalities involving a single residual [4–5]. However, there are deficiencies in this approach that must be recognized at the outset. First, the degree of "third-party" effect depends on the characteristic of the residual which can generally be described by an n-component vector of concentrations of different pollutants and therefore, each constituent present in the residual needs to be given attention. Secondly, any treatment of residuals generates other different forms of residuals. In other words, there exists a trade-off among residuals that can be described in terms of a transformation function. Therefore policies aimed at dealing with external effects must necessarily take into account the residual modification processes. This study incorporates these concepts into an approach for determining suitable management schemes for regional management of residuals.

To demonstrate the analysis the eastern part of Utah is used as a study area. With higher energy prices, the profitability associated with Utah's vast energy resources (oilshale, tarsands, coal and natural gas) has given incentives to private investors to contemplate the technical and economic feasibility of resource extraction, energy production and conversion processes. Although the extent of energy development in Utah is speculative, regional studies have envisioned certain scenarios and have projected population growth, migration, employment by sectors and land-use patterns. Based on these estimates, this study provides a framework of analysis for regional environmental planning and implementation of economic and technological measures to control environmental quality.

Model Assumptions

The management model encompasses air-borne, water-borne and solid residuals. Specifically, the analysis takes into account BOD, ammonia, suspended solids and disolved oxygen in wastewater, particulate matter in air emissions and solid wastes. It is assumed that the amounts of various residuals generated by the production and consumption activities are fixed and the only way to curtail degradation of environmental quality is through residual modification processes. This assumption is justifiable in that the cost of metering municipal wastewater and testing the concentration of various constituents is expensive. Hence, a flat rate for sewer services is common in most communities and therefore the consumer's decision to discharge is not based on price. The same arguments hold for solid wastes generated by the households. As for the industrial plants in the study region, the major problem is expected to result from air emissions and solid wastes. The quantity of residuals discharged by these plants will be assumed fixed since they are expected to operate with a given technology at some "target" levels of output. It is recognized that by appropriate economic incentives, a firm can be induced to:

1. reduce output;
2. effect changes in the use of certain inputs contributing to pollution;
3. make suitable modification in production processes; and
4. install pollution control devices.

Of these, only the last two alternatives will be treated in this analysis.

On the side of receiving media, damages resulting from pollution are taken to be infinite beyond certain point. This is equivalent to fixing environmental quality standards at selected points in the study region. Thus, the scope of analysis is confined to developing an operational model for examining alternative pollution abatement technologies within existing political and institutional constraints. Given the amount of residuals (solids, water and air-borne) generated by spatially distributed production and consumption activities, the problem is to determine a set of cost-minimizing treatment options at the residual outfalls to meet prescribed environmental standards at specified receptor points. The treatment costs are assumed to be a linear function of the pollutant quantities treated. The transformation between different forms of residuals is in fixed proportion for a given treatment option. The environmental interaction functions are assumed linear in the amount of constituents discharged. The precise relationships were derived from the gradient evaluated at some average concentration from the non-linear water quality and air quality models.

DESCRIPTION OF THE MODEL

Let C_{ij}^1 be the cost of treating 1th residual at the ith source using jth treatment option and let x_{ij}^1 be the corresponding quantity of the residual. The total cost is given by

$$TC = \sum_{i,j,1} C_{ij}^1 X_{ij}^1 \tag{1}$$

Since the total quantity of residual is fixed for a given source, impose the following constraint.

$$\sum_j X_{ij}^l = R_i^l \qquad i = 1, 2 \ldots M; l = 1, 2 \ldots N; \tag{2}$$

where R_i^l is the total amount of the residual discharged, M is the total number of sources and N is the number of (water, air and solid) residuals.

If A_{ij}^{lk} is the amount of kth constituent (BOD, SO_x, etc.) generated in the process of residual modification, the following equation yields the total amount of kth constituent $\hat{A}_i^k$ discharged at i.

$$\sum_{j,l} A_{ij}^{lk} X_{ij}^l = \hat{A}_i^k \qquad i = 1, 2 \ldots M; k = 1, 2 \ldots K; \quad (3)$$

where K is the total number of constituents of interest. The above equation can be rewritten as

$$\sum_{j,l} A_{ij}^{lk} X_{ij}^l - \hat{A}_i^k = 0 \qquad (4)$$

Let W_{ir}^{mk} represent the change in concentration of the constituent k at the receptor point r from a unit change in the concentration of m at i (this formulation allows for interaction between constituent concentration such as BOD and DO). Then the environmental quality standards at r can be stated as

$$\sum_{i,m} W_{ir}^{mk} \hat{A}_i^k \leqslant S_r^k \qquad r = 1, 2 \ldots R; k = 1, 2 \ldots K; \quad (5)$$

where R is the total number of surveillance points and S_r^k is the difference between the ambient quality with no pollution and the prescribed standard for K at r. While this formulation is true for constituents which are water and air-borne, the solid wastes are handled with the following resource constraint.

$$\sum \hat{A}_i^k \leqslant L_i^k/b \qquad r = 1, 2 \ldots R; k = 1, 2 \ldots K; \quad (6)$$

where L_i^k refers to the maximum amount of land available at i for sanitary landfill and b is the amount of land required per unit of solidwaste. Minimization of (1) subject to constraints (2), (4), (5) and (6) is a linear programming problem that can be solved for optimal residual management schemes at various outfalls. To retain simplicity of exposition, a few details about treatment options, such as method of handling sludge, locational choices for sanitary landfill have been omitted from the discussion. Yet, they are incorporated in the analysis.

DESCRIPTION OF THE STUDY REGIONS

While models and approaches have been demonstrated for developed areas with relatively stable economic structure such as the

Lower Delaware Valley region [6–9], the purpose of this study was to apply and demonstrate the residuals management concept for an area where a broad range of future development levels could result depending on resource development decisions made outside the region. As a study region, the Uintah Basin in Southeastern Utah was identified as an area of prime interest, because the region could undergo extensive energy resources development (oilshale, tar sands, oil and natural gas). A large population influx and rapid growth in infrastructure would also result from the exploitation of the region's rich deposits of energy resources. To assess the impact of these changes requires analysis of residuals generation and environmental management strategies.

The Uintah Basin can be characterized in broad terms as a rural region having generally high environmental quality levels. The area could, however, experience negative impacts due to rapid growth caused by the development of mineral and other resources. In delineating the study region (see Figure 1), which includes Duchesne and Uintah Counties, the main considerations were:

1. that the area should be large enough to include a significant portion of the development induced by changes in basic economic sectors;
2. that the area encompass the environmental resources that contribute to or are impacted by developments; and
3. that it coincides as closely as possible to conventional subregional units of data organization such as hydrologic basins and county boundaries.

Alternative Futures for the Case Study Area

Since the future of the region is highly speculative, some possible development scenarios which are combination of events occurring as a result of economic forces and decisions exogeneous to the State have been envisioned by the State Planning Coordinator's Office [10]. The economic production and consumption levels associated with alternative futures are the basis for generating the range of residuals discharges against which environmental management strategies must be assessed. Of the ten alternative futures, the residuals management model was applied to conditions corresponding to Future Zero, Future Eight and Ten. Future Zero refers to baseline set of events most likely to occur during the projection period (1970-1990). It is presumed that continued and expanded petroleum exploration will occur to a peak between 1975 and 1980, after which

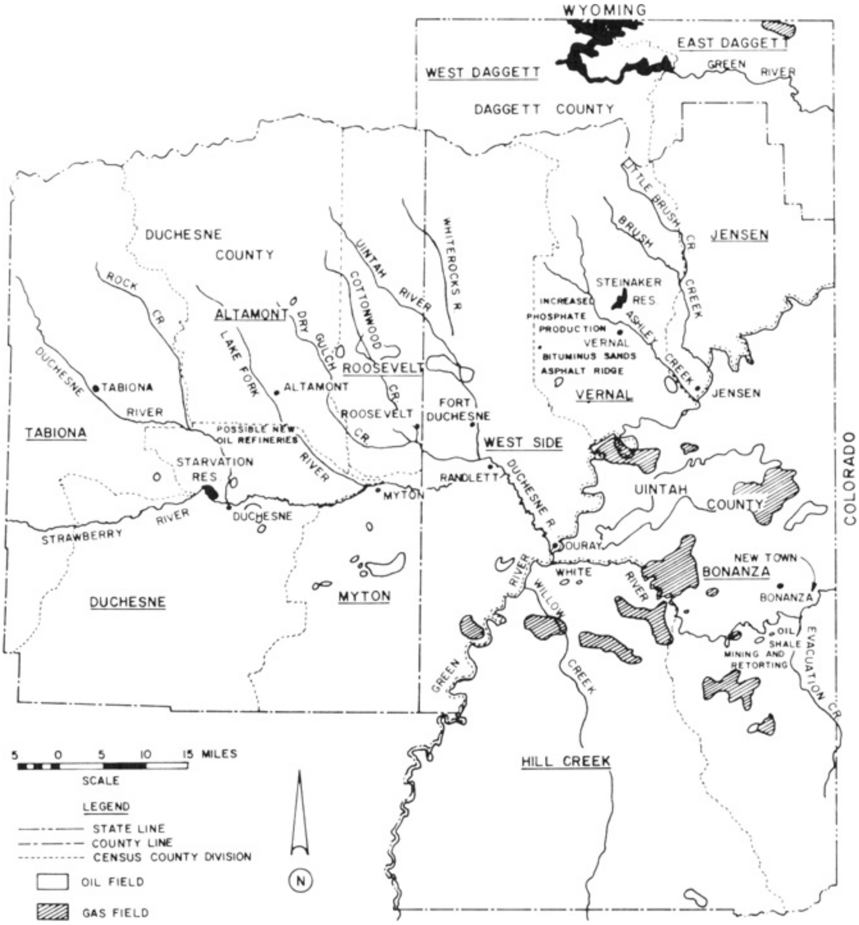

Figure 1. Map of the study area with potential development sites.

it will decline whereas basic mining employment will be sustained by production. Crude oil will continue to be exported. No additional development is foreseen. Under Future Eight, projected growth is based primarily on energy resources, but excluding events based on direct export of electrical power. These resources include geothermal, oil and gas, uranium, coal mining and oil-shale. Alternative Future Ten is an extremely expansionary future with the operation of an oil refinery, the Central Utah water Project, extraction of oil from shale and tar sands, phosphate mining and oil exploration.

Economic and Demographic Projections for Alternative Futures

The effects of alternative futures on the economy and population of the region are projected by the UPED model [11], an economic and demographic model developed by the Office of the State Planning Coordinator. The major assumption in the model is that the export demand for regionally produced goods and services is the driving force behind regional growth or deline. The demand for labor by each of the seventy-eight industry sectors is composed of two elements, basic and residentiary. The model forecasts the pressures for labor force migration which would result from either excess or deficit demand for labor in each region (multi-county planning district). It also forecasts population totals and population characteristics in terms of age, sex, and size of labor force.

To arrive at these forecasts, the model starts with the detailed data of the 1970 Census Fourth Count. It then adjusts this count for would-be-residents absent at the time of the count and for those counted who are only temporary residents. Then the model determines the number of people, by age group, who can be expected to survive and to be born to survivors by 1975, 1980, 1985, and 1990, and adjusts for those who migrate in or out for retirement purposes and for those who are not part of the labor force. By applying labor force participation rates to the aged and survived populations, the indigenous supply of labor for the region is determined.

To determine the demand for labor in each region (to be compared to the supply of labor in order to assess migration pressures) the model projects current numbers of jobs by employment sector. It adds to these numbers the basic jobs which would be created by each event in an alternative future. Finally, it estimates and adds the number of population dependent jobs which would result from the population growth (or decline) caused by these events.

Thus, the model creates, for the region, indications of the demand for labor, by employment sector, and of the supply of labor. If the demand exceeds the supply there will be pressure for in-migration. If the supply exceeds the demand there will be pressure for out-migration. The extent of this pressure will depend on the rate of unemployment in the region, in the state, and in the nation. The model projects future population levels and economic and demographic characteristics for the region. Further, by comparing projections for different alternative futures, the impacts of the various major developments of which the futures are comprised are estimated.

Application of the LP Model and Results

The sources of wastewater and municipal solidwaste consist of seven towns viz., Vernal, Jensen, Duchesne, Altamont, Myton, Roosevelt and Bonanza. The major industrial air pollution sources in the model includes oil shale processing (TOSCO, In-SITU and PARAHO processes), Gilsonite and phosphate mining, and oil-refining. Eight surveillance points were chosen on the river system for water quality and nine points (the seven towns, the oil-shale tract and phosphate mine site) were selected for maintaining air quality. The parameters required for LP problem were calculated using the projections for different alternative futures [12].

The optimal solution for municipal wastewater indicates construction of standard and total containment lagoon for every town. This is understandable since the land prices are relatively low. The only binding constraint is ammonia in the stream. The air pollution abatement for oil-refinery, Gilsonite and phosphate mining should be implemented using gravitational and centrifugal collectors. Use of electrostatic precipitators and baghouse will be optimal for certain processes at the oil-shale plant. Solidwastes were disposed of in local landfill sites at Vernal, Jensen, Myton, and Bonanza. The other three towns, Duchesne, Altamont and Roosevelt, use a common regional landfill site. The air quality levels decline at Bonanza and Phosphate mines for all futures from 24 micro gms/m^3 to 63 and 200 micrograms/m^3 respectively. Roosevelt and the oilshale tract experience a degradation in air quality from 24 to 42 and 200 micrograms/m^3 respectively under future eight and ten. A summary of total cost for various futures are shown in Table 1.

FURTHER RESULTS FROM PARAMETRIC ANALYSIS

Effluent charges — For the purpose of this study, an effluent charge schedule on BOD in wastewater and particulates in air emissions were levied separately and the resulting environmental quality for various charges was derived from the linear programming model. The charges were varied using parametric analysis on the linear programming model. Table 2 shows the relationship between the effluent charge and the BOD load at various surveillance points. From the table, an effluent charge of ten-cents/pound of BOD is sufficient to induce the waste dischargers to cut back BOD loading to the point that a stream standard of 5 mg/l is met.

In Table 3, the relationship between the BOD concentrations at surveillance points and the effluent charges is shown for a case

Table 1. Cost Summary of Residuals Management Options

	Municipal Wastewater		*Air Emissions ($/Day)*		*Solid Wastes*		
Model Run Description	*$/Day*	*$/Cap./Year*	*Oil Shale*	*Other Industry*	*$/Day*	*$/Cap./Year*	*Total Cost*
Alternative Futures & Processes							
Zero	2,785.35	28.72	0	51.05	1,254.10	12.93	4,090.56
Eight-TOSCO	3,734.28	29.39	7,829.07	657.35	1,731.92	13.63	13,952.92
Paraho	3,734.28	29.39	1,314.26	657.35	1,731.92	13.63	7,437.80
In Situ	3,734.28	29.39	3,083.80	657.35	1,731.92	13.63	9,207.25
Ten (TOSCO)	5,457.97	42.96	7,829.07	683.23	2,154.36	14.71	16,124.63

Table 2. Response to Effluent Charge on BOD

Effluent Charge	*Water Quality-BOD (mg/l)*							
$/Pound	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
0.02	5.7	4.5	3.7	5.8	4.7	3.7	2.7	1.8
0.04	5.7	4.5	3.7	5.8	4.7	3.7	2.7	1.8
0.06	5.7	4.5	3.7	5.8	4.7	3.7	2.7	1.8
0.08	5.7	4.5	3.7	5.8	4.7	3.7	2.7	1.8
0.10	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
0.15	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
0.20	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
0.25	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
0.30	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
0.50	4.2	4.2	3.7	4.4	4.5	3.4	2.6	1.8
1.00	3.2	3.6	3.7	4.4	4.5	3.4	2.6	1.8
1.50	2.1	3.0	3.7	4.4	4.5	1.3	2.5	1.3

Table 3. Response of BOD Levels at Surveillance Points

Effluent Charge	*Water Quality-BOD (mg/l)*							
$/Pound	*A*	*B*	*C*	*D*	*E*	*F*	*G*	*H*
0.10	5.5	4.5	3.7	5.8	4.7	3.7	2.7	1.8
0.20	5.5	4.5	3.7	5.8	4.7	3.7	2.7	1.8
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
.	.	.	.	.	.	.	.	.
1.00	5.5	4.5	3.7	5.8	4.7	3.7	2.7	1.8

Table 4. Response of Particulate Levels at Monitoring Points to Emission Change

Effluent Charge	*Air Quality (gm/m^3)*				
\$/kg Metric Ton	*A6*	*A7*	*A8*	*A9*	*Total Cost*
0.25	19.5	42.1	10,385.4	194.6	17,244.2
0.50	19.5	42.1	10,385.4	194.6	
0.75	19.5	42.1	10,385.4	194.6	
1.00	19.5	42.1	10,385.4	194.6	
1.25	19.5	42.1	10,385.4	194.6	
2.50	19.5	42.1	10,385.4	194.6	
3.75	19.5	42.1	10,385.4	194.6	
5.00	19.5	42.1	10,385.4	194.6	
10.00	19.5	41.3	5,643.7	194.6	382,373.
15.00	19.5		13,357.7		562,702.5
20.00					
40.00	19.5	41.0	891.4	4.7	247,648.
60.00					
100.00	19.5	32.2	211.0		173,340.
200.00	19.5	15.6	140.0	2.9	232,000.

excluding the complete containment lagoon option. With an effluent charge of \$1.00/kg of BOD, the solution did not differ from that corresponding to \$0.10. Violation of stream standards can be observed at surveillance points A and D. With higher effluent charges, it would be possible to meet the standards at these points.

Table 4 shows the concentration of particulate matter at surveillance points A6-A9 in response to a schedule of charges imposed on particulate emissions. From the table, a charge of \$200/metric ton of particulates is required to meet the air quality standard of 200 μgm/m^3.

Effluent Standards — Effluent standards on individual point discharges can also be used to achieve desired levels of environmental quality. Assume that effluent standards and the stream standards are imposed by appropriate state and local agencies. For BOD and suspended solids, the effluent standards are uniformly set at

Table 5. Effect of Stream and Effluent Standards

Surveillance Points	*Stream Standard*		*Stream and Effluent Standard*	
	BOD(mg/l)	*SS*	*BOD (mg/l)*	*SS*
A	3.5	6.3	3.7	5.6
B	3.8	9.9	3.8	9.8
C	3.7	14.6	1.9	12.6
D	4.4	8.0	4.4	8.0
E	4.5	32.1	2.3	29.7
F	3.4	28.0	2.1	26.6
G	2.6	45.7	1.7	44.4
H	2.6	15.6	1.4	15.0

ten mg/liter for all discharge points. The resulting quality levels are compared with the stream standards in Table 5. The table shows the BOD and suspended solid concentrations at each of the nine surveillance points for stream standards only and for both stream and effluent standards. It can be seen that the concentration of BOD and SS at the nine surveillance points decrease with the enforcement of effluent standards.

Legal constraints and incentives: a water rights example — Certain technological controls for waste reduction may violate legal and institutional constraints in a given area. One example is the adoption of the complete containment lagoon option for treating wastewater. With a total containment lagoon, the treated wastewater is not returned to the system. Rather, the water is lost from the stabilization ponds through seepage and evaporation. This could conceivably affect the water rights of the downstream users. Therefore, from the viewpoint of a social optimum, the water quality improvement cost of this option should account for the value of further use of effluent that is foregone due to this alternative. In other words, the cost of improved water quality due to the use of evaporation ponds should include not only the variable cost of operation and maintenance, but also the value of the product foregone since the water is not available to the downstream users.

To see this, consider a river system with a wastewater source discharging X acre feet (see Figure 2). Assume that farming is the only principal activity in the downstream parts of the river. Let

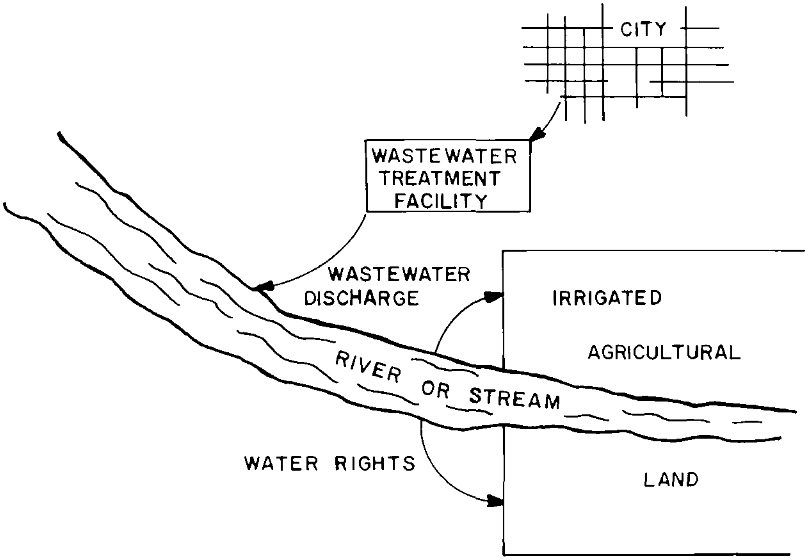

Figure 2. Interrelation of water rights and wastewater discharge.

the demand curve for agricultural use be denoted by

$$P = P(Q)$$

where P is the price of water and Q is the quantity used in agriculture. Also assume that the water right of the farmers is Q* acre feet. This water right can be viewed as a perfectly inelastic supply of water. By the waste discharger's decision to build a total containment lagoon, the water available to the farmers is reduced to Q* - X acre feet. This results in a welfare loss W_L which is equal to

$$W_L = \int_{Q^*-X}^{Q^*} P(Q)\,dQ$$

Therefore, the welfare loss W associated with a unit decrease in the discharge is given by

$$W = \frac{W_L}{X} = \frac{1}{X} \int_{Q^*-X}^{Q^*} P(Q)\,dQ$$

The unit welfare loss W is computed and added on to the variable cost associated with the evaporation ponds to approximately reflect the social cost of this treatment option.

This analysis was applied to the Uintah Basin case study. The demand curves for agricultural, the main water using activity, were obtained from a linear programming study [13]. The prices were updated to reflect the current situation. The Ashley Valley and the Duchesne River Basin were considered separately in the analysis. The unit welfare loss computed by the above technique resulted in a value of \$37/per 1000 m^3 per day for both areas. This figure was added to the variable cost of the complete containment lagoon in the LP model. The social impact of complete containment lagoon can be assessed by comparing the water quality levels and the total costs of the optimal solutions for three cases:

1. no containment lagoon;
2. containment lagoon including the unit welfare loss; and
3. containment lagoon not including the unit welfare loss.

Comparing the solutions in Table 6, it is apparent that meeting the water rights of downstream users by not allowing the total containment option result in a loss of \$1,726/day (Case 1 vs. Case 2) for society. Also, the total containment option reflecting W produces slightly higher quality levels in the stream. However, it is seen that implementation of containment lagoons results in a \$1,282/day loss to the agricultural sector.

Conclusion

Current environmental legislation requires the preparation of regional plans for managing air and water quality. The 1970 Clean Air Act Amendments directs the Air Quality Maintenance (AQM) plans to be developed for areas with potential for exceeding ambient air standards between 1975 and 1985, and the Federal Water Pollution Control Act Amendments of 1972 calls for Areawide Waste Treatment Management (208) planning in areas with substantial water quality management problems. With this emphasis, a systematic residuals management model for examining interrelationships among the pollutants and environmental media, and developing plans that provide for an integrated handling of air, water and solid residuals in a region has been developed.

The focus of this study was on a region where future changes in economic activity and the concomitant environmental impacts will largely be determined by external decisions affecting resource development. The alternative futures approach is recommended as a

Table 6. Welfare Analysis of Containment Lagoon Option

Solution and Cost / *Water Quality Surveillance Points*	*Case 1: Without Complete Containment Lagoon ($16,947)*				*Case 2: With Complete Containment Costs Include W_L ($15,221)*				*Case 3: With Complete Containment W_L Not Included ($13,938)*			
	BOD	*NH_4*	*SS*	*DO*	*BOD*	*NH_4*	*SS*	*DO*	*BOD*	*NH_4*	*SS*	*DO*
	(mg/l)				*(mg/l)*				*(mg/l)*			
A	5.0	3.6	6.6	16.1	3.5	3.25	6.3	12.7	3.5	3.25	6.3	12.7
B	3.5	1.3	13.3	11.3	3.8	4.0	9.9	11.0	3.8	4.0	9.9	11.0
C	3.5	3.8	7.1	10.0	3.7	1.4	14.6	10.2	3.7	1.4	14.6	10.2
D	5.0	4.0	7.8	10.8	4.4	4.0	8.0	9.9	4.4	4.0	8.0	9.9
E	4.6	2.0	32.1	8.9	4.5	2.0	32.1	8.9	4.5	2.0	32.1	8.9
F	3.7	4.6	27.5	11.2	3.4	4.6	28.0	9.8	3.4	4.6	28.0	9.8
G	2.7	1.5	45.6	7.7	2.6	1.5	44.1	7.6	2.6	1.5	44.1	7.6
H	1.8	2.0	15.6	7.7	1.8	2.0	15.6	7.7	1.8	2.0	15.6	7.7

technique for analyzing population and economic changes as a basis for evaluating residuals management strategies. Using optimizing management decisions in the face of uncertainty about which alternative future will ultimately prevail, optimal treatment plans have been proposed.

Use of effluent charges and effluent standards as implementation incentives were investigated through parametric analysis on the linear programming model. Analysis indicates that a charge of $0.10 per pound of BOD is sufficient to induce dischargers to cut back loadings to the point that stream standards are met. For air emissions, a charge of 200 per metric ton on particulates is necessary to meet the air quality standard of 200 μgm/M^3. The imposition of an effluent standard of 10 mg/liter on BOD results in somewhat better stream quality than is required by stream standards for BOD and suspended solids.

Certain legal and institutional constraints also affect implementation of environmental controls. Water rights are an example of such a situation in the Uintah Basin. The unit welfare loss for contained wastewater was found to be $37 per 1000 cubic meters. When this is added to the cost of complete containment lagoons in the linear programming model, the optimal solution shows a loss of $1283 per day due to impaired water rights. However, if to satisfy water rights the containment lagoon is not allowed, the cost of waste treatment would be increased by $1,726 per day indicating that there is a basis for resolving the conflict through compensation.

Overall, the analysis shows that under alternative futures for the Uintah Basin where population and development become more concentrated, the cost per capita of maintaining environmental standards will increase.

REFERENCES

1. J. M. Buchanan and W. C. Stubblebine, Externality, *Economica, XXIX*, pp. 371-384, November 1962.
2. W. J. Baumol and W. E. Oates, *The Theory of Environmental Policy*, Prentice Hall, Englewood Cliffs, New Jersey, 1975.
3. R. Turvey, On the Divergence Between Social Cost and Private Cost, *Economica, XXX*, pp. 309-313, August 1963.
4. A. V. Kneese and B. T. Bower, *Causing Off-Site Costs to be Reflected in Waste Disposal Decisions, Managing Water Quality: Economics, Technology and Institution*, John Hopkins Press for Resources for the Future, 1968.
5. T. H. Brigham, et al., *Cost-Effectiveness of a Uniform National Sulfur Emissions Tax, Socioeconomic Environmental Studies Series*, EPA-600/5-74-009, Office of Research and Development, U. S. Environmental Protection Agency, Washington, D. C. 20460.

6. W. O. Spofford, Jr., C. S. Russel, and R. A. Kelly, Operational Problems in Large Scale Residuals Management Models, *Economic Analysis of Environmental Problems*, E. S. Mills (ed.), Columbia University Press, New York, NBER 1975.
7. C. S. Russel and W. O. Spofford, Jr., *A Quantitative Framework for Residuals Management Decisions, in Environmental Quality Analysis*, A. V. Kneese and B. T. Bower (eds.), The John Hopkins Press, Baltimore, 1972.
8. C. S. Russel, Models for Investigation of Industrial Response to Residual Management Action, *Swedish Journal of Economics*, *73:*1, pp. 136-138, 1972.
9. W. J. Vaughan and C. S. Russel, A Linear Programming Model of Residuals Management for Integrated Iron and Steel Production, *Journal of Environmental Economics and Management*, *1:*1, May 1974.
10. Office of the State Planning Co-ordinator, *The Utah Process Alternative Futures 1975-1990, Vol. I: Assumptions and Projections*, Salt Lake City, Utah, 1975.
11. Office of the State Planning Co-ordinator, *The Utah Process Alternative Futures 1975-1990, Vol. II: Detailed Projections*, Salt Lake City, Utah, 1975.
12. A. B. Bishop, et al., *Environmental Quality Management in a Region with External Development Pressures*, a forthcoming EPA publication, 1977.
13. M. H. Anderson, *An Economic Analysis of Demand and Supply for Irrigation Water in Utah*, an unpublished Master's Thesis, Utah State University, Logan, Utah, 1974.

Direct reprint requests to:

Rangesan Narayanan
Research Assistant Professor
Department of Economics
Utah State University
Logan, Utah 84322