ECOLOGY I AND II, RESOURCE ECONOMICS AND WATER RESOURCE DEVELOPMENT

By

Duane Chapman

June 1971 No. 41

Functionalism and systems analysis are joined to form the concept of a functional system which may be relevant to ecology and resource economics. A speculative application is made to the management of Hetch-Hetchy Valley.

Ecology I and II, Resource Economics And Water Resource Development 1/

Duane Chapman

Some time ago R. V. O'Neill and the author attempted to examine the interface between ecology and resource economics and apply certain theoretical conclusions to the environmental problems of electricity generation (Chapman and O'Neill, 1970). This paper applies our earlier notions to environmental aspects of water supply development.

In general, economics might be defined as the study of the relationships between individual desires, social institutions, and physical possibilities. Resource economics can be termed a field of study within economics focusing upon natural resources such as land, water and air.

Ecology is somewhat more difficult to define since the recent growth in environmental consciousness. A first definition, perhaps acceptable to members of the Ecological Society of America, might define ecology as the study of the relationships between plant and animal life (including man) and the physical environment.

Readers of Environment, however, might prefer to describe ecology as an ethical and political movement holding that man should respect rights of plants, animals and the physical environment. This second definition isn't wholly adequate, but it succeeds in conveying the distinction between ecology as an academic science and ecology as a popular movement. Second definition ecologists are newer and more numerous.

Interdisciplinary Analysis

Before proceeding further, it is useful to indicate three methodological aspects of interdisciplinary study which are relevant to this subject.

First, the scientific understanding of the majority of environmental problems involves both ecology (in the definition #1 sense) and resource economics. In general, it is differences in perceived value of particular

---

1/ Paper presented at the National Symposium on Social and Economic Aspects of Water Resource Development sponsored by the American Water Resources Association and the Cornell University Water Resources and Marine Sciences Center, June 21-23, 1971.

forms of ecosystems which form the basis of environmental difficulties. Resource economics balances this perceived ecosystem value against monetary gains and losses. We shall return to this point later.

Second, interdisciplinary study often falls to the level of the lowest common denominator of the involved disciplines. The common language of discussion often omits terminology and analytic methods which are not jointly shared. An important part of this paper is a view of the degree of joint sharing of the concepts of systems analysis and functionalism in the two disciplines.

Third, the tension between description and prescription (or positivism and normativeness) is common to both fields. The point of view held here is simple: Political and philosophic controversy about what environmental policies ought to be provide the basic guide to important areas for impartial research. At the present time science in a positivistic (a descriptive) sense seems inadequately equipped in terms of theory, analytic techniques, or organizational capabilities to predict satisfactorily the consequences of large-scale policy alternatives.

Systems Analysis and Functionalism

Following C. W. Churchman (1968), a system can be seen simply as a set of parts coordinated to accomplish a set of goals. Churchman suggests five aspects of systems analysis:

1. System objectives and performance measures.
2. Fixed constraints of the system's environment.
3. Resources available for use.
4. Components: processes, goals, and performance measures.
5. Management and control of components and resources to achieve objectives.

Turning to functional analysis, we might adopt the definition of C. G. Hempel (1970):

> The object of the analysis is some "item" i, which is a relatively persistent trait or disposition (e.g., the beating of the heart) occurring in a system s (e.g., the body of a living vertebrate); and the analysis aims to show that s is in a state, or internal condition c_i and in an environment presenting certain external conditions c_e such that under conditions c_i and c_e (jointly to be referred to as c) the trait i has effects which satisfy some "need" or "functional requirement" of s, ie., a condition n which is necessary for the system's remaining in adequate, or effective, or proper, working order.

Systems analysis has had an important impact in both fields. Design of Water Resource Systems by Maass, et al (1962), for example, dealt with welfare theory, benefit-cost analysis, computer programming and politics. (But not, incidentally, with any environmental problems.)

In ecology, systems analysis has been equally influential. Perhaps Kenneth Watt's Systems Analysis in Ecology (1966) and Ecology and Resource Management (1967) are the best known.

However, the impact of functional analysis has not been equally great in both disciplines. It has been an important part of ecology and other life sciences, but not of resource economics. It might be argued that functionalism is implicit in institutional analysis, but it is probably best to conclude that functionalism per se has not been significant in resource economics.

Might these two concepts be combined in a worthwhile manner? O'Neill and this writer had suggested earlier that the notion of a "functional system" may be a useful way of integrating ecology and resource economics. Perhaps this concept may be useful in the context of water supply.

Functional Systems

This is one possible definition: Given a society (s) in a state or condition (c_i) and an environment presenting external conditions (c_e), the functional system (f) has effects (n) which are necessary for the society to remain in adequate, or effective, or proper working order. The functional system and its individual components may be controlled by management policies (m) in the utilization of resources (r). The effects (n) are subject to performance measures (p).

Figure 1 may help clarify this definition. It is nothing very new or difficult; it is intended to illustrate the definition of a functional system.

If we wish, we can define the environment as consisting of functional systems. (See Table 1 and Chapman and O'Neill (1970), p. 5). Following our previous discussion, we might argue that a functional system satisfies some differentiated collection of physical or emotional desires of the members of a society through the transformation of physical resources, and has associated with it a specific social or population structure. Perhaps we could pursue the question of whether this description is equally applicable to an ecosystem (say, a temperate forest) and a water supply system, but attention will be turned to other matters.

It is intended that the listing in Table 1 be exhaustive of environmental phenomena. Alternatively, the environment can be seen as consisting of 1) the natural and economic systems, 2) the terrestrial, aquatic, resource based, and socially based sub-systems, and 3) the collection of all functional systems.

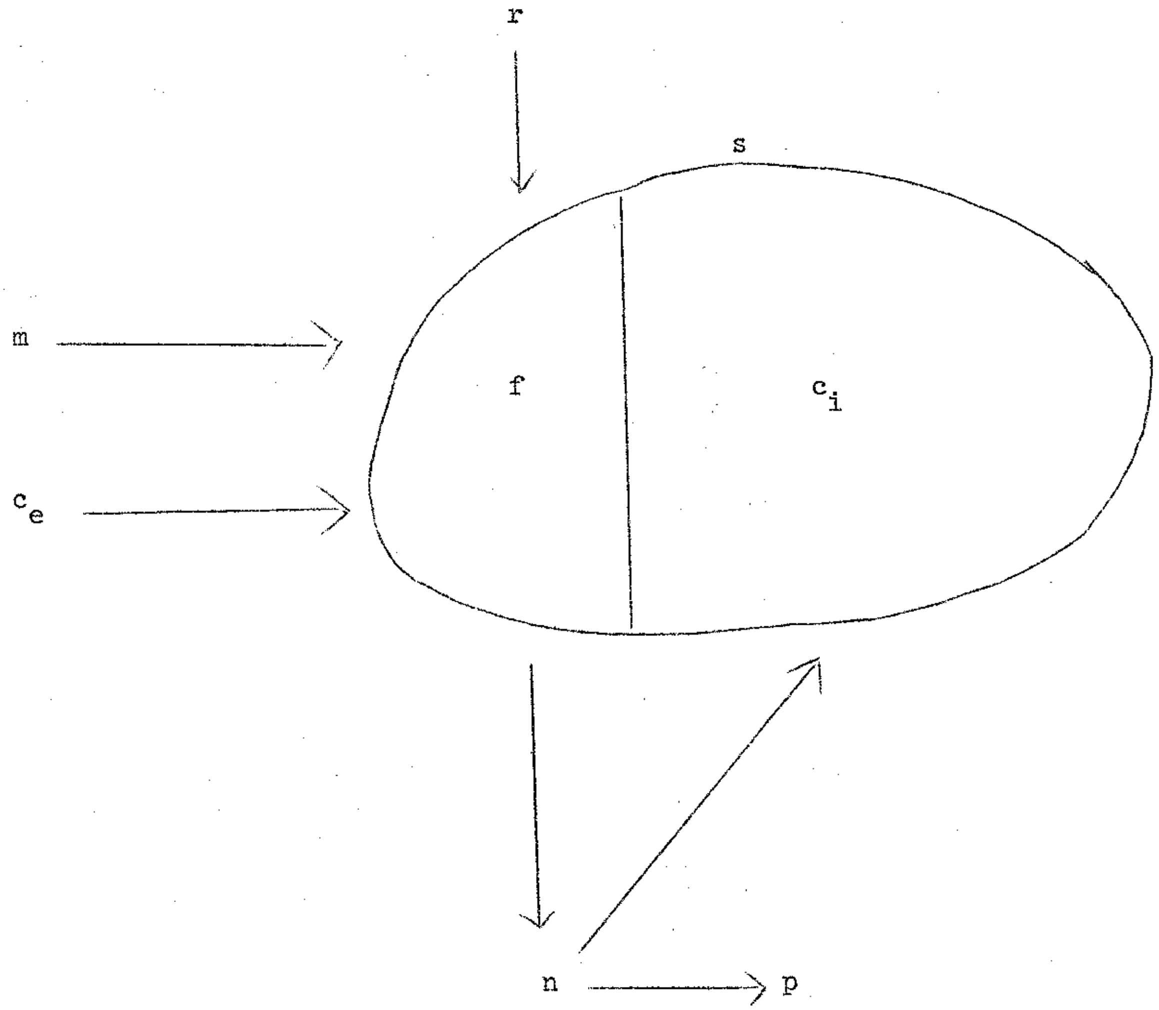


Figure 1. A Functional System

Table 1. The Environment as a Collection of Functional Systems

	Environment			
Systems	Natural		Economic	
Sub-Systems	Terrestrial	Aquatic	Resource Based	Socially Based
Functional Systems	Tundra Taiga Temperate Forest Grassland Chaparral Desert Tropical Rain Forest Tropical Deciduous Forest Savanna Other	Freshwater Polar Temperate Tropical Marine Polar Temperate Tropical Other	Electricity Other Energy Agriculture Water Supply Mining Land Use Recreation Forestry Fisheries Other	Political Religious Transportation Health Care Education Building Construction and Use Military Communication Other

Water Supply System

The remainder of the discussion will concentrate on three aspects of water supply as a functional system: components, a performance measure and management. One way of defining components of a water supply system is as follows:

1. Topography and ecology (see Table 1, natural systems).
2. Land and water use type: agricultural, municipal, industrial, commercial, recreation.
3. Structures (or bodies) for storage and transportation: oceans, air, reservoirs, natural lakes, surface structures, surface streams, underground streams.
4. Processors: climatological processes, water purification, effluent treatment, desalination, recycling.
5. Quality: salinities, acidity, normality, poisons, organic matter.

This listing of components is intended only to be illustrative: Other groupings of components are certainly logical.

The subject of performance measures for water supply systems and their components has received much attention through the development of benefit-cost analysis. A related approach is to view performance in terms of social cost and social value with these definitions:

Social Cost. The cost of an economic activity relevant to societal preferences: the sum of market cost, external diseconomy and nonmonetary cost.

Economic Activity. The process of producing or consuming a commodity or a leisure time activity.

Market Cost. The monetary cost of production of a commodity incurred by the producing enterprise.

External Diseconomy. A nonpurposeful byproduct of one economic activity raises the monetary cost of another economic activity.

Nonmonetary Cost. A negative nonmarket effect upon consumers resulting from a nonpurposeful byproduct of an economic activity. It is potentially measurable as the payment (in higher prices or taxes) consumers would be willing to pay to eliminate the byproduct.

Monetary Cost. Components of social cost which are included in a national income concept of social cost: market cost and external diseconomy.

Nonmarket Cost. Components of social cost which are not included in the market cost or market price of an economic activity: external diseconomy, and nonmonetary cost.

Social Value. The value of an economic activity relevant to societal preferences: the sum of market value, external economy and nonmonetary value.

Market Value. The price which would have led purchasers to demand the quantity consumed.*

External Economy. A byproduct (generally nonpurposeful) of one economic activity lowers the monetary cost of another economic activity.

Nonmonetary Value. A positive nonmarket effect upon consumers resulting from a byproduct (generally nonpurposeful) of another economic activity. It is potentially measurable as the payment (in prices or taxes) consumers would be willing to pay to ensure the continuation of the byproduct.

Monetary Value. Components of social value which are included in a national income concept of social value: market value and external economy.

Nonmarket Value. Components of social value which are not included in the market value of an economic activity: external economy and nonmonetary value.

---

* Recall that the price demand function is the inverse of the quantity function: $P(X) = X^{-1}(P)$.

Table 2 may help clarify these relationships. While social cost and social value are partly symmetrical, they are not wholly so. External diseconomy and nonmonetary cost are always nonpurposeful, but external economy and nonmonetary value may occasionally be purposeful.

With reference to traditional benefit-cost analysis, it is evident that it leads to an emphasis on monetary cost and monetary values and a de-emphasis of nonmonetary costs and nonmonetary value.

The past experience with monetizing the nonmonetary in water resource development has been mixed. Reservoir recreation (an important nonmonetary value) has achieved some degree of accommodation with benefit-cost analysis. Monetary values are imputed to various forms of recreation days, and reservoir recreation is now usually a purposeful byproduct of water resource development.

Nonmonetary cost, on the other hand, remains beyond the monetizing ability of agency benefit-cost analysts. Preservation and ecological values have been the political shoals of many a recent water resource proposal; we shall return later to this problem.

The same physical phenomenon may affect social cost or social value through more than one component. The elimination of stream recreation is a nonmonetary cost to the former recreationists and may cause an external diseconomy in the form of a reduction in wages and profits* from unemployed labor and capital in stream recreation consumer services.

Table 3 applies these concepts to water resource development.

These concepts are potentially applicable to a water supply system or any of its components. Application to the reservoir component results in Table 3 (see Allee and Chapman, (1971)). Agency benefit-cost analysis has generally been concerned with social value and market cost of potential projects. External diseconomies and nonmonetary cost are generally excluded. It is instructive to apply these fuller concepts of social cost and social value to the measurement of the performance of a particular component of a particular system to determine additional information about the management of the component.

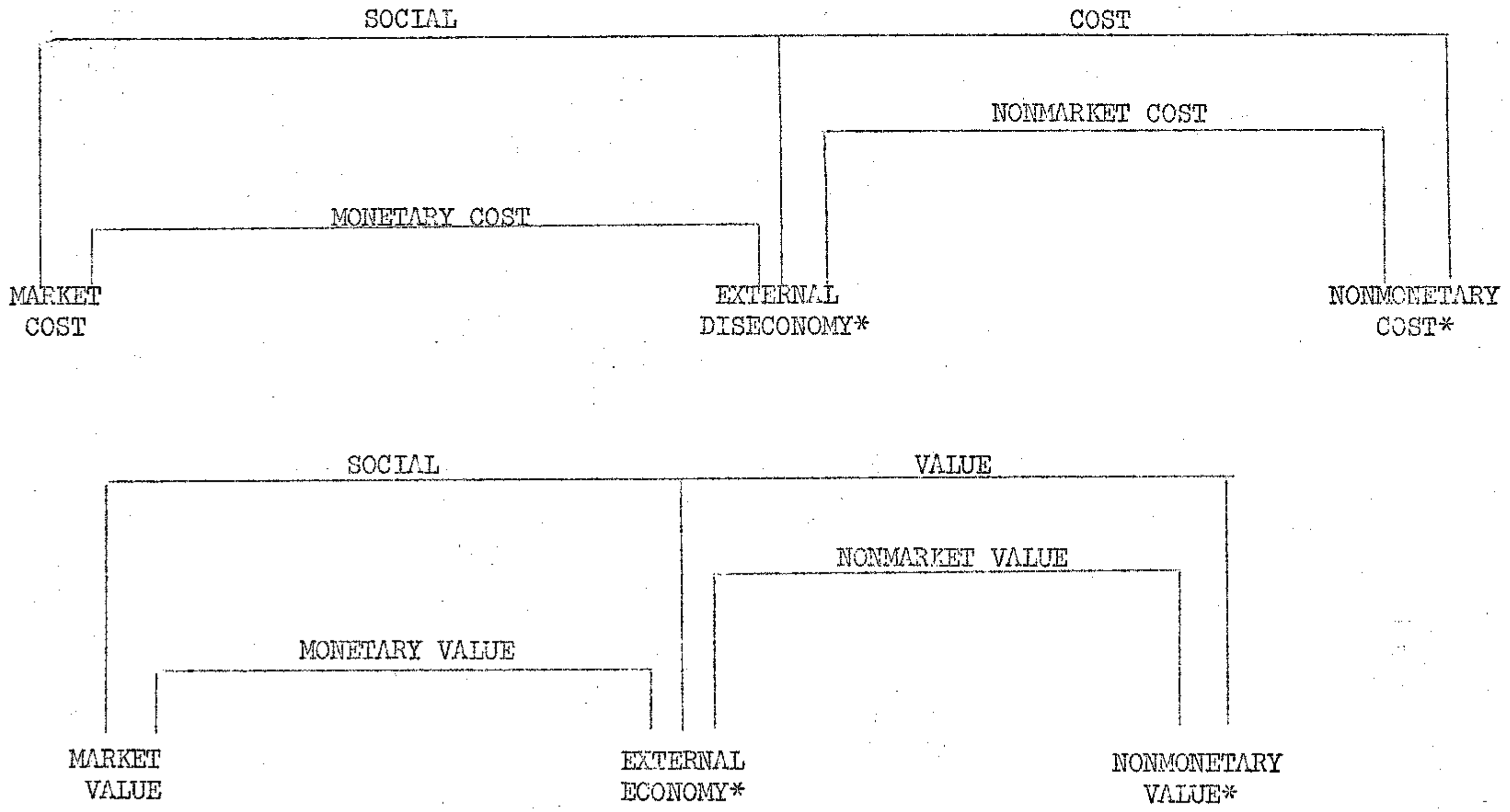
Managing Hetch-Hetchy Valley

The Hetch-Hetchy Valley has been seen as equivalent to Yosemite Valley by many authors. In 1909, John Muir wrote:

---

* Gross national product is the sum of earned income and ownership income from each economic activity. The external economy and diseconomy concepts used here are derived from the national income measures of benefits and costs.

Table 2. Social Cost and Social Value



* Substantial environmental significance.

Table 3. Social Cost, Social Value, and Water Resource Development by Reservoir Impoundment and Long Distance Transport by Canal or Pipe

I. Social Cost	II. Social Value
A. Market Cost (of) reservoir bed clearing dam construction auxiliary facilities (turbines, picnic tables, etc.) maintenance borrowed capital	A. Market Value (to) agriculture industry residences commerce government
B. External Diseconomies (net loss of wages and profits from) destroyed agricultural land destroyed stream fishery services destroyed stream recreation services, esp. to canoeing and kayaking	B. External Economies (net gain in wages and profits from) employment of otherwise idle human and capital resources flood control navigation improvement reservoir recreation services water quality improvement electricity production
C. Nonmonetary Cost population relocation species extinction loss of unique vegetation or landform interference with or loss of certain recreational experience: canoeing, fishing, mountaineering, etc. loss of scenic attractiveness	C. Nonmonetary Value aesthetic value of water quality improvement security from death through flooding satisfaction from reservoir recreation

---

"The fame of the Merced Yosemite has spread far and wide, while Hetch-Hetchy, the Tuolumne Yosemite, has until recently remained comparatively unknown, notwithstanding it is a wonderfully exact counterpart of the famous valley. As the Merced flows in tranquil beauty through Yosemite, so does the Tuolumne through Hetch-Hetchy. The floor of Yosemite is about 4,000 feet above the sea, and that of Hetch-Hetchy about 3,700, while in both the walls are of gray granite, very high, and rise precipitously out of flowery gardens and groves. Furthermore, the two wonderful valleys occupy the same relative positions on the flank of the Sierra, were formed by the same forces in the same kind of granite, and have similar waterfalls, sculpture, and vegetation. Hetch-Hetchy lies in a northwesterly direction from Yosemite at a distance of about eighteen miles, and is now easily accessible by a trail and wagon-road from the Big Oak Flat road at Sequoia."

> "The most strikingly picturesque rock in the valley is a majestic pyramid over 2,000 feet in height which is called by the Indians "Kolana." It is the outermost of a group like the Cathedral Rocks of Yosemite and occupies the same relative position on the south wall. Facing Kolana on the north side of the valley there is a massive sheer rock like the Yosemite El Capitan about 1,900 feet high, and over its brow flows a stream that makes the most beautiful fall I have ever seen. The Indian name for it is "Tueeulala." From the edge of the cliff it is perfectly free in the air for a thousand feet, then breaks up into a ragged sheet of cascades among the boulders of an earthquake talus. It is in all its glory in June, when the snow is melting fast, but fades and vanishes toward the end of summer. The only fall I know with which it may fairly be compared is the Yosemite Bridal Veil; but it excels even that favorite fall in height and fineness of fairy airy beauty and behavior."

More recently, Scharpf (1967) observed:

> "The Tuolumne River follows a tumultuous course westward across the Park a few miles north of the Tioga Road. It has a larger drainage system and more water volume than the Merced. Its Waterwheel Falls is one of the most interesting wonders of scenic America. Its Grand Canyon will stand high among America's beautiful canyons. Its valley, the Hetch-Hetchy, has been, while not so famous as Yosemite, a "celebrity" for some years.
>
> Hetch-Hetchy Valley is generally recognized as being analogous to Yosemite though on a smaller scale. The profound gorge of the Tuolumne, with its stepped profile of bare, glaciated rock emerges suddenly on a wide, flat-floored, sandy valley, just as Tenaya Canyon opens on Yosemite. Both valleys have had the same history. Glacial abrasion and plucking over-deepened the canyon, so that, when the ice retreated, a tarn occupied the basin. This tarn served as a trap for sediments brought down from the melting ice above, and the filling of the basin built out the level floor of Hetch-Hetchy. The reservoir created in Hetch-Hetchy Valley by O'Shaughnessy Dam at its outlet is but a restoration on a larger scale of the lake which once was there. Incidentally, the term "Hetch-Hetchy" is derived from a Miwok or Paiute Indian word that denotes a kind of wild food that once abounded in the valley in the days when the Indians made it their home."

Both valleys are part of the California water supply system. The Yosemite Valley with the waterfalls feeding the Merced River is of such magnificent scenery that it has a national reputation and is visited by approximately one and a half million people each year. The Merced River flows from the Yosemite Valley into the agricultural San Joaquin Valley where it is impounded by the New Exchequer reservoir. The Hetch-Hetchy Valley is flooded by the Tuolumne River impounded by the O'Shaughnessy Dam. Downstream from this dam, the Tuolumne is again impounded by the Don Pedro Dam.

Let us see if the performance measure of social cost and social value indicates the proper management of the Hetch-Hetchy Valley component of the California water supply system. Specifically, let us speculate whether the Hetch-Hetchy Valley is best used as a reservoir or as a scenic and recreational resource.

It is evident that the nonmonetary value of a reclaimed Hetch-Hetchy Valley is the crucial part of the analysis. Estimates might be made of the following quantities:

1. The vicarious value a non-visitor derives from the knowledge that other citizens do visit the area; this can be experienced with photographic essays, newscasts of rock climbers, etc.
2. The option value associated with a non-visitor knowing he might go if he wished.
3. The preservation value of knowing an unusual natural resource had been reclaimed and preserved.
4. The sale value of publication, television, and movie rights to the reclamation work.
5. The annual tax the citizenry would be willing to pay to compensate present power and water customers and to reclaim the valley.

(We might also consider selling fragments of the O'Shaughnessy Dam in local curio shops!)

For purposes of discussion, the participants in the June 22 morning session of the Symposium were asked question five above. Table 4 displays the response to this question. The median willingness to pay was $0.29 and the average was $2.17. (The question was put in the context of "a second Yosemite Valley" with an assumed visitation of millions of persons a year. Many participants indicated their preference for managing a reclaimed Hetch-Hetchy as a wilderness rather than a heavy-use area. Such a management policy would obviously alter the social value analysis here.)

To continue the illustration, the nonmonetary value of reclamation and recreation development apart from visitation use will be taken as $0.29/per person/per year.

Suppose actual visitation was rationed to one million persons and two million visitor days per year. One management plan would permit one-half million camper days in the valley and adjacent campgrounds and one-half million overnight stays in lodges, cabins and tent cabins. Day visitation in this plan might be one million people per year. Assuming recreation day values of $3.00, $5,00 and $1.50 respectively results in a figure of $5.5 million per year as an estimate of the value to users of this management plan.

Table 4. Responses of Symposium Participants To Willingness to Pay Question

Range ($/year)	Number Choosing Range
$ 0	4
.01 to .25	12
.25 to .50	6
.50 to 2.00	3
2.00 to 10.00	4
10.00	4
10.00 plus	0

Mean: $2.17

Median: $0.29

The magnitude of some of the market costs and external diseconomies can also be guessed. First, we can estimate the cost of dam removal and construction of a tie-in with the California Aqueduct for San Francisco to the nearest $100 million -- $100 million. (It seems likely that surplus capacity in the California Water Plan could replace the 175,000 AF now provided by Hetch-Hetchy. The San Francisco pipe, running west from Yosemite to San Francisco, crosses the California Aqueduct in the Northern San Joaquin Valley.) Second, it might cost $25 million to reclaim the valley floor for forest and meadow. The steep sides are likely to be mostly cleansed by rain and snow. Third, the cost of recreational facilities (including roads and administrative structures) might go as high as $100 million. An estimate of the annual upkeep for the new forest, meadow, and recreation facilities might be $20 million per year.

The current revenues from power and water sales suggest estimating losses of $12 million and $6 million per year.

(Incidentally, the assistance of a senior employee with a California construction agency was invaluable in this pre-reconnaissance report. He prefers to remain uncredited with his contribution.)

Our fantasia is summarized in Table 5. Annual equivalent costs are calculated on the basis of a 6% interest rate. The reclaimed valley has an infinite life, but the new facilities have a more prosaic 25 year life. The relevant population is taken at 225 million since it will be a few years before the project is authorized and funded.

Table 5. Social Cost and Value of Hetch-Hetchy Reclamation

Social Cost (million $)	Capital	Annual Equivalent Amount
Dam removal and S.F. tie-in to California Aqueduct	$100	$ 6 a/
Reclamation work	25	1.5 a/
New facilities	100	7.8 b/
Operation and maintenance		20
Power lost		12
Water lost		6
Total:		$53.3 m/yr.

Social Value	Million Annual Recreation Days	Unit Value	Annual Value (million $)
Camping	0.50	$3.00	$ 1.5
Lodging	0.50	5.00	2.5
Day use only	1.00	1.50	1.5
Nonmonetary value	225c/	0.29	65.3
Total:			$ 70.8 m/yr.

---

a/ 6% discount rate, infinite life
b/ 6% discount rate, 25 year life
c/ total U. S. population at time of project initiation

While Table 5 isn't quite ready to be used to seek an appropriation, it is arresting. Perhaps -- just perhaps -- Hetch-Hetchy is being used for the wrong sub-system in California's water system.

As noted above, the perceived value of particular forms of ecosystems -- their nonmonetary value -- is of primary importance to environmental problems. The correct estimation of social cost and social value as measures of system performance and component management is impossible without responding to this need. In summary, it seems apparent that systems analysis and environmental quality will have some unexpected results for both ecology I and II and resource economics in the water supply field.

References

Allee, David and Chapman, Duane, 1971. "The Economics of Water Development and Environmental Quality." A contribution to a study for the National Water Commission, A Balance Between Environmental Quality and Water Development. Charles R. Goldman, Principal Investigator, Box GG, Davis, California 95616.

Chapman, Duane and O'Neill, R. V. December 1970. Ecology and Resource Economics: An Integration and Application of Theory to Environmental Dilemmas. ORNL-4641, Oak Ridge National Laboratory, Oak Ridge, Tenn. Reprinted as ORNL-NSF-EP-4, April 1971.

Churchman, C. West. 1968. The Systems Approach. Dell, New York. pp. 29, 30, 65.

Hempel, Carl G. 1970. "The Logic of Functional Analysis." In Brody, Baruch A., Editor, Readings in the Philosophy of Science. Prentice-Hall, Englewood Cliffs. Reprinted from Gross, Llewellyn, Editor, 1959, Symposium on Sociological Theory. Harper and Row, New York. p. 124.

Maass, Arthur et al. 1962. Design of Water-Resource Systems. Harvard University Press, Cambridge.

Muir, John. 1909. "Let Everyone Help to Save the Famous Hetch-Hetchy Valley." Society for the Preservation of National Parks, San Francisco. p. 14.

Scharpf, Robert. 1967. Yosemite National Park. McKay, New York. pp. 30, 31.

Watt, Kenneth. 1966. Systems Analysis in Ecology. Academic Press, New York.

Watt, Kenneth. 1968. Ecology and Resource Management. McGraw-Hill, New York.