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THE ROLE OF SYSTEMS ANALYSIS IN WATER SUPPLY PLANNING: AVOIDING THE FALLACY OF COMPOSITION [1]

by Jay C. Andersen [2]

Things are not always as they seem. Presented here are a few examples of first impressions and possible errors in thought patterns. As an example, by some means the size of the earth is to be increased by one foot in diameter. Transcontinental Airlines and others are concerned with how much further it will be around the circumference of the earth. What is your answer? Quick! What's your answer?

You probably over-estimated. Turn to an analytical system.

$C = \pi D$

where C = circumference

D = diameter

Then, with change in D (ΔD), we can calculate

$$\Delta C = \pi \Delta D$$

or, $\Delta C = 3.1416 \times 1$

$= 3.1416$ feet

Fortunately, a system can lead us to a correct determination. Inspection and first impressions often fail.

How do we interpret trends? We may observe the stability in growth in certain variables and project as Mark Twain did:[3]

> In the space of one hundred and seventy-six year, the Lower Mississippi has shortened itself two hundred and forty-two miles. That is an average of a trifle over one mile and a third per year. Therefore, any calm person, who is not blind or idiotic, can see that in the Old Oölitic Silurian Period, just a million years ago next November, the Lower Mississippi River was upward of one million three hundred thousand miles long, and stuck out over the Gulf of Mexico like a fishing-rod. And by the same token, any person can see that seven hundred and forty-two years from now, the Lower Mississippi will be

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[1] Paper presented at U. S. Army Corps of Engineers Conference on Water Supply Planning, Albuquerque, New Mexico, March 20-23, 1978.

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[3] Mark Twain, "Life on the Mississippi," THE FAMILY MARK TWAIN, Harper & Brothers, New York, p. 86.

> only a mile and three-quarters long, and Cairo and New Orleans will have joined their streets together, and be plodding comfortably along under a single mayor and a mutual board of aldermen. There is something fascinating about science. One gets such wholesale returns of conjecture out of such a trifling investment of fact.

In economics we often refer to the fallacy of composition. What is the "fallacy of composition"? The fallacy is, "What is true for the individual or part is necessarily also true for the group or whole."

Let's turn to some examples that are more directly involved with water resources than Mark Twain's example.

Example: Increased water supply to a farmer increases production so that he realizes a bumper crop. The farmer's income is larger than formerly. Therefore, if water supply is increased to all farmers, they will be better off. This applies to farmers as a group.

Wrong. Because price declines as total output goes up, and as all farmers realize bumper crops, price is depressed. If price declines overbalance the large output, farm incomes fall. Whether total income rises or falls depends oupon the price elasticity of demand for the products; that is, the coefficient of change in relative quanitity as compared to the relative change in price. For most agricultural products, the demand is inelastic so that price varies relatively more than quantity. Thus, as quantity is increased, price is forced down relatively more so that total income to farmers falls.

That's an easy example. It's plain to see the fallacy of extending the finding beyond its logical limits. In economics the difference between the individual and the aggregate is distinguished as micro-economics and macro-economics. Let's turn to some examples that are less obvious. In water supply analysis, a systems approach provides the macro view that avoids the fallacy of composition.

Example: Improvements in irrigation efficiency lead to increases in welfare.

Not necessarily. Begin with the concept of irrigation efficiency. It's definition is the ratio of the amount of water consumptively used in evapotranspiration of plants to the amount of water diverted. Thus, the higher the proportion of the diversion actually used up, the more efficient the system. The problem arises in the distinction of the incentive system at the micro (farm) level and the results in a basin-wide context. Individual proprietors seek to increase their efficiency because their water right is often defined in terms of the amount that they are authorized to divert from the canal or stream. They see the opportunity to (1) distribute water more evenly and increase yields, and (2) irrigate more acres with a better water supply because of careful husbandry. They may do this by sprinkling, improving canals and ditches, leveling the land, or simply applying more intensive labor and management to the irrigation process. As might be expected, a smaller proportion of water diverted from streams and canals returns to the downstream water flow.

In the Sevier River Basin in Utah, which is a closed basin, many have said that the flow of the river is entirely diverted seven times. The accuracy of this statement cannot be attested, but it seems to be approximately true. In the Sevier Basin when upstream users adopt improved irrigation practices and irrigate more acres with a full-season supply, the water supply to the lower basin becomes lessened. This happens despite a court decree that allocates portions of the flow to upper and lower basin users. Whether overall welfare is increased or decreased depends on the relative values of the upstream and downstream uses and the cost of the improvemnts. As a certainty there arises an equity problem. Legal actions have become commonplace in the Sevier Basin.

It is a problem. Farmers who want to improve irrigation say that irrigation water rights are property rights. They claim they can do as they please with these rights. They stress that not being able to expand acreage reduces incentive to conserve water and become efficient.

But, what of the downstream user who also has a patented water right and a long-standing use of water coming from the upstream return flows? Is the water right less valid? Only the courts can decide this equity issue. It is clear that any analysis of this water supply bearing on the economic efficiency and equity of the situation must depend on an overall system evaluation.

<u>Example: Each of a group of farmers sell one-fourth of their direct flow water rights for use in an energy development so that we expect a decline in agricultural production</u>.

Not necessarily. In one case where this has happened, the power company paid farmers perhaps 10 times the agricultural value for a portion of the water right sold and has built a dam to store and regulate the flow of the river. This has provided for a season-long availability of water. Lined canals and other conveyances have been built to improve the conveyance efficiency of the delivery system so that a greater proportion of the water is actually delivered. In summary, the water supply the farmers have is more secure and in greater quantity, especially in the late part of the year, than was formerly the case. A cursory pre-evaluation could have led to erroneous conclusions.

<u>Example: For energy projects it is proposed to adopt a "total containment" policy for water diverted to prevent the salty water from returning to the river in order to insure a higher quality water in the lower reaches of the river</u>.

It may not work. There are two parts to the quality problem. The measurement may be salt load, which is the total quantity of salt flowing down the river in a dissolved state. Or, the measurement may be concentration, which indicates the proportion of salt to a given amount of water. Each of these may be important depending on the particular concern in the downstream area.

In a river modeling study of the Colorado River, the results suggest that as energy development with total containment proceeds through time, the total tons of salt load would decrease relative to the base situation.

Compare lines 1 and 3 in Table 1. As can be seen in Table 1, the salt load would be decidedly higher with medium rather than the high energy utilization level which would lead to greater flows. The salt load would be small under high utilization and the consequent low flow.

At the same time, salt concentration in the river would rise with accelerated energy development. The conclusion is that an increased rate of energy development would result in an increase in concentration at Imperial Dam. This effect is due to the reduced flows of water for dilution particularly due to the anticipated total containment technology. A situation which seems to escape some concerned parties is that water returned from once-through cooling in the upper basin is likely of better quality than the quality of water flowing in the lower basin.

Table 1. Predicted Salinity Effects at Imperial Dam of Alternative Future Uses in the Colorado River Basin

Assumed Flow Million Acre Feet/Year	Utilization Level			Salt Load (Million ton/year)			Salt Concentration (mg/l)		
	Agric.	Energy	Export	1977	1983	1990-2000	1977	1983	1990-2000
14	Medium	Medium	Medium	916	912	784	828	922	1090
14	High	Medium	Medium	927	920	790	844	956	1162
14	Medium	High	Medium	916	905	755	828	928	1142
14	Medium	Medium	High	872	875	780	839	937	1097

Source: Bishop, A. B., J. C. Andersen, et. al. "Colorado River Regional Assessment Study," Prepared for National Commission on Water Quality, Utah Water Research Laboratory, Utah State University Logan, Utah. Part 1, pp. 156-158.

It appears that energy may have significant impacts on local and regional water allocations and quality. Upon whom the impacts fall will depend to a great extent on institutional and economic constraints and incentives which are imposed, either as a result of historical development or future policy directions. It is not so clear that energy development will be a detriment to either upstream or downstream users of the Colorado River.

Investigations of the problem have lacked depth and a broad systems perspective in many cases. The case of the total containment technology being represented to solve salinity problems is an example. If only one side (in this case the salt load) is considered, the answer to the problem may be different than if other factors are brought to bear, such as having water for dilution and the extra costs incurred. A strong objective look at the social, economic, and physical problems is suggested.

Example: Use of recreation facilities adjacent to a reservoir tends to be self-limiting because of aversion to congestion so that a socially optimal rate of use is achieved.

Not with free access.[4] Social or economic welfare is generated by the use or exploitation of a free but fixed facility. The divergence between marginal social and private costs leads to resource misallocation. The services of the common facility directly enters the utility functions of consumers. Crowding is perceived by users as a deterioration in the quality of the services rendered by the facility. In effect, incremental use of the facility reduces the marginal utility function of the individuals who consume the services of the facility. An allocative efficiency problem results because unrestricted use of the facility generates costs in the form of utility reductions that are not borne by marginal users.

In Figure I, the curve TWP represents the total willingness of users to pay for the services of a reservoir recreation facility with specified quality. This function reflects normal demand conditions for the service. The curve TC represents the constant long-run time and travel costs required to gain access to and make use of the facility. If incremental use of the facility generates no congestion costs, the optimal level of use would occur where economic surplus (TWP - TC) is maximized. This is shown as X*.

If the facility is of limited capacity, however, crowding effects will begin to occur after some level of use, say X_c. The resulting decrease in the perceived quality of the facility and reduction in the value of its services to users entails congestion costs. The sum of "production" and congestion costs is shown as TC'. The socially optimum level of facility use occurs at X**, where net economic surplus (TWP - TC') is maximized.

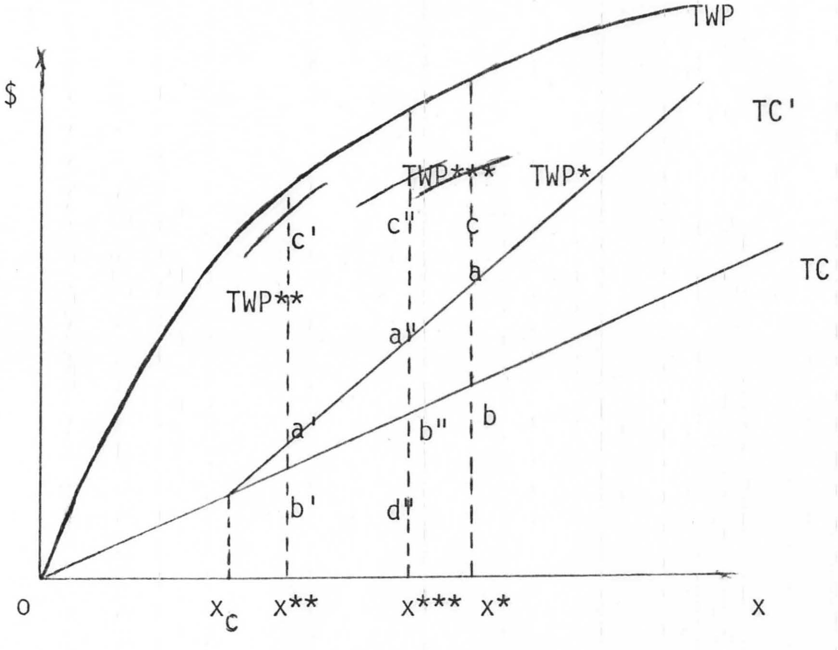

Figure I

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[4] This example follows Haveman, R. H. "Common Property, Congestion, and Environmental Pollution" Quarterly Journal of Economics, May 1973, No. 2. pp. 278-287

However, under conditions of open access the level of facility use will not be restricted to X**. The situation can be conceptualized by constructing a separate schedule of users' willingness to pay at each stipulated level of facility use beyond X_c (implying some level of total congestion costs). Because congestion costs are borne by facility users, the functions depicting these schedules lie below the original TWP. The level of each function at the stipulated quantity of facility use (X) shows users' total willingness to pay, given that quantity of use. The slope of each function at the stipulated X indicates the value to marginal users of an increment in facility use. For example, if the level of facility use is set at X*, aggregate congestion costs equal ab and, with all of these costs borne by facility users, net total willingness to pay is X^*_c. A segment of this function is shown as TWP*, TWP**, and TWP***, which depicts function segments for use levels X*, X**, and X***, respectively.

By focusing on the socially optimal use level X**, it is clear why facility use will not be voluntarily restricted to that level. As use of the facility extends beyond X**, total congestion costs increase beyond their optimal level of a'b', and the constructed total willingness-to-pay function shifts down from its optimal level of TWP**. The level of use of the facility will increase until the marginal willingness to pay associated with a particular level of use is equal to the slope of TC. In Figure I, this equilibrium level of use is X***. At X***, the net economic welfare attributable to the services of the facility is b"c", which is less than the maximum achieveable welfare increment of b'c' obtained by restricting facility use to X**. In this congestion case, overuse is encouraged because real crowding costs imposed by users on each other are not reflected in marginal use decisions.

In this congestion case, resource misallocation and welfare loss is self-limiting, but not to an optimum level. Both the extent of over-use and the welfare loss reach an upper bound caused by deterioration in the quality of the services rendered by the facility. In effect, the level of facility use is limited by the feedback of congestion on willingness to pay in much the same way that the imposition of a price or charge rations the facility. Use of the facility is halted before the economic welfare generated by the generated by the activity is driven to zero. But use goes beyond the social optimum rate. A mechanism to ration use (price, permits, etc.) could be useful. In summary, a planner is obligated to analyze the use <u>and congestion</u> of the recreation facility, not just the total use and interests and willingness of individual users.

<u>Example: The community of North Logan, Utah, has a surface municipal water supply that is inadequate by itself during 8 to 10 months of the year. The city has the choice of using its own well or buying water from neighboring Logan city. One would assume that the community should choose the source for augmentation of supply and stick with it.</u>

Watch out for a different kind of situation that requires more than a superficial examination. The pump is on a large well, and the lift is up to the reservoir, which is a lift of 600 feet or so. The pump has a 100 horsepower electric motor. Utah Power and Light Company has a two-part power tariff. The first part is a "demand" charge. This charge is related to the motor horsepower and is a substantial minimum flat rate that must be paid in any month when the pump is turned on. The second part is based on power used above the minimum. Therefore, in some months when only minimal augmentation of the surface water is needed, the cost of pumping a few gallons of water is exhorbitant. In some months in the summer, a substantial amount of water is needed so the cost of pumping each gallon is quite reasonable. Our town buys water from Logan City when a small amount is needed and pumped when Logan City's price is higher. Again, it is necessary to look at the details.

Example: A closed groundwater basin that is receiving no recharge should be most sparingly and carefully used to extend its life.

But, what about present value concepts in which any positive rate of discount of the future makes income in the near term more valuable the same amount in the distant future. A closed groundwater basin is essentially a mine. Following Anthony Scott, 5/ the theory of the mine can be represented as in Figure 2.

In this case, the value of the resource is not the same for every unit extracted as it is for most minerals. There is declining marginal productivity. Notice that either too rapid or too slow rate of resource withdrawal is inefficient as defined by the difference between total revenue and total cost or the profit curve.

In Figure 2, A is the rate of maximum current profit per acre foot of water and B indicates the maximum profit per irrigation season. These two rates define the range of relevant values. Now, what is the optimum? Clearly, if those who control the water have only one more year or season after which they can withdraw no more water, then the appropriate rate is B, the maximum profit for the year. If there is no discount on future income and if the amount of the reserves and present and future costs and prices are all known, then profit per acre foot should be maximized at A. But, to maximize the present value of the resource, future profits must be discounted. Any rate of interest above zero induces owners of the water to shorten the life of the groundwater mine. Thus, operators increase the rate of extraction toward B, the maximum rate of profit per season.

Let us now introduce the concept of user cost. In Figure 3, we have UC and UC'. UC' is at a higher rate of discount than UC. User cost is defined as the present value of profits foregone by a decision to use a unit of water today. Note that with a higher discount rate less future profit is foregone by using the resource today. Thus, as rate of discount is increased, the optimal rate of extraction increases from C to D. In each case this represents the maximum difference between the profit curve and user cost. Thus, the water users are not motivated toward maximum conservation. In this case, like others, high interest rates (discounts on the future) discourage conservation and preservation.

5/ Anthony T. Scott. "The Theory of the Mine Under Conditions of Certainty." in Mason Gaffney (ed) Extractive Resources and Taxation. Johns Hopkins Press, 1970.

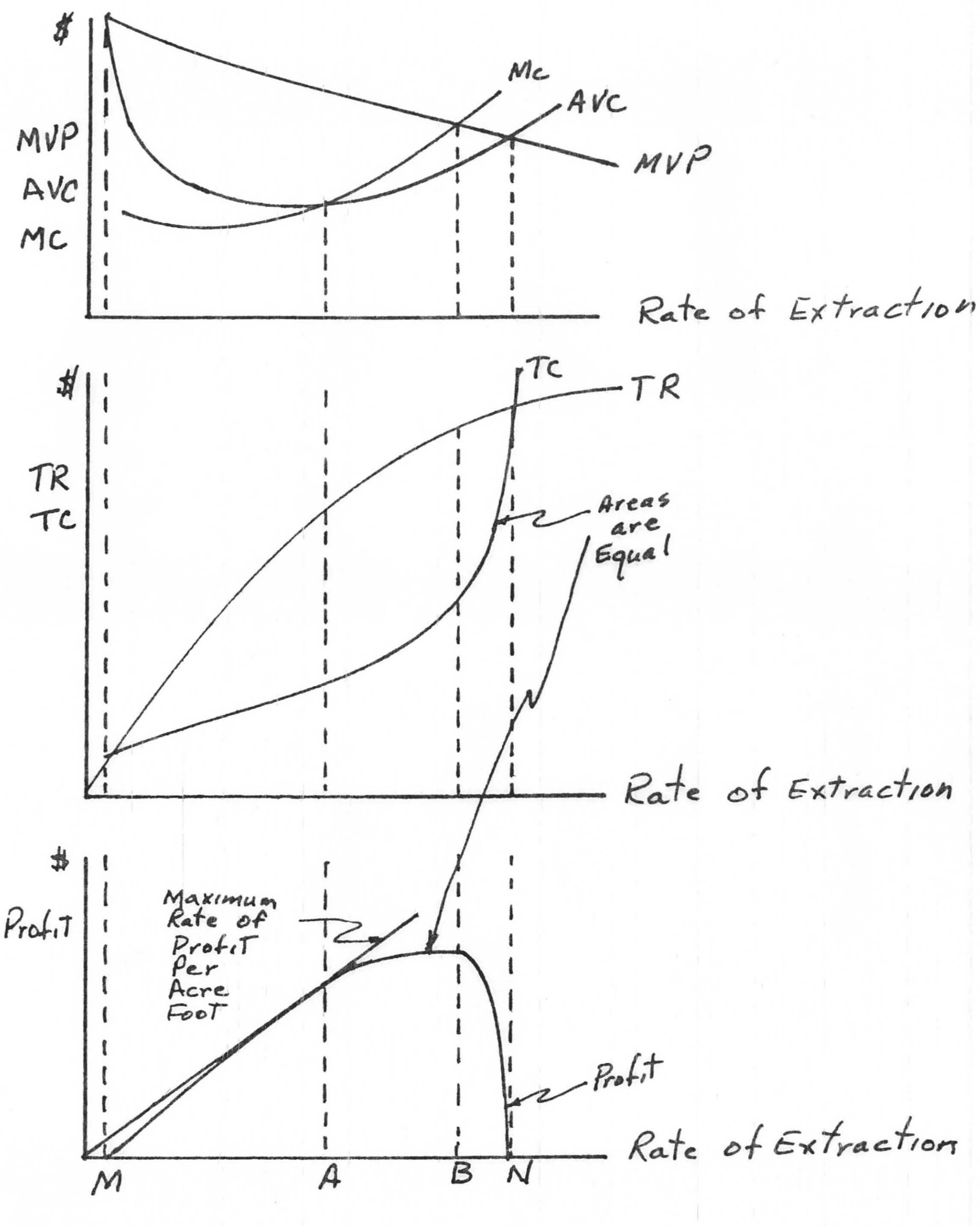

Figure 2. The Theory of the Mine Relating Various Economic Variables to Rate of Extraction

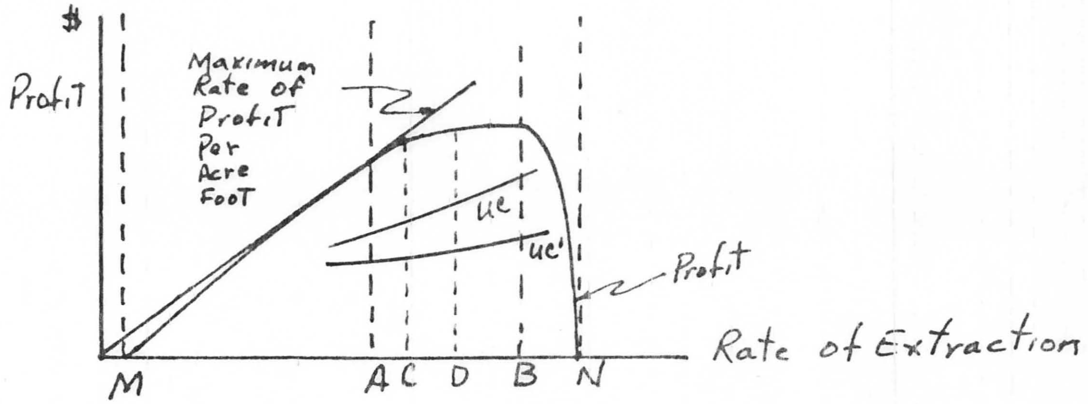

Figure 3. The Effect of a Change in Discount Rate on User Cost and the Optimal Rate of Extraction

Example: A drought comes where a city has first rights to the surface water. Downstream irrigators can have what's left over. Put a brick in the toilet, shower with a friend, and save water. We must conserve.

That's the usual campaign. But let's look at it. In the city of Logan, Utah, and several others in the Mountain West and elsewhere, the city water comes from surface flows and flows downhill to the city. The water that goes to the city is used both inside and outside the house. Water that stays in the pipes (inside use) goes back through the sewer and treatment facilities and is returned to the river. There is no evidence that water is lost by going through toilets, showers, tubs, and sinks. Of course, water consumptively used in lawns and gardens does not return to be used for irrigators. Credibility has been lost by well-meaning people campaigning for conservation inside. Most thinking people see through the shallowness of such arguments. Better not cry wolf when there is no danger. We see again that conservation by saving is relevant only for stock type resources. Purely flow resources cannot be saved.

Example: In avoiding contamination of water supply with elements such as phosphorus, the most appropriate approach is to keep the material out of the waterway in the first place.

Not always so. Sources may be diffuse and difficult to corral. That term may be most appropriate since feedlots and irrigation return flows are common examples. There are probably several options for management including the possibility of limited or no action to let downstream users take the effluent if that is most efficient. Figure 4 is a systems model for phosphorus management. Note that there are valves or control points at various places in the system. Each option should be analyzed to achieve the most efficient management scheme.

A systems approach is essential to look at the ramifications, causes, and effects of any change as it occurs over space, among users, through time, and as between management options available. It is seldom true that there is only one answer or only one way to look at a water supply problem. To avoid the fallacy of composition and to achieve efficiency and equity in resource mangement, an open mind and sweeping view is essential. Remember Mark Twain. Don't go beyond the range of your data and analytical model. Worse yet is if you don't have an analytical model.

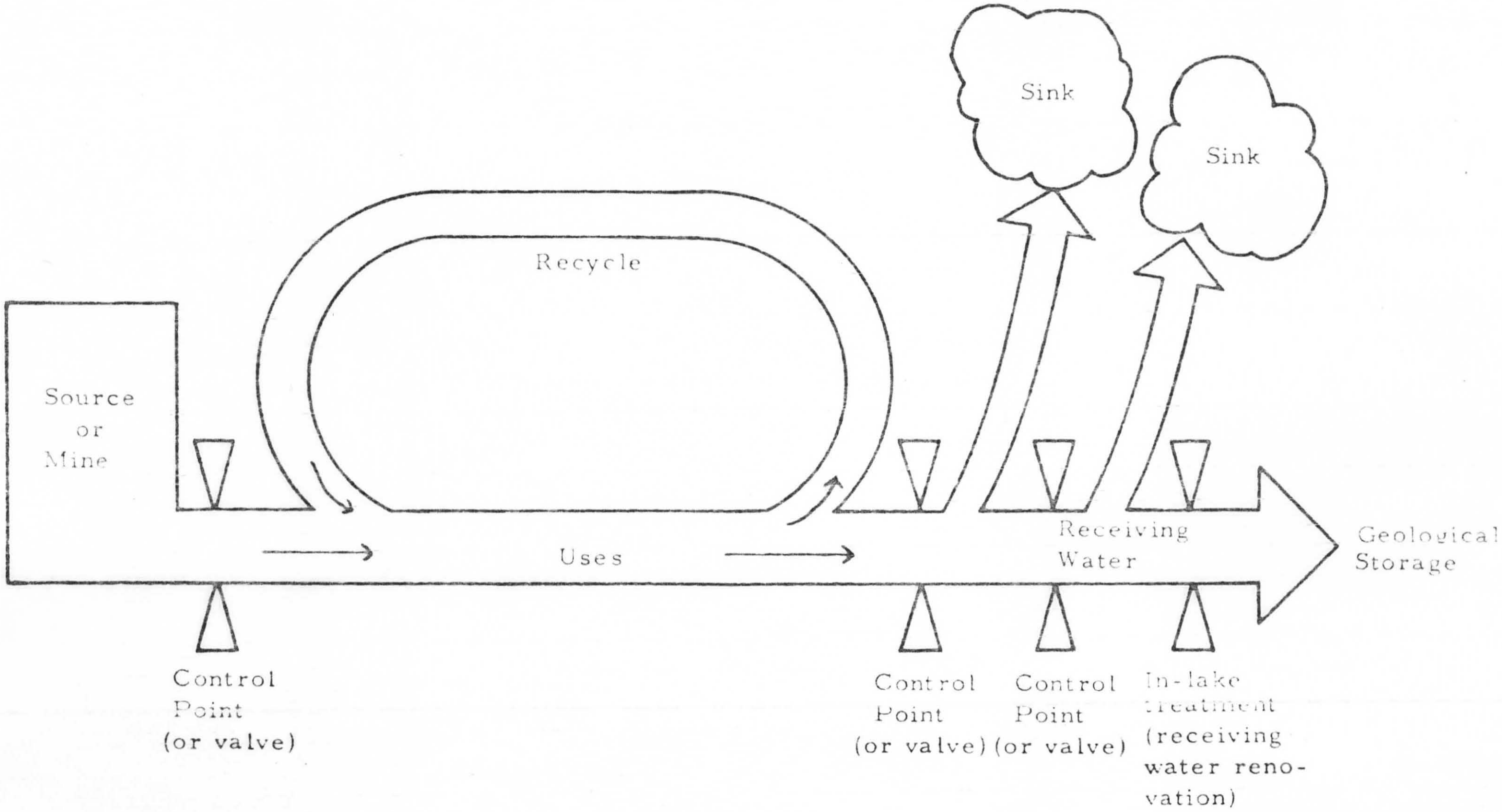

Figure 4. Phosphate Source, Use, and Final Destination with Possible Points of Control.