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RESEARCH

Benefit–Cost Analysis of Stormwater Quality Improvements

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ABSTRACT / The major purpose of this paper is to explore the potential value of benefit–cost evaluation for stormwater quality management decisions at a local level. A preliminary benefit–cost analysis (BCA) screening method is used for maximum extent practicable (MEP) analysis, identifying promising management practices, and identifying societal and economic tradeoffs for local stormwater problems. Ballona Creek, a major urban storm drain in Los Angeles, California, USA, is used to illustrate the practicality of the benefit–cost evaluation. The Ballona Creek example demonstrates the economic limits of stormwater management in an urban region and attests to the value of coordinated basinwide management compared to uncoordinated management by individual landowners. Evaluation results suggest that in urban areas, the benefit of stormwater quality improvements might be far greater if accompanied by comprehensive redesign of drainage networks and neighboring land uses. In this case, benefit–cost analysis is found to be useful for evaluating and understanding stormwater management alternatives despite the uncertainties in characterizing stormwater quality and the effects of stormwater management on improving receiving water quality.

Many receiving waters are compromised by human activities, particularly pollution from nonpoint sources and stormwater runoff. Jeopardizing water quality reduces recreational opportunities, degrades scarce habitats, and limits water supply availability. Under the Clean Water Act, states have the primary authority for establishing designated uses for waterbodies and for developing numerical and narrative water quality criteria for nutrients, minerals, physical characteristics, and biological indicators to protect habitat, water supply, and recreational uses. In addition, according to Section 402(p) of the Clean Water Act (CWA), agencies with municipal permits must utilize best management practices (BMPs) to reduce pollution in receiving waters to the maximum extent practicable (MEP). The MEP requirement implies that an agency must employ management practices unless one of the following three conditions has been established: (1) other effective BMPs will achieve greater or substantially the same pollution control benefits; (2) the BMP would not be technically feasible; or (3) the cost of the BMP implementation would greatly outweigh the pollution control benefits (US District Court 1995). The economic criterion of the MEP definition has been the most difficult criterion to evaluate since both costs and benefits of implementing a management practice need to be established. Federal, state, and local agencies are struggling to satisfy these stringent regulatory requirements, as defined by the CWA, to improve degraded receiving waters.

Scientific and financial resources for protecting and enhancing receiving waters are limited. Agencies and municipalities generally develop stormwater management programs based on expert advice, familiarity with management practices, availability of management practices, and by selecting the lowest cost stormwater quality management options available (sometimes, regardless of their effectiveness).

Since the protection and enhancement of receiving waters affected by stormwater runoff is important to the preservation of the environment, the regional economy, and the varied uses of receiving waters, stormwater quality management evaluation should be based on the benefits realized from expenditures. Benefit cost analysis (BCA) is proposed and demonstrated for helping to evaluate and develop stormwater quality management alternatives and plans. Following a brief review of BCA, a preliminary BCA method for stormwater quality management is developed. This method is then applied

KEY WORDS: Benefit–cost analysis; Stormwater quality management; Best management practices; Receiving water

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to Ballona Creek in Southern California, USA, and the implications of the results and approach are discussed.

Benefit–Cost Analysis

Benefit–cost analysis (BCA) is the identification, economic valuation, and quantitative comparison of the advantages and disadvantages of public policies based on their net contribution to society's overall well being. Originally required by the Flood Control Act of 1936, benefit cost analysis has long been used by the Army Corps of Engineers and other agencies to assess the net economic value of public works projects and compare alternative water resources and infrastructure projects (Krupnick and Portney 1991).

Economic analyses of public policies and projects have evolved from limited consideration of salient costs and benefits to more comprehensive analyses that incorporate less tangible costs and benefits associated with the environment and public health and safety (Arrow and others 1996, Howe 1971, US Water Resources Council 1983, Zerbe and Dively 1994). This level of analysis provides new challenges in quantifying values of natural resources, life, and risk. In most cases relating to natural resources, it has been easier to estimate costs (such as treatment of wastewater) than benefits associated with implementing a policy (the value of treating effluent discharging into receiving waters). Benefit–cost analyses have been widely used for comparing the desirable and undesirable impacts of proposed policies related to the environment, health, and safety. Even with the recognizable difficulties in quantifying benefits and costs related to natural resource management projects, examples are available that demonstrate the potential value of such analyses in policy decision-making (Gramlich 1977, Oster 1977, Loomis 1987).

Beyond the summary evaluation of economic consequences, BCA also provides a framework for structuring and understanding the factors and uncertainties affecting decision outcomes (Arrow and others 1996). In particular, BCA is valuable in educating policy-makers on the tradeoffs in investments during debates concerning environmental protection and improvements. As such, BCA offers some guidance for both understanding and making decisions regarding complex environmental issues.

BCA Evaluation of Stormwater Quality Management Practices

The economic evaluation method presented here is a preliminary BCA, developed for stormwater management (SWM) practice selection for a local area. Given the complexity of benefits and costs regarding stormwater management and the near ubiquity of potential locations where analysis might need to be applied, it was felt that only an expedient preliminary BCA method, allowing ready sensitivity analysis and testing of assumptions, would be suitable for this general problem. The main purpose of this method is to screen out, quickly and inexpensively, stormwater quality management practices that are highly undesirable based on their high costs relative to their pollution control benefits. This analysis is based on "likely upper bound valuation," that is, the estimated unimpaired economic values of beneficial uses considered in the report are much higher than those found in the literature to help ensure that the analysis will eliminate SWM practices only if their costs greatly outweigh their pollution control benefits (Wilchfort and others 1997, Lew and others 1997).

The benefit cost analysis method is summarized as follows:

1. *Identify receiving water reaches:* In moving downstream, stormwater often affects several receiving waters. Receiving water reaches with beneficial uses that are impaired or potentially impaired by stormwater quality runoff are identified.
2. *Identify beneficial uses of receiving water reaches:* Current and potential beneficial uses for each identified receiving water are defined. Beneficial uses of receiving waters are often defined by state regulatory agencies, but can often be identified in the field.
3. *Identify pollutants originating in stormwater that affect beneficial uses:* Identify the pertinent pollutants for each of the receiving waters based on their effect on each beneficial use and probable origin in stormwater runoff. For example, pollutants affecting contact recreational use value might include debris concentration and fecal coliform concentration.
4. *Establish pollution concentration thresholds:* Develop a relationship between beneficial uses and pollutant concentrations based on two threshold limits for each pollutant and beneficial use:
   a. Maximum concentration threshold for which a beneficial use is unimpaired by stormwater quality. Pollutant concentrations below this threshold do not limit the beneficial use.
   b. Minimum concentration threshold which eliminates a beneficial use. For concentrations above this pollution concentration, no benefit value occurs.

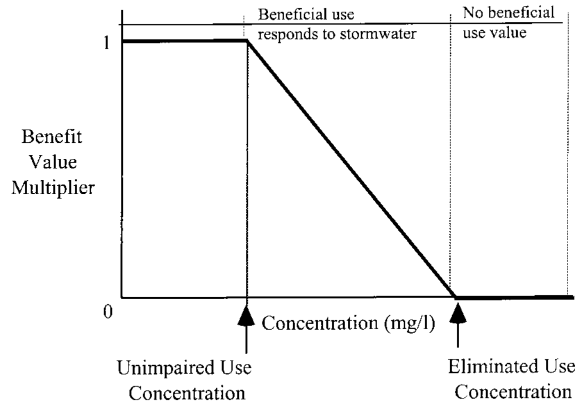

Figure 1. Beneficial use value and pollution concentration relationship.

These concentration thresholds are used as follows:

For a preliminary evaluation, in the absence of better information, a simplified representation of the relationship between beneficial uses and pollutants is based on linear interpolation between these two concentration thresholds as shown in Figure 1. The unimpaired beneficial value is weighted by the benefit multiplier calculated from the linear relationship to provide the benefit value of improved receiving water quality. A vertical step between full benefit and no benefit may occur where the unimpaired use and the eliminated use concentrations are the same; in this case the benefit multiplier is either zero or one.

It is worthwhile to note that improvements in water quality that leave concentrations above the eliminated use limit do not contribute economic benefits. Economic benefits associated with a management practice arise from an increase in beneficial uses. Where water quality cannot be improved to a level that yields some improvement in beneficial use, it is not economically efficient to employ that management practice (Mar 1981). For example, if fish are killed by contaminant levels above 10 μg/liter, then reduction of the contaminant from 50 μg/liter to 30 μg/liter does not improve the actual value of the river for fish. Similarly, improvements in water quality that reduce concentrations below already unimpaired concentrations do not substantively increase beneficial uses and their values.

In many practical engineering problems, often little is known about the relationship between beneficial use and water quality beyond such approximate thresholds. For such practical problems, there are also usually no resources to further refine these relationships.

5. *Establish current pollution concentrations:* Establish current pollutant concentrations in each identified receiving water for each pollutant affecting a beneficial use.
6. *Eliminate currently unimpaired receiving waters and unimpaired beneficial uses:* Compare the current pollutant concentrations and the threshold concentrations for unimpaired beneficial use. If all current pollutant levels are below the unimpaired limits, the receiving water does not need to be analyzed further. If a beneficial use on a receiving water is unimpaired, that beneficial use can be eliminated from further consideration. This step eliminates the expense of analyzing some waters and uses that will not be economically improved by stormwater quality improvements.
7. *Estimate economic values for unimpaired beneficial uses:* The unimpaired beneficial uses values in this analysis are based on the benefit transfer approach in which results developed for a particular study area are used in another study area for which it was not originally intended (Smith and Kaoru 1990). Values for beneficial uses obtained through literature review are used to approximate the value of beneficial uses of the receiving water that is being analyzed. Ranges of such values are often variable in the literature (Lew and others 1997, Wilchfort and others 1997), including values for relatively unique and highly valued resources.
8. *Estimate pollution concentrations with each management practice implemented:* For simple cases, pollutant concentrations in the receiving water with the implementation of management practices can be based on a mass balance on receiving water that accounts for all runoff sources. For receiving waters with small retention times such as small streams without appreciable storage of contaminants in sediments, the following mass balance equation can be used:

$$\frac{\sum Q_{\text{source}} C_{\text{source},p}}{Q_{r,p}} = C_{r,p} \qquad \forall p, r \qquad (1)$$

where: $Q_{\text{source}} C_{\text{source},p}$ is the mass flux rate of pollutant (p) in receiving water (r) from each stormwater runoff and other sources (grams per second); $Q_{r,p}$ is total flow in receiving water (r) (cubic meters per second); and $C_{r,p}$ is the concentration of pollutant (p) in receiving water (r) (grams per liter).

9. *Estimate improvement in beneficial use economic value:* Estimate the increase in the affected beneficial

use of each receiving water. The benefit value of a management measure is a function of the difference between the receiving water pollution concentration with and without stormwater management alternative. The relationship developed in step 4 (shown in Figure 1) is used to calculate the improvement of each beneficial use affected by one polluter. The relationship, represented by equation 2 is assumed to be linear, when part or all of the improvement in concentration is between the two beneficial use thresholds.

$$\Delta M_p = s_p \Delta C_p \qquad (2)$$

where: ΔM_p is the change in benefit multiplier; S_p is the slope of linear relationship (liter per gram) as shown in Figure 1; ΔC_p is the change in receiving water pollutant (p) concentration due to stormwater management (grams per liter).

The benefit value of each beneficial use is the unimpaired beneficial use value established in Step 7, multiplied by the change in the benefit multiplier:

$$B_{bu} = B_{tot} \Delta M_p \qquad (3)$$

where B_{bu} is the increase in beneficial use value due to implementation of stormwater management and change in pollutant concentration in receiving water (dollars), and B_{tot} is the unimpaired beneficial use value (dollars), from step 7.

Some beneficial uses may be affected by more than one pollutant. In the absence of additional information, three approaches were considered to account for the effect of multiple pollutants on beneficial uses: (a) interpolation, (b) averaging, and (c) use of the limiting pollutant. The interpolation method averages the benefit values within an area bounded by the upper and lower thresholds of the pollutant concentration. For example, a relationship for two pollutants affecting a beneficial use of a receiving water can be developed as shown in Figure 2. A linear interpolation can then be used to establish the value of the benefit multiplier from the area bound by the unimpaired use and no use thresholds.

The averaging method is a simple averaging of the benefit multipliers of all pollutants as if only one pollutant were important. The change in benefit multiplier is established for each pollutant individually and then averaged to produce a benefit multiplier that is used to calculate the benefit value of the management alternative.

The limiting pollutant method assumes that the

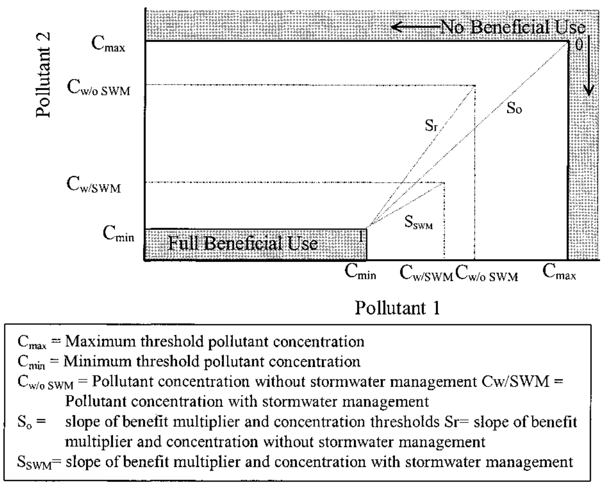

Figure 2. Interpolation method: concentration beneficial use relationship.

benefit value of a management alternative is limited by the pollutant with the most adverse impact on the beneficial use. The benefit multiplier for each pollutant is calculated separately and the smallest value is used to calculate the overall benefit value of the management alternative.

In comparing the three methods, the limiting pollutant method is likely to produce the lowest benefit estimate for beneficial use improvements and the interpolation method the highest estimate. Where beneficial uses are affected by more than one pollutant, use of the interpolation method is less likely to undervalue the benefits of water quality improvements. For maximum extent practical evaluations, the interpolation method was chosen.

10. *Estimate overall alternative benefit value:* For each receiving water, calculate the benefit value of using the management measure to improve receiving water quality. In cases where receiving water reaches have more than one impaired beneficial use, the benefit value will be calculated for each beneficial use (B_{bu}) separately and then summed to produce the total benefit value (B_r) of improving the receiving water quality as represented by equation 4.

$$B_r = \sum_{bu} B_{bu} \qquad \forall r \qquad (4)$$

11. *Estimate costs to implement the alternative:* Estimate the additional costs of implementing the stormwater management alternative based on annualized capital cost and operation and maintenance costs.

12. *Compare estimated total benefit and cost values:* Compare costs and benefits using net benefit and benefit/cost ratios to assess the alternative's economic efficiency.

Benefit–Cost Analysis for Ballona Creek

The preliminary BCA method described above was used to examine the effect of three levels of stormwater management alternatives on beneficial uses in the Ballona Creek watershed (Wilchfort and others 1997). Ballona Creek is a large hydrologic unit in the Los Angeles basin and is used to demonstrate the conduct and results of an economic analysis, following the method discussed above. Three alternative treatment methods are compared in the benefit cost analysis. Level 1, detention with screening, provides aesthetic improvement and reduction in mass loading of debris and total suspended solids (TSS). Level 2, filtration with disinfection, reduces fecal coliform concentrations and provides improvements in stormwater quality to meet recreational use standards. Level 3, advanced treatment by reverse osmosis, reduces dissolved metals and toxics concentrations and improves stormwater quality to meet all receiving water objectives as identified in the Regional Water Quality Control Board (RWQCB) Basin Plan.

Identifying Receiving Water Reaches

Ballona Creek, a formerly natural creek that carried flows from the Los Angeles River to the Pacific Ocean, was channelized and concrete-lined by the US Army Corps of Engineers in the late 1930s. Ballona Creek is currently maintained by the Los Angeles County Department of Public Works (US Army Corps of Engineers 1995). Ballona Creek extends from an extensive underground system of storm drains to a downstream outlet near Dockweiler State beach. The Ballona Creek watershed is approximately 130 square miles and serves the cities of West Hollywood, Beverly Hills, Culver City, and parts of Central Los Angeles via 48 side drains. The watershed area is 80% urbanized, with the partially developed foothills and mountains making up the remaining 20%. Ballona Creek and main tributary drains are shown in Figure 3.

The dry weather base flow in Ballona Creek consists of urban runoff from irrigation, vehicle washing, paved area washdown, illicit discharges, and permitted National Pollutant Discharge Elimination System (NPDES) discharges. Flows in the creek vary by several orders of magnitude between dry and wet seasons.

Identifying Beneficial Uses of Ballona Creek Watershed

Existing and potential uses of Ballona Creek have been designated by the RWQCB in the Water Quality Control Plan for the Los Angeles Region (California RWQCB 1994). A summary of the waterbodies' existing and potential beneficial uses as determined by the RWQCB are summarized in Table 1.

A field investigation in June 1996 revealed limited opportunities for beneficial uses (both existing and potential) on the upstream reach of Ballona Creek owing to the confined and concrete-lined nature of the channel. More significant beneficial use opportunities exist on the lower reach of the estuary and the Marina del Rey marina area. Five reaches were defined for this analysis following the viewing of Ballona Creek. The reaches are based on common beneficial uses and the possible impacts of water quality on these uses. The reaches along Ballona Creek are summarized in Table 2 and shown in Figure 3.

Identifying Relevant Pollutants Affecting Beneficial Uses

Ballona Creek water quality has been degraded by pollutants from industrial and municipal effluents as well as urban dry weather and stormwater runoff. Pollutants include high levels of debris, dissolved metals, and bacteria. High levels of DDT in sediments have been detected due to past use and discharge (California RWQCB 1994). Water quality monitoring data obtained at gauge points indicate high pollutant loads in the creek. Nevertheless, only selected pollutants appear to significantly harm existing beneficial uses along the creek. Pollutants selected for this analysis are based on their likelihood of originating from highways or their potential detrimental effect on the various beneficial uses (Lew and others 1996). The most important pollutants are debris, fecal coliform, lead, and oil and grease. Debris is the most important pollutant affecting noncontact recreation, contact recreation, and navigation. During winter months large quantities of debris in stormwater often completely halt navigation activities in the marina (one of the largest on the West Coast). High fecal coliform counts result in closure of the estuary to rowing (including a major collegiate rowing center). High coliform counts also limit fishing and shellfish harvesting activities in the marina and estuary areas. Lead may affect aquatic life and wildlife due to bioaccumulation in the food web and possibly affect harvesting and fishing. Initial results of a three-year program to investigate the correlation between stormwater discharge and environmental effects in Santa

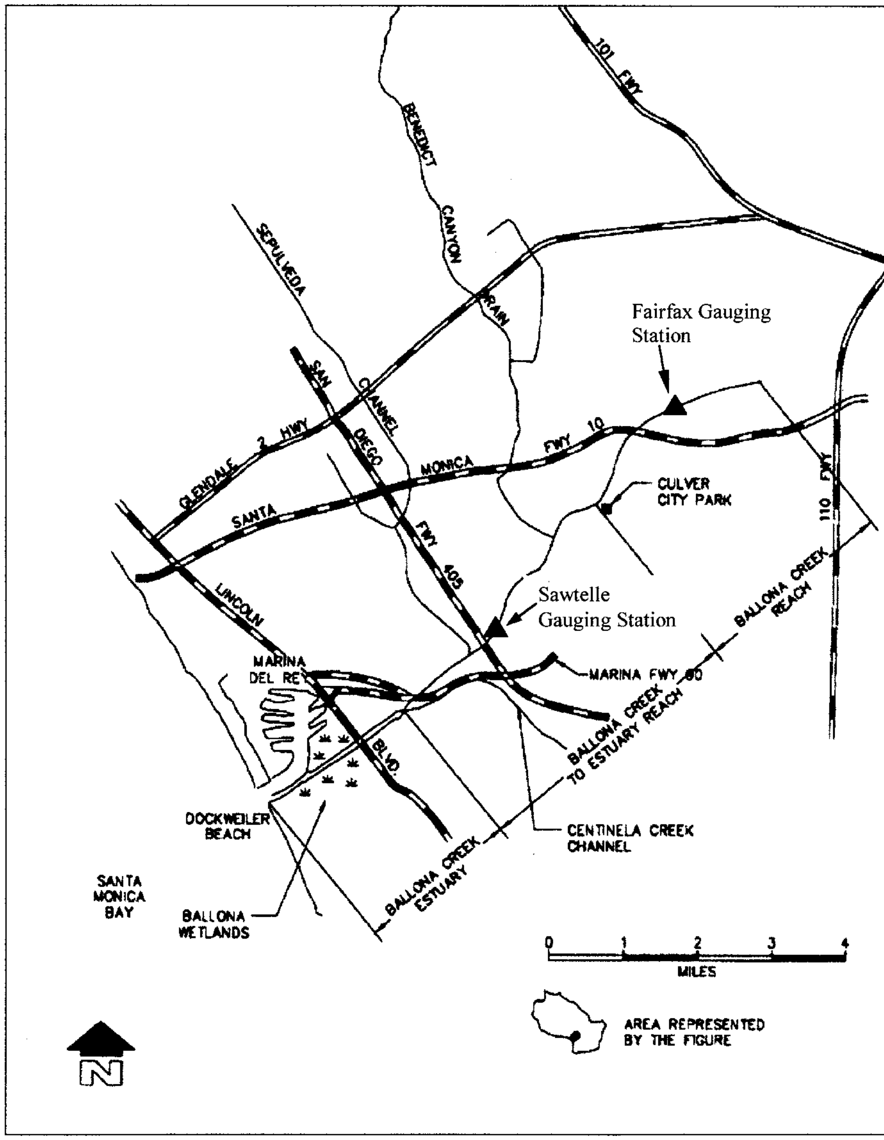

Figure 3. Ballona Creek watershed.

Monica Bay found that there are elevated concentrations of metals, including lead, directly offshore of Ballona Creek mouth. Nevertheless, examination of species richness trends across the gradient of stormwater influence did not reveal any significant relationship to stormwater discharges or sediment or interstitial water toxicity at Ballona Creek (Bay and Schiff 1996). Sufficient concentrations of lead also can raise costs of sediment disposal from the creek's outlet. Oil and grease have not been shown to have direct effects on beneficial uses, but may be aesthetically displeasing and at very high levels may harm habitat quality. A summary of the beneficial uses and the applicable pollutants considered in establishing the benefit of stormwater quality improvements for Ballona Creek appears in Table 2.

Establishing Pollutant Concentration Thresholds and Values of Beneficial Uses

The benefit of improved receiving water quality is based on the added economic value for each receiving water's beneficial uses. Given the paucity of data, a simplified linear relationship is assumed between beneficial use values and water quality (Figure 1). Two concentration limits are used to form this relationship: unimpaired use limit and eliminated use limit. An unimpaired beneficial use concentration threshold value defines the highest pollutant concentration at which a

Table 1 RWQCB designated beneficial uses[a]

Waterbody	Existing beneficial use	Potential beneficial use
Ballona Creek estuary	Navigation (NAV) Contact recreation (REC-1) Noncontact recreation (REC-2) Commercial and sport fishing (COMM) Shellfish harvesting (SHELL) Habitats: estuarine (EST), marine (MAR), wildlife (WILD), rare, threatened, or endangered species (RARE), migratory (MIGR), spawning (SPWN)	
Ballona lagoon/ Venice canals	NAV, REC-1, REC-2, COMM, SHELL Habitats: EST, MAR, WILD, RARE, MIGR, SPWN, Wetlands (WET)	
Ballona wetlands	REC-1, REC-2 Habitats: EST, WILD, RARE, MIGR, SPWN, WET	
del Rey Lagoon	NAV, REC-1, REC-2, COMM Habitats: EST, WILD, RARE, MIGR, SPWN, WET	
Ballona Creek to estuary	REC-2	Municipal water supply (MUN), REC-1, Habitat: Warm freshwater (WARM), WILD
Ballona Creek	REC-2, WILD	MUN, REC-1, Habitats: WARM

[a]California RWQCB (1994).

Table 2 Revised Ballona Creek reaches and beneficial uses[a]

Reach	Beneficial uses	Pollutants	Comments
Ballona Creek	Aesthetics	Debris Oil and grease	
Ballona Creek to estuary	REC-2 Habitats: EST, MAR	Debris Oil and grease	Bike path
Estuary	REC-1 REC-2 Habitats: EST, WILD	Debris Fecal coliform Lead toxicity Oil and grease	Rowing/small boats Bike path Birds/aquatic life
Ballona wetlands	Habitats: MIGR	Lead toxicity	
Beach and marina	REC-1 REC-2 COMM	Debris Fecal coliform Lead toxicity	Swimming Bike path Fish/Mussels
NAV	Oil and grease	Small boating	
SHELL		Large boating	

[a]See Table 1 for abbreviations.

beneficial use is unharmed by water quality or, alternatively stated, the lowest pollutant concentration at which a beneficial use becomes impaired. An eliminated use concentration threshold value represents the lowest pollutant concentration at which a beneficial use is entirely suppressed due to water quality. For pollutants identified as significant, limits are based, where possible, on water quality objectives for inland surface waters established by the RWQCB, the Los Angeles County Health Department, and the State Water Resources Control Board (SWRCB) standards. In cases where thresholds have not been determined or only qualitatively defined by the regulatory authorities, pollutant concentration thresholds were estimated for their potential impact on Ballona Creek based on literature review and expert opinion (Wilchfort and others 1997). Table 3 provides a summary of unimpaired and eliminated use concentration thresholds for the pollutants affecting Ballona Creek.

Current Pollutant Concentrations

The Los Angeles County Department of Public Works provides water quality data at two locations along Ballona Creek. Samples are taken at Fairfax Avenue in

Table 3 Pollutant concentration threshold value summary[a]

	Fecal coliform (MPN/100 ml)		Debris (tons/storm event)		Oil and grease (mg/liter)		Lead toxicity	
Beneficial uses	Full use	No use	Full use	No use	Full use	No use	Full use	No use
REC-1	400	5,000	N.A.	N.A.	0	75	150 μg/g[b]	150 μg/g[b]
REC-2	N.A.	N.A.	0	100	0	150	N.A.	N.A.
NAV	N.A.	N.A.	0	8	0	150	N.A.	N.A.
SHELL/COMM	70	70	0	8	N.A.	N.A.	8 μg/liter	50 μg/liter
Habitat	N.A.	N.A.	N.A.	N.A.	N.A.	N.A.	8 μg/liter	50 μg/liter

[a]N.A.—not applicable; MPN, most probable number; see Table 1 for other abbreviations.

[b]Sediment concentration.

Table 4 Pollutant loads in Ballona Creek at Sawtelle Gauge[a]

	Wet weather			
Pollutant	Maximum	Mean	Median	Design storm flow (m^3/sec)
Oil and grease (mg/liter)	9	3	3	
Fecal coliform (MPN/100 ml)	3,000,000	281,800	22,000	
Lead (μg/liter), dissolved	70	15	10	70
Debris (tons/event)	—	10	—	
Nonvolatile suspended solids (mg/liter)	2,150	210	110	

[a]Water quality monitoring data provided by Los Angeles County Department of Public Works, Environmental Programs Division (1994–1995 storm season).

the upper reach and at Sawtelle Avenue at the mid-reach (Figure 3). Wet weather data are available from 22 October 1987 to 11 March 1995 for the months between October and March and monthly dry weather data are available from 11 May 1988 to 5 September 1995. The total amount of debris conveyed through Ballona Creek is based on estimates from the Army Corps of Engineers (Army Corps of Engineers, Los Angeles District 1995).

The wet weather flow in Ballona Creek used for this analysis corresponds to a 1-in. rainstorm event and is based on 13–14 February 1995 records. This 1-year, 24-h storm event flow averaged 4066 m^3/sec [1547 million gallons per day (mgd)] (Brown and Caldwell 1996). Although a 1-year, 24-h design storm is used for this analysis, the use of multiple or probabilistic hydrologies, at additional time and cost, may be advisable in some cases. A summary of pollutant loads and flow in Ballona Creek used in this study appears in Table 4.

Elimination of Selected Pollutants and Unimpaired Beneficial Uses

Where treatment of flows does not reduce pollutant concentration levels sufficiently to improve the economic benefits of a particular use or where a pollutant is shown to have no degrading effect on designated beneficial uses, the pollutant is eliminated from further consideration. For example, lead concentrations in sediment dredged at the mouth of Ballona Creek appear to be below the unimpaired beneficial use limits (US Army Corps of Engineers 1995) and therefore lead was eliminated from further consideration.

Some of the potential and existing beneficial uses within the Ballona Creek watershed are either unaffected by current stormwater quality of Ballona Creek, are nonexistent, or cannot be improved with stormwater management practices. For example, the concrete-lined storm drain configuration of the channel and its adjacent land uses inherently limit recreational and habitat opportunities along most of the creek. Since this evaluation considers benefits based on incremental change in water quality, the increase in economic value from water quality improvements for these beneficial uses is very limited or zero. For these reasons, considering beneficial uses such as water supply, contact recreation, habitat designations, and wetlands will not affect the benefit–cost analysis and are eliminated from further consideration in this case (Wilchfort and others 1997).

Estimating Unimpaired Beneficial Use Economic Values

Estimating the economic value of beneficial uses under conditions unimpaired by stormwater quality is

Table 5 Values for unimpaired beneficial uses

Beneficial use[a]	Average literature values, ($/h/person)	Likely upper bound values	
		$/h/person	$ loss/day eliminated
NAV	3.6	10	48,000
REC-1	2	10	3,000
REC-2	13.8	15	180,000
SHELL/COMM	$570/day/vessel	$1000/day/vessel	12,000

[a]See Table 1 for abbreviations.

one of the most difficult steps in BCA of stormwater quality management. Review of economics literature, field investigation of Ballona Creek, and numerous interviews with agency personnel concerned with Ballona Creek helped define the economic values for beneficial uses in Ballona Creek. These values might be lower than true unimpaired beneficial uses since they are based on knowledge and perception of existing conditions. However, in most cases existing beneficial uses appear to be limited more by neighboring land use, channel design, and other features than stormwater quality.

To be conservative, a "likely upper bound value" philosophy is adopted for the valuation of benefits. Higher values than those typically found in the literature have been chosen for this analysis to ensure high benefit values and lessen the likelihood that an economically desirable management practice will be screened out.

Use values. Beneficial uses considered in the evaluation include navigation, contact and noncontact recreation, and shell and commercial sport fishing. Navigation is considered the most important beneficial use in the Ballona Creek watershed with about 550 power boats and 950 sail boats in use at the marina during peak summer weekend days. Noncontact recreation is attributed to the use of a bike path along the creek for transportation, recreation, and exercise. Contact recreation activities include swimming at the beach adjacent to the creek's outlet and rowing at the creek's estuary. Shell and commercial sport fishing is evident mostly at the marina and beach near the creek.

Values for these beneficial uses are based on studies reported in the literature. Table 5 presents a comparison between literature values and assumed unit values of unimpaired (receiving waters) and a summary of likely upper bounds for the economic values of Ballona Creek beneficial uses (Wilchfort and others 1997).

Nonuse values. Nonuse value, also termed existence value, preservation value, or intrinsic value, is the value associated with the desire to bequeath environmental resources to one's heirs or future generations, a sense of stewardship or responsibility for preserving certain features of natural resources, and a desire to preserve or enhance options for future use (Freeman 1993). Even though little debate exists regarding the importance of nonuse values, determining nonuse values has been a major issue both in the literature and in the implementation of public policy (Ohio v. USDoI 1989). Sanders and others (1990) derived nonuse values for several rivers in Colorado using the contingent valuation method (CVM) and found that, on average, the nonuse value for the typical Colorado resident for 15 rivers was $125 annually or $8 per river per year (in 1996 dollars). The 15 rivers referred to by Sanders and others were the 15 most valued rivers by Colorado residents for their recreational, aesthetic, and water quality attributes.

Ballona Creek, a channeled concrete or rip-rapped storm drain, is significantly different from the high-quality river environments that were valued by Sanders and others and would most likely have significantly lower nonuse values. Due to the unaesthetic urban character of Ballona Creek, and its neighboring land uses, it is unlikely that nonuse values would be significantly greater if stormwater quality were improved. Therefore, nonuse value is assumed to be negligible relative to the other beneficial uses and is not considered further in the evaluation.

Estimating Pollutant Concentrations with Stormwater Management Alternatives

The BCA consists of comparing benefits and costs for three levels of stormwater management/treatment that represent different pollutant removal capabilities. Level 1, detention with screening, provides aesthetic improvement and reduction in mass loading of debris and total suspended solids (TSS). Level 2, filtration with disinfection, reduces fecal coliform concentrations and provides improvements in storm water quality to meet recreational use standards. Level 3, advanced treatment by reverse osmosis, reduces dissolved metals and toxics concentrations and improves storm water quality to meet all receiving water objectives as identified in the RWQCB Basin Plan. Table 6 provides a summary of pollutant loading with and without imple-

Table 6 Loads/concentrations and changes in benefit multiplier[a]

Pollutant	Ballona Creek loads/ concentrations with treatment				Improvement in benefit (fraction of unimpaired value)			
	Existing	Level 1	Level 2	Level 3	Existing	Level 1	Level 2	Level 3
Oil and grease (mg/liter)	3	2	0	0	0	0.020	0.040	0.040
Fecal coliform (MPN/100 ml)								
REC-1	281,781	211,336	2,818	282	0	0.000	0.474	1.000
SHELL	281,781	211,336	2,818	282	0	0.000	0.000	0.000
Lead (μg/liter)	10	6	4	0	0	0.048	0.048	0.048
Debris (tons)								
REC-2	10	1	1	1	0	0.095	0.095	0.095
NAV	10	1	1	1	0	0.938	0.938	0.938

[a]See Table 1 for abbreviations.

mentation of the three different levels of SWM. These treatment alternative designs and costs were obtained from the "Storm Water Facilities Retrofit Evaluation, Draft Report" (Brown and Caldwell 1996).

Estimating Improvement in Beneficial Use Values

The effects of reduced loading from stormwater runoff are calculated based on a simple mass balance. Current pollutant concentrations at Ballona Creek are averaged values as shown in Table 4. Summaries of pollutant concentrations and changes in benefit multipliers as a result of stormwater runoff treatment are presented in Table 6.

Estimating Overall Stormwater Management Economic Benefit Value

Economic benefit estimates for economic analysis represent the dollar value associated with incremental beneficial changes in uses of the receiving water. These incremental annual benefit estimates are based on an *ex-ante* approach in which physical and economic consequences of implementing management practices are evaluated and compared to existing conditions (Freeman 1993). The economic valuation is based on present conditions and compared to future improvements. Past conditions are irrelevant to the economic analysis (Howe 1971).

Estimates of annual marginal benefits are based on a 1-year design storm and existing water quality and conditions at Ballona Creek and Santa Monica Bay. Benefits are assumed to be uniform for all years that a management practice is employed. Even though pollution at Ballona Creek and the bay will conceivably change with time, it is impractical to determine the degree and direction of change due to a multitude of uncertainties related to pollution sources. Changes in population, vehicle traffic, and social make-up of the Ballona Creek watershed, changes in uses of receiving waters, and technological advancements can all contribute to either improvement or degradation of future water quality and beneficial uses at Ballona Creek and the bay. Due to the difficulties in characterizing future changes in water quality, this preliminary economic valuation assumes a fixed water quality and beneficial uses based on existing conditions.

Benefit estimates assume that all existing beneficial uses are impaired 40 days annually. This assumption exceeds the average number of days each year Ballona Creek is closed to rowing practice, the most impaired and sensitive use identified. This number of closure days is supported by a worst-case analysis of rainfall records that indicate a maximum of 22 events (greater than 0.5 in. rainfall) annually over 35 years of record. For this worst year, approximately 50 closure days would have occurred (assuming a 48-h period of no use following a rainstorm).

Estimating Costs of Implementing Stormwater Management

Annualized costs of treatment alternatives are based on capital costs and operation and maintenance for 20 years incorporated into a present worth cost estimate using a 4% discount rate as the assumed difference between the cost to borrow money or service bond debt and its potential earnings from investment opportunities (Brown and Caldwell 1996). Estimated costs and benefits for the three treatment alternatives analyzed are summarized in Table 7.

Comparison of Benefits and Costs for Stormwater Management Alternatives

The economic evaluation may lead to the exclusion of a potential stormwater management practice if its cost of implementation greatly outweighs its pollution

Table 7 Comparison of annualized benefits and costs ($1000/yr)

Treatment level	Cost	Benefit	Net value	B/C ratio
Existing	0	0	0	0
Level 1	168,166	1,492	−166,674	0.0089
Level 2	262,170	1,613	−260,557	0.0062
Level 3	418,672	1,644	−417,028	0.0040

control benefits. Benefit–cost ratio and net economic value for the three treatment alternatives are summarized in Table 7. Net benefit values range from $166 million to $417 million per year and benefit–cost ratios are well below 1. These results clearly indicate that it is not economically desirable to implement any of the alternatives considered in this analysis. There are socially better investments commonly available for these costs, and there are likely to be much more environmentally effective investments as well.

Sensitivity of Results to Assumptions

In conducting an economic evaluation, as with almost any analysis, many assumptions are required. Although erroneous assumptions can be negligible or can cancel each other out, some thought should be given to how likely it would be that assumptions could be so far off as to change the conclusions of the analysis. For this study, we tried to select unimpaired valuations, interpolation methods, receiving water concentrations, and annualization calculations that overstate the beneficial value of potential stormwater management practices.

Nevertheless, it might be useful to delimit the robustness of our conclusions by calculating how much we would have to have erred in our estimates of the value of beneficial uses to change the study's conclusions. Benefits would have to increase by more than 10,000% to change study results. These results appear in Table 8. Additional sensitivity analysis appears in the original report (Wilchfort and others 1997). The conclusion that the three treatment alternatives fail the economic analysis appears to be rather robust.

Many stormwater quality management practices are available from the literature (APWA 1981, SWQFT 1993). This study examined the economic desirability of only three treatment alternatives for Ballona Creek. Other, less expensive alternatives or source reduction alternatives might be considered. However, to be economically desirable, such alternatives would have to retain similar levels of effectiveness as the examined treatment measures at costs several orders of magnitude less.

Table 8 Benefit increases required to alter economic evaluation conclusions

SWM level	Value of increase ($1000/yr)	Increase in benefits (%)
Level 1	166,674	11,200
Level 2	260,557	16,200
Level 3	417,028	25,400

SWM: stormwater management.

Table 9 Pollutant loads from state highway facilities

Pollutant	Load/ concentration	Design storm flow (m^3/sec)
Oil and grease (mg/liter)[a]	15	
Fecal coliform (MPN/100 ml)[a]	1600	2.2
Lead (μg/liter)[a]	50	
Debris (tons/event)	0.14	
Nonvolatile suspended solids (mg/liter)[a]	125	

[a]Caltrans District 7 Storm Water Monitoring.

Comparison of One Polluter and Basinwide Treatment

The economic evaluation was extended to compare the economic efficiency of one source treating its runoff versus basinwide runoff treatment. State highways contribute stormwater runoff to Ballona Creek. The estimated flow from state highways and the associated drainage area during a 24-h 1-year design storm is 2.2 m^3/sec (49 MGD). A summary of pollutant loads/concentrations and flow from state highways appears in Table 9.

The results of the economic evaluation for stormwater management of state highway runoff are similar to those obtained based on basinwide runoff treatment; none of the three treatment alternatives were found to be economically efficient. Furthermore, a comparison of results from basinwide treatment and state highway runoff treatment clearly demonstrates that basinwide treatment is much more cost effective than one polluter treating alone. Table 10 provides a summary and comparison of the economic results of basinwide and state highway runoff treatment for the three treatment alternatives.

Table 10 Benefit/cost ratio and annual net economic value ($1000)

	Existing		Level 1		Level 2		Level 3	
Treating entity	Net value	B/C ratio	Net value	B/C ratio	Net value	B/C ratio	Net Value	B/C ratio
State highway	0	0	−15,041	0.0014	−17,080	0.0021	−24,835	0.0015
Basinwide	0	0	−166,674	0.0089	−260,557	0.0062	−417,028	0.0040

Extending Economic Evaluation to Other Areas

The preliminary economic evaluation approach demonstrated here has potential for extension to other stormwater quality management problems and other environmental problems generally. While the approach is preliminary, it is relatively easy to explain, requires a commonly available amount of data, is inexpensive and fairly rapid, and provides a structured economically based approach to stormwater management. However, some thought should be given to such extensions.

The results of such preliminary analyses are most useful if they are clear-cut, as they appear to be for Ballona Creek. Were the net costs much closer to the net benefits, within a factor of two or perhaps even ten, then the conclusions regarding economic desirability might become debatable, given the uncertainty of the assumptions. But where results are clear-cut, a preliminary economic analysis can demonstrate economic desirability or, conversely, economic inefficiency quickly and inexpensively. This analysis required roughly six weeks and five person-months of effort. At the very least, such preliminary economic analysis should help stormwater management deliberations and planning become more focused, productive, and rapid, with benefits for all parties.

The clear conclusions of this study are likely to hold for other similar basins in the Los Angeles area. Most of the highly urbanized watersheds in the region would appear to have fewer beneficial uses with lower unimpaired economic values. Therefore, the stormwater quality management alternatives examined here are unlikely to be significantly more attractive in other highly urbanized watersheds. However, the mix of beneficial uses (including greater importance of habitat), potential for lower costs of management alternatives, and potential for higher beneficial use values when unimpaired by water quality might lead to further studies being desirable.

Stormwater Quality Management Policy Implications

Several policy implications can be drawn from this work. First, there are limits to the economic and social desirability of stormwater quality management practices. These limits can be roughly, but often effectively, ascertained using benefit–cost analysis.

Second, the economic value of many urban streams may not be limited by stormwater quality. Such streams typically have neighboring land-uses and storm drainage systems planned and designed without intent to foster beneficial uses of receiving waters. Indeed, often these land-use and storm drainage systems have been designed to exclude people and wildlife to improve the safety, hydraulic, and financial performance of these systems.

Third, BCA can help identify the extent stormwater runoff affects beneficial uses prior to committing limited resources for treating stormwater runoff. BCA further allows the explicit, although approximate, quantification of overall performance among different environmental and infrastructure investments and local planning alternatives. In the case of Ballona Creek, the treatment alternatives examined did not appear to be worthwhile social investments. However, among the treatment alternatives, basinwide treatment alternatives showed greater promise (by B/C ratio) than treatment by only a single major landowner. In the case of Ballona Creek it appears that stormwater treatment is unlikely to be economically justifiable without a basinwide approach and substantial modification of the neighboring land-use and drainage system.

Fourth, BCA provides an analytical framework for structuring and organizing discussion of stormwater quality discussion and management. This particular framework has the advantages of being fairly easy to communicate, having a rigorous theoretical/social welfare basis, and consistency with accepted planning approaches in other public areas, particularly in water resources and transportation.

Conclusions

This study demonstrates the usefulness of preliminary benefit–cost analysis as a screening method for maximum extent practicable (MEP) analysis, identifying promising management practices and identifying societal and economic tradeoffs for local stormwater problems at locations with relatively uncomplicated water quality processes.

The Ballona Creek evaluation demonstrates the usefulness of a simplified benefit cost analysis (BCA) in addressing stormwater quality problems. Despite limited information and numerous uncertainties in developing the relationships between beneficial uses and pollutant concentrations, the analysis in this case provided unambiguous recommendations for stormwater quality management. At times, a simplified BCA can be done for stormwater quality management quickly and inexpensively, and if done carefully, the simplifications will not jeopardize the quality of recommendations.

The Ballona Creek example demonstrates the economic limits of stormwater management in an urban region. Treatment of storm flows into Ballona Creek was found to be far from economical, and there appeared to be no reasonable changes in the analysis assumptions that would have resulted in recommending any of the stormwater treatment options examined. Most beneficial uses were found to be relatively unaffected by stormwater quality, but rather limited by factors related to the urban nature of Ballona Creek's surrounding and hydraulic design. In modifying Ballona Creek into a concrete lined drain, some uses of the upstream reaches of the creek, such as recreation, habitat, and aesthetics have been implicitly negated. This finding suggests that benefit of stormwater quality improvement might be far greater in urban areas if accompanied by comprehensive redesign of the drainage network and neighboring land uses. In addition, the Ballona Creek example attests to the value of basinwide coordination of stormwater management compared to uncoordinated management of one landowner.

The limited economic desirability of stormwater management for Ballona Creek, a highly urban creek, may be similar in other urban settings. This has implications for national urban stormwater quality management and policy, the development of cost-effective regional water quality management plans, and the distribution of limited resources for improving stormwater quality.

This study demonstrates the usefulness of benefit–cost analysis for environmental problem-solving. Benefit–cost analysis probably should not be the sole approach used for environmental planning and policy analysis. However, its use can help eliminate clearly uneconomical alternatives and focus on more promising planning and policy alternatives. In addition, the BCA framework provides a basis for organizing deliberations of complex problems.

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