ECONOMICS OF WATER QUALITY CONTROL[1]

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In economic textbooks, water pollution has been the classic example illustrating external technological diseconomies. Authors usually attempt to show that externalities occur when the effects or costs of a given course of action must be borne by a person or group of persons other than the one responsible for the decision to take that action. These authors further point out that the market mechanism, in general, fails to cope with or to mitigate these spillover effects in a manner which leads to a socially optimal allocation of resources.

In partial recognition of the market's inability to achieve a socially optimum resource allocation, Congress passed the Federal Water Quality Control Act of 1965. This Act requires each state to establish water quality standareds on interstate streams, and further requires that these standards be reviewed with respect to the guidelines set forth by the Secretary of the Interior.

An analysis of water quality standards can be based on several criteria. One is economic efficiency. A few years ago a Western Regional Technical Committee proposed a regional research project, applying the following criteria for evaluation of stream standards:

$$\Delta C_i^a = \Delta B_i^a \tag{1}$$

$$\frac{\Delta B_i^a}{\Delta C_i^a} = \frac{\Delta B_j^a}{\Delta C_j^a} \tag{2}$$

$$\frac{\Delta B_i^a}{\Delta C_i^a} = \frac{\Delta B_i^b}{\Delta C_i^b} \tag{3}$$

$$\frac{\Delta B_i^a}{\Delta C_i^a} = \frac{\Delta B_j^b}{\Delta C_j^b} \tag{4}$$

in which ΔC and ΔB refer to incremental changes in treatment costs and damages avoided (benefits), the subscripts identify geographic areas, and the superscripts identify specific quality parameters on constituents. In these equations, the change in treatment costs in an area are equated with the damages avoided for each parameter, and that the benefits to cost ratio are equated from one locality to another, and with respect to all the quality constituents under consideration.

Some authors (4,11) consider the economic efficiency criterion too narrow in scope, and have urged consideration of national and regional income effects as well as nonquantifiable aesthetic effects. I agree with these broader objectives but, for purposes of this paper, I will stick with economic efficiency.

Many excellent books and articles have been published on urban water quality and water pollution (7,8). Several studies have been made in which the physical and economic effects of urban and industrial waste treatments have been analyzed for river basins and individual industries. Little work, however, has been done on the agricultural aspect of water quality degradation, either in attempting to quantify the magnitude of the pollutants produced by agriculture, or in studying the effect of adverse water quality conditions on agriculture.

In this paper we will (1) identify and describe some of the major pollutants produced by agricultural activity, and (2) briefly describe some of the adverse effects of water quality constituents on agriculture, including certain recreational activities, regardless of the source of the constituent. We will then discuss two possible methods of quality control. Finally, we will consider the short- and long-run problems and possible effects on agriculture of water quality controls.

MAJOR POLLUTANTS PRODUCED BY AGRICULTURE

1. Sediments

It has been estimated that the rivers of the United States carry a billion tons of sediment to the ocean and deposit an additional 3 billion tons in reservoirs and on valley lands each year (3). Sediments which originate on agricultural lands result primarily from erosion—although all the silt in American rivers does not originate from agricultural lands.

Logging roads used in timber harvesting are often cut along steep unstable ridges. In many instances this may cause an excessive amount of soil disturbance and an unacceptable amount of siltation down stream.

On rangeland, overstocking leads to destruction of cover and to soil compaction, which in turn results in sheet erosion, flashy runoff, gullying, and sedimentation. Cultivated lands, even in the arid West where irrigation requires very slight slopes, introduce sedimentation and colloidal materials into the drainage return flows and tail waters. Elemental phosphorous attached to clay particles is carried into streams by soil erosion from crop land.

2. Animal Manures and Wastes

Water pollution from feedlots and dairies is of greater concern in the more humid regions of the country, but is not an exclusive problem of those areas. Where feedlots are on sloping land, an intense rain storm can carry a large amount of animal wastes into a stream in a very short time (12). If we accept the commonly used assumption that one animal unit produces a sewage disposal problem equivalent to that of 15 to 18 persons, the approximately 90 million animal units of cattle in the United States present a problem of rather formidable proportions.

The organic material in livestock wastes reduces the dissolved oxygen supply in the water courses that it enters. In addition, animal wastes are one source of nitrates and phosphates in flowing streams as well as in the underground water. Animal excreta may also contain pathogenic organisms.

3. Chemical Fertilizers and Soil Amendments

The conclusions of an Agricultural Waste Water Symposium at the University of California, Davis (1), included the following: (1) Fertilizers and soil amendments do not appreciably increase the salinity of ground or drainage water except in localized areas. (2) Of the three plant nutrients most frequently applied (nitrogen, phosphorus, and potassium) only nitrogen may pass into ground water in significant amounts. (3) On the whole, the amounts of fertilizers and soil amendments applied were, in many instances, exceeded by the quantities removed in the harvested portions of the crop. In certain areas, substantial contamination may occur due to heavy fertilization of a specific crop. For example, data from a 20-year study of a 1,000-acre citrus grove located in a semi-closed basin, with only one outlet, near Riverside, California, indicate that 25 to 50 percent of the applied nitrogen is carried away with the drainage water (1).

4. Pesticides

Anyone who reads the little messages printed on automobile bumper stickers is well aware of the public turmoil over pesticide residues, especially the chlorinated hydrocarbons, in our water supply. In 1964, 320 million pounds of pesticides, and in 1966, 353 million pounds, were applied on the nation's farms and ranches (5).

Pesticides enter water courses in two principal ways. In one, they are adsorbed onto particulate matter and then transported "piggy back" to the water course in surface runoff from treated fields. Or, they may be dissolved in the soil water and transported with it through field drains to streams and lakes. Since the solubility of some chlorinated hydrocarbons is so low, some toxicologists estimate it will take decades to remove completely the existing deposits from agricultural areas, even if use of the chemicals was completely banned today.

5. Temperature

Although it is not normally thought of as an agricultural pollutant, water temperature can be quite critical under certain situations. When spread on a field during the heat of the day, irrigation water increases significantly in temperature. Tail water, and even subsurface drainage, can become sufficiently warm to create problems for downstream users.

6. Salts or Dissolved Minerals

Salinity, as increased by agricultural production, is probably the single most important constituent of water quality in the irrigated regions of the world. Societies based on an irrigated agriculture have appeared and disappeared through several millennia of man's history. Economies or cultures based on irrigated agriculture, and which have survived more than a few hundred years, are really an exception rather than the rule.

Under humid conditions, soluble salts are carried through the soil and transported by streams to the ocean. However, when water is applied to a crop under arid conditions, most of the moisture leaves the soil through evapotranspiration; but the salts remain in the soil. To prevent salinization of the soil, a portion of the irrigation water (leaching fraction) must percolate past the plants' root zone to the water table. If this leaching fraction does not remove as much dissolved salts as entered with the irrigation water, the net result is an unfavorable salt balance. Depending on the leaching fraction used by the irrigator, this can cause a 2- to 10-fold increase in the salt concentration of the return flow water.

Reuse plus evaporation and natural salt sources increase the concentration of salts as one moves from the source to the mouth of a river system. For example, the Colorado River at Glenwood Springs, Colorado, had an average salt concentration over the past 26 years of 0.40 tons per acre-foot; at the lower end of the river at Imperial Dam near Yuma, Arizona, the concentration for the same period was 1.14 tons of salt per acre-foot, and it is still increasing (13). Projections for new projects authorized on the Colorado River assume that each acre of land will produce 2 tons of additional salt load per year in the river. The projected salt concentration for the year 2000 at Imperial Dam is 1.65 tons per acre-foot.

EFFECT OF POLLUTANTS ON AGRICULTURE AND RECREATION

1. Salinity

Since I consider the salinity problem highly critical, I would like to discuss it first and, in doing so, comment briefly on a research project underway in the Imperial Valley of California.

Dissolved salts in irrigation water affect plant growth in two ways, i.e., by the osmotic effect which restricts the plant's ability to take up water from the soil, and by the toxic effects, which may be manifest in a number of ways. Bernstein (2) and co-workers at the U.S. Salinity Laboratory at Riverside have expended considerable effort in estimating crop response to saline irrigation water. Although their work is not complete, they have made some tentative classifications and estimates of growth curves. Crops in the saline-sensitive group include celery, green beans, and most stone fruits. Medium-tolerance crops include carrots, alfalfa, and many of the feed grains. High-tolerance crops include date palm, bermuda grass, and barley. It is interesting that, in general, the greater the salt tolerance, the lower the economic value of the crop.

To maintain an acceptable level of salts in the root zone, the leaching fraction must increase as the salinity of the irrigation water increases. That is, the marginal rate of substitution of water quantity for water quality along a production isoquant is increasing.

Physical limitations to drainage and percolation rates of the soils being irrigated place an upper limit on the maximum leaching fraction allowable. When the upper bound has been reached, a farm operator is faced with the decision either to accept a lower yield from the existing crop or to replace it with a crop of higher salt tolerance.

In our study of the Imperial Valley, one of the objectives is to assess the impact of the degradation of water quality in the lower Colorado River on farm incomes and cropping patterns. We have developed what we consider a satisfactory response surface for quantity and quality of irrigation water. We use this response surface to develop activities in a linear programming model which includes four salinity levels, three irrigation regimes, three leaching fractions, on three sizes of farms for each of seven different crops.

The first tentative data from this study indicate that for each 100 ppm increase in salt concentration (.14 tons of salt per acre-foot) in the lower Colorado River due to upstream development, net agricultural income for the 450,000 acres of crop land in the Valley would decrease approximately $1.6 million. That is, the annual cost of the technical external diseconomy in this one location caused by increasing the salt concentration of the river would be $1.6 million.[3]

If we were considering a developmental project at the headwaters of the River, we would have to sum the damages for each existing project all the way downstream to the Gulf of California. The sum of these downstream damages is an opportunity cost of building a project upstream, and should be included in the benefit-cost analysis.

Salinity can also affect water-based recreation. A second objective of our Imperial Valley study is to assess the effects of different management strategies for the irrigation water in the Valley, on the recreational use of the Salton Sea. The Salton Sea is a closed drainage basin primarily dependent on irrigation return flows from the Imperial Valley to maintain the elevation of its water surface (currently about 230 feet below sea level).

Although the Salton Sea was a fresh water lake about 65 years ago when it was filled by the full flow of the Colorado River after a break in a diversion dam, it is now slightly saltier than the ocean. The reproductive cycle of the sport fish in the Sea is sensitive to the salt concentration of the water. That is, the hatchability of the eggs is very low at concentrations only slightly higher than exist at present. Therefore, the amount of return flow from the district, and the salt concentration of the flow, will have a direct bearing on the recreational benefits that can be derived from the Salton Sea.

2. Temperature

Although I could find no quantitative data on the rise in water temperature during irrigation, the effects are fairly well documented. There is an inverse relationship between the content of dissolved oxygen and the water temperature. Other things being equal, an increase in water temperature reduces the dissolved oxygen available to support aquatic life, slows the aerobic decomposition of organic wastes, and increases the rate of evaporation. Green-house and field experiments have revealed that excessively warm or cool irrigation water can inhibit plant growth. A desirable range of temperatures for irrigation water is 55° to 85°F (6).

3. Nitrates and Phosphates

The right combination of organic nitrogen and soluble phosphorus can trigger massive growths of algae. These, in turn, produce undesirable effects, especially for recreational activities:

(1) Increased biological oxygen demand loadings due to the enlarged biomass may reduce fish populations.

(2) Algae and other aquatic plants clog the water with floating masses of unsightly matter which adversely affect sports such as swimming and water skiing.

Algal bloom at certain seasons of the year in the Salton Sea, due primarily to the nutrient enrichment from the irrigation return flows, is expected to have an increasing negative effect on recreational benefits.

4. Sediments

Silt buildup on the fields was the second most important factor contributing to the demise of the ancient culture in Mesopotamia, following salinization of the soils. The sediments left behind after the spring floods created a cleaning problem each year, and gradually, over several hundred years, field elevations were raised above the head ditch levels, reducing the head of water available for irrigation.

Silting of water reservoirs as a result of erosion in the watershed has significantly reduced the economic life of storage systems both in the United States and in other parts of the world, humid as well as arid.

There is no known method of satisfactorily removing silt from the bottom of a reservoir, and cleaning irrigation canals is quite expensive. However, dredging operations and desilting processes at diversion dams have eliminated this specter of loss of agricultural lands such as occurred in ancient Mesopotamia. This technology does come at a cost.

METHODS OF CONTROL

Effluent Charges or Stream Standards

If we accept the objective of economic efficiency in the control of water quality, a single basin-wide water management firm is an excellent approach, as has been demonstrated by Kneese (7) and Kneese and Bower (8). A single basin-wide firm can internalize externalities. These authors suggest two alternative methods of public intervention to achieve the efficiency goal. The first is a system of effluent charges, levied on each polluter, equal to the marginal damages associated with the wastes discharged. If a public agency were the basin-wide water manager, and if it were capable of measuring all costs associated with waste discharge, our criteria of economic efficiency could be achieved.

The second alternative is to use stream standards. The U.S. Congress, in passing the Water Quality Control Act of 1965, was in a rush to prevent further degradation of the nation's water courses. Due to the urgency of the situation, Congress refused to wait for the long, drawn-out research required to assess properly the total and marginal damage functions necessary for the establishment of effluent charges. Instead, Congress established water quality guidelines in terms of minimum or maximum stream standards for each constituent of water quality. Implied in these guidelines are minimum quality standards for each waste outfall in a river basin. In terms of our criteria of economic efficiency, using effluent charges, a stream standard implies that the damage function is infinite or vertical up to the standard set while the benefits from damages foregone for levels of the quality parameter above the stream standard, are zero.

It appears that unless the agency setting the stream standards had as much information available concerning the damage function as was needed to set adequate effluent charges, economic efficiency would be achieved only by chance alone. For example, if a stream standard of 4 mg/liter of dissolved oxygen were set by a quality management agency, the inference is that the agency felt the marginal damages avoided by downstream users were equal to the marginal treatment costs of all firms required to maintain 4 ppm dissolved oxygen in the stream.

Effects of Stream Standards on Agriculture

Earlier we described the major pollutants produced by agriculture and their effects on agriculture and recreation. We now turn to the problem of the short- and long-term effects of water quality controls on agriculture.

In setting their standards, the states have made it quite clear that no one has the right to pollute. Agriculture will be treated as any other industry in regards to enforcement of quality standards.

Agriculture is a unique industry only in the sense that most of the pollutants produced come from diffused sources, unlike other waste dischargers that have a single waste discharge point or outfall. This characteristic will make enforcement of quality standards very difficult, but not impossible. Some of the major agricultural pollutants are conservative in nature. That is, biologically nondegradable and relief comes through dilution with high quality water or expensive treatment. For example, dissolved salts are not biologically degradable. Relief from the high salt concentration in the lower Colorado River can come only from importing a fresh water supply from another river basin or a desalinization plant. A rough estimate of the capital investment required to treat the 3 million acre-feet of water diverted yearly by the Imperial Irrigation District is $1 billion.

Inclusion of maximum levels for dissolved minerals, say 1,000 ppm, in stream standards for a river such as the Colorado could create havoc with the construction schedule of the Bureau of Reclamation. Strict enforcement of such a standard may force discontinuance of construction of new projects on the upper stream.

Some lowering of the existing salt concentrations could probably be obtained by encouragement or enforcement of more efficient irrigation methods in existing projects. Reduced water use within a project brings fewer tons of salt into an area and, therefore, fewer tons of salt need be removed to maintain a salt balance. The fewer acre-feet of water diverted and spread out over fields, the smaller will be the losses from evaporation and irrecoverable percolation.

Any administrative tool such as requiring irrigation districts to pay the shadow price of water at the diversion point, or requiring districts to line distribution canals and laterals, would decrease transfer losses, raise water costs to users, and, in turn, encourage more efficient use of existing water supplies (9).

Land use zoning has been suggested as a method of meeting water quality standards. At first glance this proposal appears to have some merit, but as an operational tool it would be difficult to implement. Zoning traditionally has been used as a device to guide the direction of change in new uses and not to abate a nuisance or force a change in an existing use. For example, zoning could be used to prevent any new livestock feedlots from being built near a water course, but it could not be used to force removal of an existing feedlot.

For pollutants such as silt, nitrates and phosphates, and pesticides, which come from diffused sources, abatement will probably come through encouragement, or enforcement, of certain management practices. It would not be hard to visualize state water quality control agencies requiring that certain methods or practices be used in timber harvest to reduce soil erosion or requiring landowners in a drainage basin to plant cover crops on bare land to prevent gullying and soil loss.

In the case of fertilizers, certain rapidly soluble nitrogen forms may be banned from the market, or maximum dosages may be prescribed, just as certain slowly degradable pesticides have been banned or their use controlled.

Pollutants with point sources, such as animal wastes from feedlots and confined poultry, will be treated as any other biological waste. Manure lagoons and simple waste treatment plants similar to those used for municipal sewage treatment may, and probably will be, required.

The economic implications of this discussion are that individual waste dischargers will, in the near future, be required to incur direct costs that were formerly absorbed by other water users downstream. These costs will no doubt increase the costs of producing agricultural commodities and, due to the competitive nature of the industry, will be difficult to pass on to the consumer, at least in the short run. Since all state quality standards must conform to federal guidelines, and since the Federal Government maintains the right to ensure equal enforcement, we visualize few, if any, shifts of production between geographic regions of the country.[4]

Due to the significant economies of scale possible in construction of waste treatment plants (10), confined feeding of fat cattle, dairy animals, and poultry will probably be concentrated in larger and larger units in the future.

FOOTNOTES

1. To be presented to Western Agricultural Economics Association, Tucson, Arizona, July 21, 1970.

2. Agricultural Economist, Farm Production Economics Division, Economic Research Service, U.S. Dept. of Agriculture, stationed at Davis, California.

3. For a similar study of the economic effects of saline irrigation water see Stewart and Pincock, *Impact of Water Quality on the Agricultural Industry in the Colorado River Basin,* WAERC, Water Resources and Economic Development of the West, No. 19, 1967, pp. 116-136.

4. Robert McKusick has pointed out that this statement is based on the assumption that the same activity will create the same amount of pollutants regardless of the location of the activity. This assumption may not hold true in all cases.

REFERENCES

1. Bingham, F.T., "Effects of Fertilizer and Amendments on Water Quality," *Agricultural Waste Water,* University of California, Water Resources Center, Report No. 10, 1966.

2. Bernstein, Leon, *Quantitative Assessment for Irrigation Water Quality,* Society for Testing Materials, Special Technical Publication No. 416, 1967.

3. Bullard, W.E., "Social and Economic Aspects of the Relation of Land Use to Water Quality," *Social and Economic Aspects of Water Resource Quality Control,* U.S. Public Health Service Region IX, Portland, Oregon, 1962.

4. Castle, Emery N., *Economic and Administrative Problems of Water Pollution,* Mimeo. Paper, Oregon State University, 1966.

5. U.S. Dept. of Agriculture, Economic Research Service, *Quantity of Pesticides Used by Farmers, 1966,* AER No. 179, 1970.

6. U.S. Dept. of the Interior, Federal Water Pollution Control Administration, *Water Quality Criteria,* 1968.

7. Kneese, A.V., "The Economics of Regional Water Quality Management," *RFF,* Johns Hopkins Press, 1964.

8. Kneese, A.V., and Blair T. Bower, "Managing Water Quality," *RFF,* Johns Hopkins Press, 1968.

9. Moore, C.V., and J.H. Snyder, *Alternative Water Policies for an Arid Region,* Third Interstate Water Conference, Fort Collins, Colo., 1969.

10. Owens, T.R., and W.L. Griffin, *Economics of Water Pollution Control for Cattle Feedlot Operations,* Special Report No. 9, Dept. of Agricultural Economics, Texas Tech. College, Lubbock, Sept. 1968.

11. Report to the Water Resources Council, *Procedures for the Evaluation of Water and Related Land Resource Projects,* June 1969.

12. Smith, George E., *The Contribution of Agriculture to Water Pollution,* Unpublished paper, Water Resource Research Center, University of Missouri, Columbia, 1969.

13. U.S. Dept. of the Interior, *Quality of Water, Colorado River Basin,* Progress Report No. 4, 1969.