J. ENVIRONMENTAL SYSTEMS, Vol. 11(4), 1981-82

EVALUATING THE BENEFITS OF WATER REUSE

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ABSTRACT

The decision to use water reuse technology has been made on purely economic grounds in the past. As supplies of water pure enough to serve as a potable supply become more scarce, it will be necessary to take into account the size of the remaining potable supply as well as the cost of reuse technology when evaluating the potential for water reuse. This paper discusses the application of utility theory to this type of multiattribute problem.

Water reuse and water conservation technologies are receiving more attention as it becomes increasingly obvious that supplies of water clean enough to serve as a potable source are rapidly dwindling as well as becoming more expensive to produce. Conservation measures that involve using less water are generally inexpensive to implement. Water reuse measures that involve using the same water repeatedly for one use, or cascading water from one use to another before discharge to a wastewater treatment plant, are more costly. Many water reuse options that are technologically feasible are not economical compared to the current cost of potable water in most locations in the United States.

However, use of water resources is a complex value problem that should be evaluated with respect to a number of factors including cost. The size of the

doi: 10.2190/RUW1-29U0-KFAG-V9KE
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remaining supply, the energy needed to produce it, and the pollution load added by the intended use of the water are some of the concerns that may influence decisions on water use/reuse. In some situations, it is appropriate to value these kinds of concerns in terms of dollars; however, this is not always the case. For example, commanders of military installations have been directed by the Department of the Army to reduce total installation energy usage by 25 per cent. Therefore, they might be willing to pay a little more for reuse technology that uses less energy to supply water than the potable water system uses. Patriotic or strategic concerns in the coming years may cause similar goals to be set by industries or municipalities. Some mechanism will be needed to define the value of saving energy, so that it can be considered along with the cost of using energy.

The cost of the pollution load added to the water could also be expressed in terms of the dollars necessary to treat the resulting wastewater. However, it may not be possible to increase the capacity of existing wastewater treatment facilities due to lack of space, local opposition, unavailability of operational skill, etc. In addition, some value may be associated with not polluting the shrinking potable supply; this may or may not be related to concern for future generations.

The size of the remaining potable water supply could be expressed in terms of the cost of producing it, or the price for which it could be sold. If the supply is in danger of being completely depleted in the near future, the cost of moving to another location could be calculated. However, for the military, total depletion of the water supply may be unacceptable in the face of personnel, political, or strategic considerations. In that case, the value of extra years of supply will have to be defined.

Utility theory is a branch of decision analysis that came into vogue around the turn of the century in an attempt to quantify consumer preferences for commodities. All of the variables that impact a decision are discussed in their natural units of measurement and the preferences of the decision maker are probed until the tradeoffs between the variables can be expressed mathematically in terms of utility functions. Cost/benefits analysis rests on a consideration of the tradeoffs between variables. The dollar value assigned to each benefit or cost is thought of as representative of the tradeoffs between the dollar cost of an alternative and the other non-monetary factors under consideration. However, because these tradeoffs are not explicitly stated, the results of cost-benefit analysis are sometimes not consistent with the real preferences of the decision maker or the society he/she represents. This can be avoided by the use of utility analysis to force the decision maker to specify preferences for one variable over another throughout the range of possible values.

The tradeoffs between cost of reuse technology and expected lifetime of the water supply is the subject of the discussion that follows. Table 1 shows the costs of four alternative water reuse options for a photographic film processing laboratory located in the southwestern United States. The laboratory draws its potable water from a sole source aquifer that has an estimated remaining lifetime

Table 1. Cost of Alternative Actions

Action	NPDES Non-Compliance Days/Year	Estimated Aquifer Life (Years)	Power Usage kwh/Year	Cost of Water $/Year
1. No reuse	38–45	20	88,000	16000
2. Rinse Water Reuse	28–37	50	56,000	18000
3. Chemical Solution Reuse	15–30	30	71,000	19000
4. Total Reuse	3–17	60	60,000	25000

of twenty to twenty-five years at current usage rates. The costs of each reuse scheme have been expressed in terms of four variables: $/year for process water supply; kWh/year needed to produce process water; % increase in lifetime of aquifer due to reuse; and days/year that the sewage treatment plant is in non-compliance due to shock loads from the photo lab that are too large to be equalized. The four alternative actions under consideration are: no reuse; reuse of the rinse water only; reuse of developing solutions after chemical make-up; or a cascade reuse system for the whole facility including treatment of the water between processes.

Table 2 shows a rank ordering of the alternative reuse options for each variable. A rank of 4 identifies the most desirable action, 1 the least desirable action. None of the alternative actions are clearly superior to the others. If all the variables had equal weight in the mind of the decision maker, their rankings could be summed across the row for each alternative, and the alternative with the highest score would be chosen. Similarly, if the variables can be assigned weights with respect to each other, the rankings could be multiplied by the weights, and then summed for each alternative. Table 3 shows an example of this technique. This approach is not applicable to many problems. In general, it is rarely possible to assign weights to each variable that remain constant over the ranges of the other variables. In other words, how important each variable is in relation to the others depends on the specific levels of the other variables. Utility theory can be applied to this problem by first generating indifference curves for the two variables by repeatedly questioning the decision maker's preference for combinations of dollars and years against suitably chosen reference points. A procedure for experimentally determining indifference curves has been described by MacCrimmon and Toda [1]. Utility functions for the two variables can then be derived from the relationship between the indifference curves as shown by Fishburn [2, 3] and Luce and Tukey [4].

The relationship between the amount of money that a decision maker is willing to spend to gain additional years of water supply varies from person to person. However, reasonable assumptions can be made about the shape of the

Table 2. Rank Ordering of Actions

Action	*Days/Year*	*Years of Life*	*kwh/Year*	*$/Year*	*Total*
#1	1	1	1	4	7
#2	2	3	4	3	12
#3	3	2	2	2	9
#4	4	4	3	1	12

Table 3. Weighted Ranks of Actions

Action	*Days/Year Weight = 0.5*	*Years of Life Weight = 0.8*	*kwh/Year Weight = 0.3*	*$/Year Weight = 1*	*Total Weighted Score*
#1	0.5	0.8	0.3	4	5.6
#2	1.0	2.4	1.2	3	7.6
#3	1.5	1.6	0.6	2	5.7
#4	2.0	3.2	0.9	1	7.1

curve that describes the tradeoffs between these variables. Figure 1 is a representation of some of the potential shapes this curve might take. One assumption is that the slope of the curve is positive or 0 at all points; this implies that an increase in the water supply from one level to a higher level is always worth more or the same amount of money, but not less. This property of indifference curves is called monotonicity [1]. Second, the slope is not constant over the range of values of the two variables. If it is, the relationship is described by a straight line, and the weighted averages technique can be used. Finally, it may be possible to set boundary conditions for one or both variables. The maximum boundary condition for the life of the water supply can be set by dividing the volume of the existing supply by the minimum volume of water that would be used per year with all technologically feasible reuse options employed. The minimum boundary condition for the life of the water supply may be the expected life at current usage rates, or an assumption may be made that usage rates may increase, causing an even shorter lifetime. Similarly, it may be possible to estimate the minimum and maximum amounts of money that will be available to pay for water supply. These boundary conditions are then used to define the range of each variable. In Figure 2, the boundary conditions for water supply lifetime have been set at twenty to sixty years. The minimum amount that water supply can cost can be found in Table 1: $16000/year. The upper bound has not been estimated.

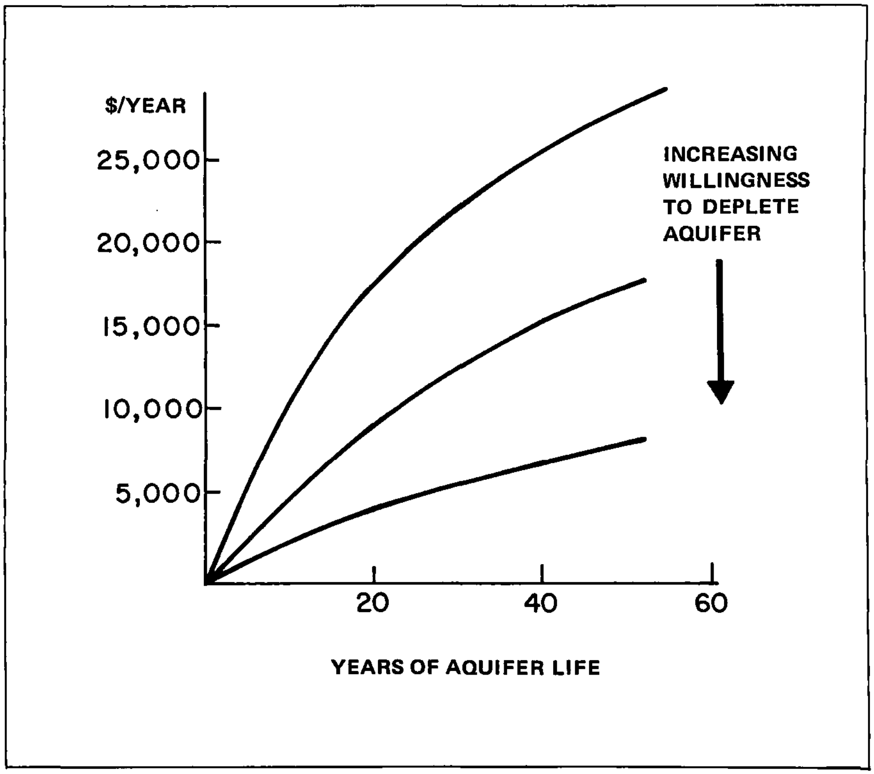

Figure 1.

According to the procedure published by MacCrimmon and Toda [6], the first step in drawing an indifference curve is to establish a reference point. In this case, an obvious choice exists; the facility is already paying $16000/year to supply water from an aquifer with a twenty year estimated life. This is the point labelled P_0 in Figure 2. Based on the property of monotonicity, all points to the left and above of P_0 are undesirable; this region is crosshatched in Figure 2. Then the decision maker is asked to identify the $ value X at which she/he would be indifferent between (20, $16000) and (30, X). The point (30, X) is labelled P1 on Figure 2, and all points to the left and above it are unacceptable. This process is continued, always with respect to P_0, until the shape of the indifference curve can be sketched in.

The analysis could be stopped at his point if these two variables were the only ones of interest because their relationship over the expected range of values has

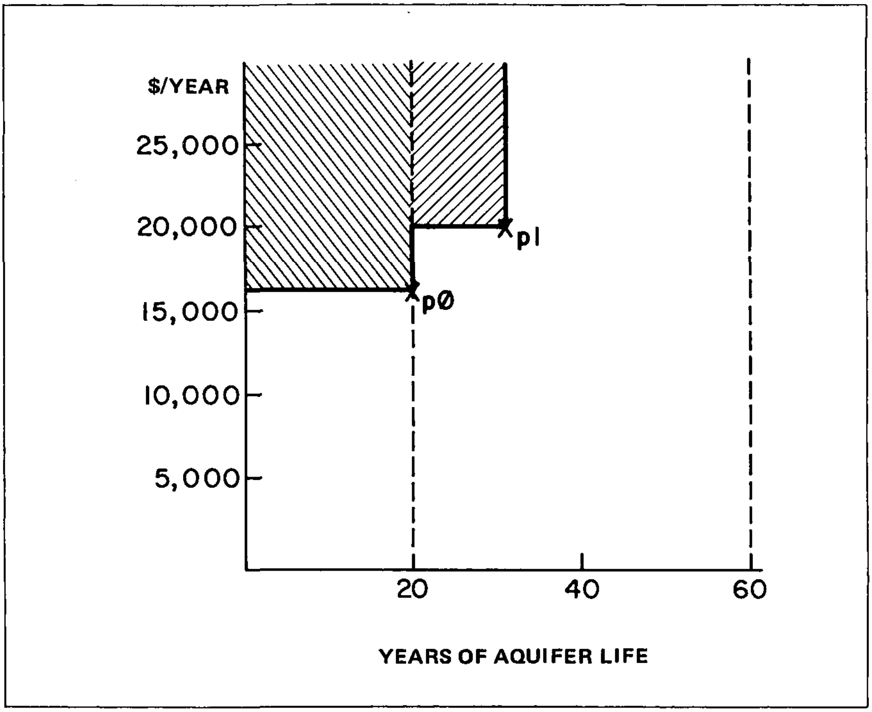

Figure 2.

been described. However, because two other variables must be considered in this decision, it is necessary to derive the utility functions for all of them. The utilities for each variable can then be added directly to obtain the total utility associated with each alternative action.

Therefore, at this point the first indifference curve is set aside, the axes are redrawn with the same boundary conditions, a new P_O is specified, and the indifference curve through that P_O is ascertained. Then the two indifference curves are superimposed upon each other. If the two curves intersect, a contradiction exists. This is pointed out to the decision maker, and his/her preferences in that region are again probed until decision maker and analyst are satisfied that the curves are representative of the real feelings of the decision maker.

Figure 3 presents the method for deriving utility functions from two indifference curves. This is referred to as the method of double trade-off by Fishburn. "A 'flight of stairs' is drawn between the two curves by a connected series of horizontal and vertical line segments, a 90 degree turn being made whenever a segment touches a curve. The successive points on the curve touched by the stairs define equal intervals of utility for each factor and part of each utility function may be estimated from these points." [7]

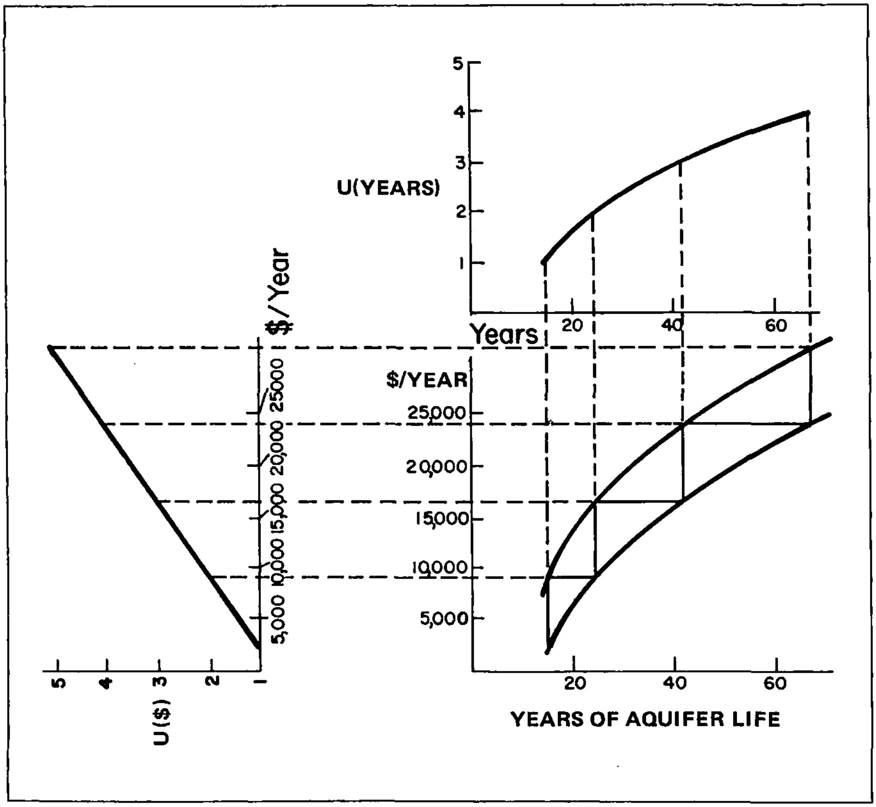

Figure 3.

MacCrimmon and Siu [8] have developed a method for making tradeoffs between three or more variables. The levels of all but two of the variables are held constant while tradeoffs between those two variables are defined. They have written an interactive computer program called ICM to generate indifference curves for problems involving three dimensional space which includes checks for consistency.

Once the utility function for each variable has been drawn, the total utility for each alternative action can be found by summing the separate utilities for each variable at the level that it is expected to occur for each particular action. Table 4 shows an example of this for the two variables whose utility functions are shown in Figure 3.

These procedures are fairly straightforward and not overly time-consuming. When faced with a problem involving many variables, the application of utility theory is an excellent way to ensure that each variable is given the correct weights over its range, and that the final decision is a good reflection of the

Table 4. Utilities of Actions

Action	*$/Year*	*Years of Life*	*Total Utility*
#1	2.8	1.0	3.8
#2	3.1	3.5	6.6
#3	3.3	2.3	5.6
#4	4.1	4.0	8.1

decision maker's preferences for all the relevant variables. The application of utility theory to water resources problems will become more important in the future as the protection and enhancement of existing reserves becomes imperative.

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