THE USE OF PRESENT VALUE CRITERION APPLICATIONS IN MAKING MOSQUITO CONTROL DECISIONS[1]

DOUGLAS D. OFIARA AND JOHN R. ALLISON

Department of Agricultural Economics, University of Georgia, Georgia Experiment Station, Experiment, GA 30212

ABSTRACT. Present value criterion in mosquito-control decisions was presented with several examples that illustrate its applicability and the modifications it allows. An actual case study from data derived in Chatham County, GA was presented. Findings of this case study suggest that permanent control contributed to the reduction of ground adulticide applications and quantities, adult densities of female mosquitoes per light-trap night, and the proportion of primary target salt-marsh species relative to total species per light-trap night.

INTRODUCTION

In recent times more concern has been placed on government budgets including federal, state and local municipalities, with mosquito control districts (MCD) being no exception. Budgets are becoming more closely scrutinized by local county commissions with the result that MCD directors must increasingly justify their budget proposals and sometimes their operations. When formulating budget proposals and mosquito control measures, directors usually consider options in the long-term to achieve best control of mosquitoes within their jurisdiction. These alternatives usually involve the use of two basic control measures; temporary control involving the use of larvicides and adulticides, and permanent control also known as source reduction which involves physical alterations of wetlands and other areas, e.g., ditching and pond construction.

Over time, however, comparisons of projects of different scale (size) and time periods can be complicated. The application of present value analysis of such complications in mosquito control decisions is presented in this paper.

METHODOLOGY AND APPLICATION

Present value criterion (sometimes known as investment criterion) is the technique that economists use to compare costs and/or benefits of various projects over time, to decide among projects and select a "best."

Cost-effectiveness analysis and benefit-cost analysis (variations of present value criterion) are often confused. The former concerns the minimum cost way to achieve a given objective. One criticism is that by ignoring benefits this method does not address the economic rationale of achieving the given objective. Hence, this procedure is appropriate when considering how the project can be implemented least expensively (Randall 1981). Benefit-cost analysis considers both the benefits and the costs associated with a project, thus it considers economic justifications determining the implementation of a project, that is whether the outcome of a project is worth the costs of achieving it.

Investment decisions and the choice among various projects involve a time element in most cases and a concern among economists is to properly evaluate present and future dollars. This is usually accomplished through the mechanism of discounting.

Permanent control projects may have both front end investment—initial investment upon starting the project (e.g., purchase of machinery)—and a cost outlay (e.g., operating expense) in the base period as well as over a time horizon, and have an effective life also over some time horizon. Temporary control projects could have front end investment as well as cost outlays over a time horizon, but, have no effective life other than the current time horizon, since the effective life of currently used chemicals is designed to be short lived (i.e., no residual effect).

The basic present value (PV) formula for benefit-cost analysis is:

$$1)\ PV = -C_0 + \frac{(B-C)_1}{1+r} + \frac{(B-C)_2}{(1+r)^2} + \ldots + \frac{(B-C)_n}{(1+r)^n}, \text{ or}$$

$$2)\ PV = -C_0 + \sum_{i=1}^{n} \frac{(B-C)_i}{(1+r)^i}, \text{ and}$$

$$3)\ PV = \sum_{i=1}^{n} \frac{(B-C)_i}{(1+r)^i},$$

[1] Financial support of this report has been provided by the U.S. Environmental Protection Agency under Assistance Agreement No. CR-809369-02-0 to the University of Georgia. It has not been subjected to the Agency's required peer and administrative review and therefore does not necessarily reflect the views of the Agency and no official endorsement should be inferred.

where C_0 refers to the initial cost outlay, B the benefits in each period, C the costs in each period, r the discount rate, and n the time period (Herfindahl and Kneese 1974:197). These three formulas are appropriate for projects that realize costs and benefits over a time period. The present value of net benefits (benefits less costs, discounted) is the appropriate measure for comparing projects (e.g., temporary versus permanent control) over time given equal scale and time period. The decision criterion is to select that project with the maximum present value of net benefits over time. If we just want to examine project costs (i.e., cost effectiveness) the formulas can be easily modified, written as:

$$4)\ PV = C_0 + \sum_{i=1}^{n} \frac{C_i}{(1+r)^i}, \text{ and}$$

$$5)\ PV = \sum_{i=1}^{n} \frac{C_i}{(1+r)^i}.$$

In this case the present value of costs is the appropriate measure for comparing projects over time. The decision criterion is to select that project with the smallest present value of costs over time. These formulas can also be used when benefits realized from alternative projects are equal, that is, one only needs to consider comparative costs since the only concern is to provide a project in the cheapest way possible (Steiner 1966).

In addition to the above formulas a ratio of discounted benefits to discounted costs is sometimes used in evaluating projects:

$$6)\ B/C \text{ ratio} = \frac{\sum_{i=1}^{n} B_i/(1+r)^i}{\sum_{i=1}^{n} C_i/(1+r)^i}.$$

When benefits equal costs this ratio will equal 1, hence if this ratio is greater than 1 benefits will be above costs. The use of this ratio is not without controversy among economists. Most agree that selection of a project should not be based solely on the B/C ratio, it should be used in conjunction with discounted net benefits to rank alternative projects (Margolis 1959, Herfindahl and Kneese 1974:192). Also most agree that maximizing the B/C ratio in order to select a project is inappropriate (Herfindahl and Kneese 1974:191–192, Eckstein 1958:64). Where most economists would discourage the use of the B/C ratio concerns aggregate (i.e., total) benefit—cost comparison of projects, conversely most agree that B/C ratio is useful in examining incremental (i.e., marginal) benefits and costs associated with the project in each period (Herfindahl and Keneese 1974:192, 194; Eckstein 1958:73, 126). The association between *total* benefits and costs with *marginal* benefits and costs in project choice will lend perspective on the latter point. Recall the decision criteria for net benefits, choose that project with maximum discounted net benefits. Maximization of discounted net benefits (total benefits less total costs) occurs where discounted marginal benefits (MB) equal discounted marginal costs (MC) or where the ratio of discounted MB to discounted MC is equal to 1.

For most applications, equations (3) and/or (5) apply and are meant for projects that accrue both costs and benefits or just costs alone in the base period (year 1) and so on. Equations (1–2) and/or (4) only apply if an initial cost outlay immediately upon starting the project is necessary (e.g., purchase of required equipment) along with costs and benefits in the base and successive periods.

When comparing projects of unequal scale (size), use of capital investment, and time frame the decision criterion for both net benefit and cost-effectiveness analysis changes; the following points apply. The B/C ratio, equation (6), is useful in comparing alternative projects of unequal scale only when no extreme variation in scale (referred to as capital intensity) is present (Eckstein 1958:55). In a sense the ratio reduces the scale factor; consider two projects one twice the size of the other so that all proportions are equal, then the ratios will be the same. But, this raises another issue concerning the use of capital investment in the project, i.e., front end investment versus rationing of capital investment among various periods through the project's life similar to annual operating expenses. Then the criterion and comparison become more complicated (see Eckstein 1958 for a more detailed discussion). When faced with unequal time frames in comparing projects, the time frames should be made compatible. This can be accomplished by carrying out the shorter project to an equal time period in which the comparison is to be made or by using a least common denominator (LCD) to determine equivalent time periods (e.g., a 3 year and 5 year project have a LCD of 15 years).

The literature is rich with discussion of the appropriate discount rate to use (see Herfindahl and Kneese 1974, Bohm 1976, Mishan 1976). Generally, if costs (or net benefits) are in real terms (after inflationary effects are removed)—constant dollars—the real discount rate should be used; if costs (or net benefits) are in nominal terms (current dollars) the nominal discount rate should be used (Just et al. 1982). Real rates of discount from empirical economic studies are in the range of 0–4% and nominal rates range 8–16% (Just et al. 1982:305–306). The following digression will help to distinguish between real terms (constant dollars) and nominal terms (current dollars). Current dollars reflect the value of the dollar with inflationary effects for each time period. For example, if a project over 1978–88 is to be evaluated, costs for each period *unadjusted* for inflation so that the stream of costs would be in 1978 dollars, 1979 dollars and so on would represent current dollars. If, however, the stream of costs were *adjusted* for inflation using an index (consumer price index or producer price index from the Survey of Current Business, U.S. Department Commerce), the costs could be indexed to 1967 dollars or 1978 dollars or any year for that matter and represent a constant dollar measure. That is, constant dollars are current dollars *adjusted* for inflation. Most current applications adjust to 1967 dollars if constant dollars are used.

The analyst must then identify benefit and cost items, quantify and value these benefit-cost items, choose a time horizon and discount rate and face an investment constraint. Identification of benefits and costs as well as valuation can become difficult. Some general points and concepts will provide assistance. Benefits and costs can be both direct and indirect, with the former being any benefits and costs that result from the project (mosquito control) to the investment company (here the MCD). Indirect benefits and costs are more subtle in nature and can be thought of as any effects that result from mosquito control and do not accrue to the MCD, that is, any benefits and costs from mosquito control that accrue only to society. Also, economists separate benefits and costs into private and social benefits and costs. These arise when economists think of society in general and the resulting effects the project will have on society. If these are equivalent to benefits and costs to the local MCD, then no divergence exists. An example on the cost side are negative benefits (or environmental costs) from control activities which represent indirect costs and can be thought of as social costs in the sense that society has to bear the burden, e.g., environmental effects of insecticides as pollutants (for further discussion of these concepts see Bohm 1976, Mishan 1976, Gittinger 1972, Eckstein 1958).

Both temporary and permanent control projects can realize benefits. Benefits in an economic sense are usually measured from the area under a demand curve for a market good. Because a demand curve reflects amounts people would be willing to pay rather than forego consumption of the good in question, the concept willingness-to-pay (WTP) is a representative measure of benefits (Eckstein 1958, Bohm 1976, Just et al. 1982). Consider a market good such as hydroelectric power. Benefits to the consumer would be equivalent to the maximum amount he or she would be willing to pay for electric power rather than be without it; this represents gross benefits. But the consumer is charged for this energy consumption which represents both costs to the consumer and revenues that accrue to the hydroelectric project (this measure has been used in studies to represent benefits, see Eckstein 1958). The difference between gross benefits and costs to the consumer (or revenues to the project) represents net benefits and is known as consumer surplus (the area under a demand curve above costs). It should be clear that using revenues alone would understate benefits, consumer surplus must be added to revenues (Bohm 1976:95, Prest and Turvey 1965).

However, for goods such as public mosquito control that are characterized by an absence of a market (public/nonmarket goods) the WTP concept is still appropriate although benefit estimation becomes more complex. One approach that has received much attention lately involves consumer surveys (see Kneese 1984, for a recent summary of this work).

Another concept, alternative costs, used in this paper, has also been used to represent benefits (Eckstein 1958, Herfindahl and Kneese 1974, Gittinger 1972, Mishan 1976). Where two alternative projects are available and only one project can be adopted (in our example the MCD chooses permanent control), the costs of the other project can be thought of as resources released and available for use in still other projects or requirements. If the project adopted has cheaper costs than the alternative project, the difference in costs can be interpreted as a benefit to the project adopted (Herfindahl and Kneese 1974:267–270, 276–279, Eckstein 1958:52–53, 167–169; Mishan 1976:4, 27–28).

CASE EXAMPLES

Consider an MCD director facing a choice between controlling a salt-marsh area 750 acres in size with temporary or permanent control measures. The director has a budget of $150,000 to allocate for this project and is considering a 10-year time period with projected costs in current dollars, and 1983 is the base period (Table 1). Using a discount rate of 8% the PV for temporary control is $39,442. The director expects that it will take at least 10 years to alter this 750 acre salt-marsh area with permanent control measures. Distributing the costs equally over 10 years the PV is $44,175. If the

Table 1. Hypothetical cost comparisons of a temporary control project versus a permanent control project on a 750 acre salt marsh area, 1983.

Year	Temporary control		10-Year permanent control		20-Year permanent control		10-Year permanent control project							
							Adjustments to costs[a]							
	Projected costs	Present value	Projected costs	Present value	Projected costs	Present value	Maintenance	Chemical control	Spot treat.	Total	Projected benefits[b]	Projected costs[c]	Projected net benefits[d]	Present value
	-dollars-													
1983	6,483	6,003	6,583.5	6,096	3,291.75	3,048	-	6,483	-	6,483	-	13,066.5	-13,066.5	-12,099
1984	4,589	3,934	6,583.5	5,644	3,291.75	2,822	-	4,589	-	4,589	-	11,172.5	-11,172.5	-9,579
1985	4,312	3,423	6,583.5	5,226	3,291.75	2,613	-	2,000	-	2,000	2,312	8,583.5	-6,271.5	-4,979
1986	2,416	1,776	6,583.5	4,839	3,291.75	2,420	-	500	-	500	1,916	7,083.5	-5,167.5	-3,798
1987	12,047	8,199	6,583.5	4,481	3,291.75	2,240	-	1,000	2,500	3,500	11,047	10,083.5	963.5	656
1988	6,974	4,395	6,583.5	4,149	3,291.75	2,074	1,000	1,000	1,700	3,700	5,974	10,283.5	-4,309.5	-2,716
1989	5,469	3,191	6,583.5	3,841	3,291.75	1,921	1,000	0	1,000	2,000	5,469	8,583.5	-3,114.5	-1,817
1990	2,520	1,361	6,583.5	3,557	3,291.75	1,778	1,000	0	500	1,500	2,520	8,083.5	-5,563.5	-3,006
1991	6,108	3,056	6,583.5	3,293	3,291.75	1,647	1,000	0	1,000	2,000	6,108	8,583.5	-2,475.5	-1,238
1992	8,860	4,104	6,583.5	3,049	3,291.75	1,525	1,000	0	1,000	2,000	8,860	8,583.5	276.5	128
10-year total	59,778	39,442	65,835	44,175	32,917.5	22,088	5,000	15,572	7,700	28,272	44,206	94,107	-49,901	-38,448
1993					3,291.75	1,412								
1994					3,291.75	1,307								
1995					3,291.75	1,210								
1996					3,291.75	1,121								
1997					3,291.75	1,038								
1998					3,291.75	961								
1999					3,291.75	890								
2000					3,291.75	824								
2001					3,291.75	763								
2002					3,291.75	706								
20-year total					65,835	32,320								

Note: All figures are in current dollars. Present value computed using a discount rate of 8%.

a. Adjustments to permanent control project costs are decomposed into annual maintenance costs, chemical control costs required until the permanent control measures assist in control efforts, and spot treatment for emergency suppression during mosquito outbreaks.

b. Projected benefits in this example are defined as the direct cost savings from less reliance on chemical control resulting from the effectiveness of permanent control measures.

c. Projected costs in this case are the sum of adjustments to permanent control costs plus the projected costs of the 10-year permanent control project.

d. Net benefits are the difference between benefits and costs. In the absence of benefits as in the first 2 examples, net benefits are synonomous to project costs (always showing a loss).

costs of the permanent project were spread equally over a 20-year period the corresponding PV is $32,320. To make the proper comparison of the two alternative control projects (temporary versus permanent), equal time periods should be used. This means that the temporary control project costs should be projected and discounted over 20 years. Still this example is not quite realistic because of additional costs not considered.

Permanent control projects may incur additional costs in the form of: 1) annual maintenance costs, 2) temporary chemical control measures necessary until the entire area has been altered either by ditching or pond construction for example, and 3) emergency or spot chemical control on an as-needed basis if conditions are such that mosquito population outbreaks occur. Up to this point we have only considered costs and the present value criterion is designed to consider both costs and benefits of alternative projects.

In our example, benefits to permanent control that are measurable consist of cost savings from less reliance on chemical control measures. Assume that the MCD director expects to reduce chemical control over the area undergoing permanent control once a quarter of the area has been altered which will take 2–3 years. After this the director expects chemical control measures to decrease to zero in the tenth year (1992), although spot treatment will still be used on an as-needed basis. Projected costs for these adjustments to permanent control, maintenance costs, chemical measures and spot treatment appear separately in Table 1. In addition, projected benefits also appear. The procedure now is to subtract the costs from benefits to arrive at the net benefits of this permanent control project.

When net benefits are negative either from the absence of project benefits or when benefits are less than project costs, the decision criterion is to select that project that realizes the smallest absolute value of discounted net benefits. In the absence of benefits this will be synonymous to project costs. Thus, it makes sense to select that project with the smallest PV of costs (the criteria used in the previous example).

However, the criterion changes when comparing projects that yield positive net benefits. Generally, the project to be selected will be one that produces the largest net benefits (maximum PV of net benefits), other things being equal (e.g., project scale and time period).

In the present example project benefits are greater than costs in only 2 years (1987 and 1992). Projected net benefits reflect the fact that over-all direct benefits are less than costs realizing a negative net benefit. Based upon an 8% discount rate the PV of net benefits is −$38,448 for this 10-year permanent control project in comparison to −$39,442 for the temporary control project.

It must be emphasized that this example only considers direct benefits in the form of cost savings from reduced chemical control. As a result net benefits can be negative. In general, however, mosquito control is undertaken because society believes benefits from control outweigh costs.

CASE STUDY

The following example is based on actual data from the Chatham County Mosquito Control Commission (CCMCC), Savannah, GA. The areas selected for this comparison were chosen so as to depict areas with equal characteristics (e.g., proximity to salt marsh areas, size, etc.) and with mosquito density influences from internal sources with little or no influence from external sources. The latter criterion was most crucial to examine the effects of control activities in the selected areas. The community of Thunderbolt was selected to represent a temporary control project and Isle of Hope the permanent control project. In this case study we do not know beforehand that investment (costs) nor level of control in the permanent control project is greater than or less than the temporary control project.

Over the study period 1962–83, for the purpose of this example, Thunderbolt mainly underwent temporary control efforts, while Isle of Hope was impacted by both temporary and permanent control efforts. Isle of Hope is located close to Skidaway Island so that permanent control on Skidaway Island assisted in controlling salt-marsh mosquitoes at Isle of Hope. Figure 1 illustrates both communities as well as the area that was ditched (shaded area) on Skidaway Island.

The ditching projects on Skidaway Island commenced in 1962, then continued off-and-on and were completed in 1968. Maintenance costs were only realized during this same period with tidal flushing occurring, thereby not requiring further maintenance. In addition, Isle of Hope underwent ground adulticiding efforts. Table 2 contains the deflated (constant) costs for all these activities, as well as temporary control costs for Thunderbolt (note that all figures are in constant terms, 1967 = 100, U.S. Department of Commerce 1980, 1983, 1984).

For the purposes of this application: 1) the study period (1962–83) was treated as if the MCD director is back in the 1962 period and faces an investment decision in the future; and 2) benefits to the permanent project were defined as cost savings resulting from less reliance on chemical control, the difference in annual ground adulticiding spray applications between Thunderbolt and Isle of Hope beginning in 1973. This figure was computed from the product of applications not required and the mean adulticiding cost per application for each year. Net benefits were then derived and discounted at 4% resulting in a total PV of −$24,664 over 1962–83 (Table 2).

This is compared to a PV of −$9,947 associated with the temporary control project over the same period (Table 2). In this case the temporary control project realizes less costs than the permanent control project.

Assuming that the source reduction and maintenance costs should be distributed equally over the project period (1962–83), the PV of net benefits for the permanent project becomes −$12,453. If the analysis is carried for an additional 5 years (1962–88), the PV of net benefits for the permanent control project becomes −$11,193 and those for the temporary control project −$12,582 (Table 2).

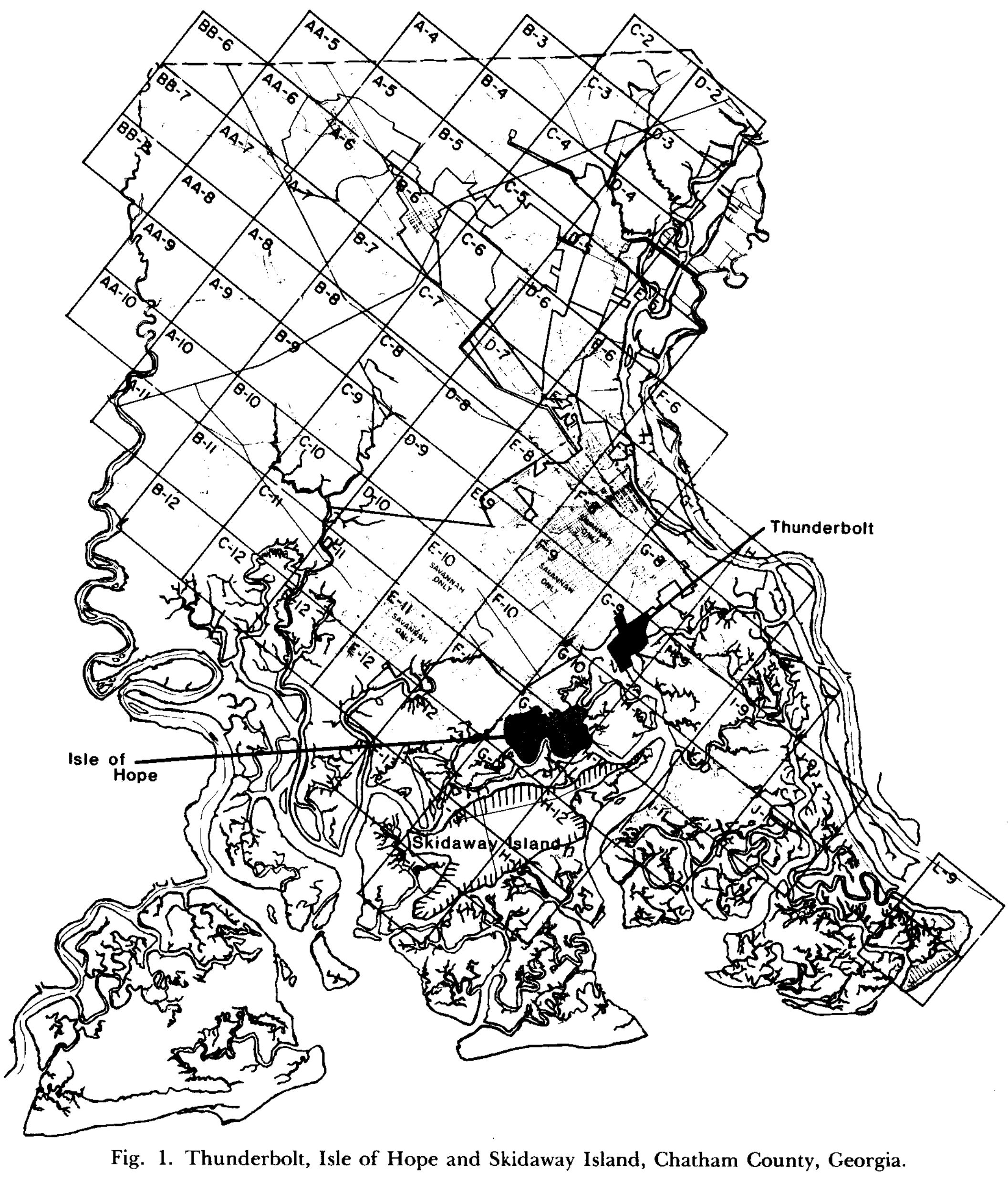

Fig. 1. Thunderbolt, Isle of Hope and Skidaway Island, Chatham County, Georgia.

Table 2. Benefits, costs and present value for comparison of a permanent control project (Isle of Hope) with a temporary control project (Thunderbolt), Chatham County, Georgia, 1962-88.

	Permanent control project costs and benefits							Temporary control project[d]		Permanent control project[e]			
	Adjustments to costs												
Year	Source reduction	Maintenance	Temporary control	Total costs	Benefits[a]	Net benefits[b]	Present value[c]	Costs	Present value[c]	Costs	Benefits[a]	Net benefits	Present value[c]
	dollars												
1962	2,538	-	NA	2,538	-	-2,538	-2,440	NA	NA	1,122	-	-1,122	-1,079
1963	6,737	290	596	7,623	-	-7,623	-7,047	769	-711	1,694	-	-1,694	-1,566
1964	5,271	1,191	875	7,337	-	-7,337	-6,522	480	-427	1,950	-	-1,950	-1,734
1965	-	93	303	396	-	-396	-338	531	-454	1,348	-	-1,348	-1,152
1966	3,508	610	585	4,703	-	-4,703	-3,866	543	-446	1,590	-	-1,590	-1,307
1967	1,817	357	768	2,941	-	-2,941	-2,324	912	-721	1,728	-	-1,728	-1,366
1968	639	98	662	1,399	-	-1,399	-1,063	757	-575	1,574	-	-1,574	-1,196
1969	-	-	911	911	-	-911	-666	973	-711	1,775	-	-1,775	-1,297
1970	-	-	602	602	-	-602	-423	586	-412	1,416	-	-1,416	-995
1971	-	-	136	136	-	-136	-92	111	-75	901	-	-901	-609
1972	-	-	251	251	-	-251	-163	220	-143	978	-	-978	-635
1973	-	-	599	599	171	-428	-268	621	-388	1,287	368	-919	-574
1974	-	-	370	370	271	-99	-59	645	-387	991	727	-264	-159
1975	-	-	212	212	151	-61	-35	400	-231	775	554	-221	-128
1976	-	-	230	230	316	86	48	580	-322	756	1,040	284	158
1977	-	-	479	479	261	-218	-116	639	-341	969	528	-440	-235
1978	-	-	389	389	272	-117	-60	732	-376	842	590	253	-130
1979	-	-	372	372	966	594	293	1,882	-929	789	2,051	1,262	623
1980	-	-	351	351	585	234	111	1,303	-618	730	1,216	487	231
1981	-	-	496	496	674	177	81	1,302	-594	843	1,143	301	173
1982	-	-	270	270	541	270	119	1,143	-502	595	1,190	595	261
1983	-	-	395	395	790	395	167	1,382	-583	707	1,415	707	299
Total*	20,509	2,637	9,853	32,999	4,998	-28,000	-24,664	16,513	-9,947	25,361	10,822	-14,539	-12,453
1984	-	-	-	-	-	-	-	1,403	-569	733	1,403	670	272
1985	-	-	-	-	-	-	-	1,403	-547	733	1,403	670	262
1986	-	-	-	-	-	-	-	1,403	-526	733	1,403	670	252
1987	-	-	-	-	-	-	-	1,403	-506	733	1,403	670	242
1988	-	-	-	-	-	-	-	1,403	-486	733	1,403	670	233
Total*	-	-	-	-	-	-	-	23,525	-12,582	29,024	17,837	-11,186	-11,193

Note: Dollars are constant (real) dollars deflated by the producer price index (PPI=1967) for selected cost categories (e.g. pesticides, fuel, labor, and machinery and equipment) and then aggregated. Costs presented are aggregated costs. NA refers to not available.

* Columns may not add precisely due to round-off error.

a. Benefits defined as cost savings from less ground adulticiding sprays in Isle of Hope compared to Thunderbolt. Assumes that if the permanent control project had not been implemented, Isle of Hope would have required the same number of spray applications as Thunderbolt (see Table 3 for this comparison).

b. Net benefits defined as benefits less costs.

c. Present value is the discounted value of net benefits using a real discount rate of 4%.

d. Represents Thunderbolt and analysis carried out an additional 5 years on the basis of the assumption stated in footnote e.

e. Assumes costs of source reduction and maintenance part of permanent control project are split equally over the project period (1962-82). In addition the analysis was carried an additional 5 years using the mean value of costs, benefits from the previous 5 years (1979-83) on the assumption that project costs and benefits that accrue will be equivalent to the mean costs and benefits of the most recent 5 years.

Source: Chatham County Mosquito Control Commission Monthly Records, 1962-83.

DISCUSSION

Although the permanent control project resulted in larger costs compared to the temporary control project in the first example of the case study (−$24,664 versus −$9,947), it is felt that a longer time period would show the effectiveness of permanent control in terms of dollars. An indication of this is the upward trend in benefits accruing to the permanent control project.

However, the entire picture should be examined before drawing any conclusions based on the above economic analysis. Considering that the two study areas encountered fairly similar weather and tidal conditions as well as other control activities such as larviciding, any differences among the two areas could be attributable to the control projects. A comparison of annual ground adulticiding spray applications is presented in Table 3. The observed mean number of annual spray applications is 17.7 for Thunderbolt and 10.6 for Isle of Hope and this difference is significant at the 5% level (t-test). Examination of the relative dispersion (S.D./$\bar{x}$) of annual spray applications for Isle of Hope (0.25) and Thunderbolt (0.52) for 1962–83, shows that annual applications are less variable in Isle of Hope compared to Thunderbolt. Further examination of mean annual spray applications by time periods indicates that: 1) the mean application level for the 1962–72 period was not significantly different across Thunderbolt and Isle of Hope implying that the two areas *did* receive similar ground adulticiding control measures prior to 1973 (the beginning of when the permanent control project is believed to demonstrate effectiveness); 2) after 1972 (1973–83) the observed mean level of annual ground adulticide applications was significantly different across areas at the 5% level; and 3) mean ground adulticide applications prior to 1973 (1962–72) versus post-1973 (1973–83) differed significantly at the 5% level only for Thunderbolt (*t*-test). Ground adulticiding equipment is usually metered to deliver the same application rate and fewer applications mean smaller quantities of pesticide mate-

Table 3. Ground adulticiding spray frequencies for Thunderbolt and Isle of Hope, Chatham County, Georgia, 1963-83.

	No. annual applications		
Year	Thunderbolt	Isle of Hope	Diff.*
1963	11	14	+3
1964	6	13	+7
1965	8	5	-3
1966	10	9	-1
1967	15	11	-4
1968	10	9	-1
1969	15	14	-1
1970	12	10	-2
1971	9	10	+1
1972	9	8	-1
1973	18	14	-4
1974	26	15	-11
1975	12	7	-5
1976	19	8	-11
1977	17	11	-6
1978	17	10	-7
1979	36	10	-26
1980	32	12	-20
1981	33	14	-19
1982	27	9	-18
1983	30	10	-20
Mean ± S.D.:			
1963-83	17.7 ± 9.2[a]	10.6 ± 2.7[a]	
1963-72	10.5 ± 2.9[b]	10.3 ± 2.8	
1973-83	24.3 ± 8.0[ab]	10.9 ± 2.6[a]	

Note: An adulticide frequency refers to the night and/or day 1 or more spraying trips were made. Hence in 1963 Thunderbolt was treated a total of 11 separate nights/days.

* Difference between Isle of Hope and Thunderbolt.

a. Mean values are significantly different from one another at the 5% level across areas, using a two-tailed t-test.

b. Mean values are significantly different from one another at the 5% level across time periods (1963-72 vs. 1973-83) within area, using a two-tailed t-test.

Source: Chatham County Mosquito Control Commission Annual Ground Adulticiding (Fogging) Records, 1963-83.

rials are placed in the environment. Furthermore, fewer spray applications and lesser quantities of insecticide may result in slower development of resistance by mosquitoes.

The examination of annual female densities per light-trap night collection for all species collected shows that the observed mean value for Isle of Hope is 5.6 contrasted to 20.4 for Thunderbolt (Table 4). A comparison of these mean values indicates that they are significantly

Table 4. Densities of female mosquitoes for Thunderbolt and Isle of Hope, Chatham County, Georgia, 1962-83.

	All species		*Ae. sollicitans*		*Ae. taeniorhynchus*		*Ae. sollicitans* & *taeniorhynchus*		Proportion of *Ae. sollicitans* & *taeniorhynchus* of all species	
Year	Thunderbolt	Isle of Hope	Thunderbolt	Isle of Hope	Thunderbolt	Isle of Hope	Thunderbolt	Isle of Hope	Thunderbolt	Isle of Hope
	No./Light-trap night*								%	
1962	7.1	27.5	-	-	-	-	-	-	-	-
1963	26.6	10.5	16.7	2.6	8.0	5.7	22.3	7.8	89.5	59.8
1964	27.8	22.5	11.9	2.7	10.2	7.7	22.1	10.4	77.3	41.6
1965	4.0	6.0	1.8	1.2	1.3	0.5	2.6	1.5	64.8	21.2
1966	10.9	2.1	7.5	0.2	3.1	0.6	9.2	0.6	84.6	23.9
1967	29.4	3.5	16.9	1.2	10.9	1.0	27.8	2.0	94.3	43.7
1968	17.8	1.5	26.0	2.2	15.8	1.0	38.2	1.4	93.7	50.6
1969	34.8	2.7	47.9	0.7	9.7	1.2	57.6	1.8	99.1	54.9
1970	6.7	2.8	1.6	0.8	3.2	0.8	4.8	1.2	71.6	41.5
1971	7.5	3.3	1.2	0.1	4.9	1.2	5.1	1.2	67.0	27.7
1972	21.2	2.6	7.5	0.2	11.8	0.7	19.2	0.8	79.4	19.0
1973	19.0	5.0	7.4	0.5	7.4	0.6	13.7	0.9	71.9	15.2
1974	22.2	1.3	4.3	0.2	7.9	0.3	12.2	0.4	63.7	22.1
1975	19.6	2.1	5.3	0.1	3.0	0.2	8.3	0.2	42.7	7.3
1976	15.7	1.9	6.2	0.2	3.8	0.3	9.1	0.4	57.7	16.8
1977	21.6	1.8	2.2	0.1	20.3	0.7	19.3	0.7	88.3	33.0
1978	26.2	2.8	5.8	0.4	16.2	0.2	20.1	0.4	76.8	7.1
1979	17.5	0.8	2.7	-	11.6	0.1	13.6	0.1	76.7	6.7
1980	16.6	4.0	1.4	0.2	10.2	1.2	11.4	1.2	68.9	23.6
1981	45.2	5.4	6.9	0.2	37.0	1.6	43.9	1.6	83.7	29.3
1982	14.5	2.7	1.3	0.2	8.6	0.7	9.8	0.7	67.5	21.1
1983	11.2	1.7	0.4	0.1	8.7	0.8	8.9	0.9	79.2	27.3
Mean ± S.D.:										
1962-83	20.4[a]	5.6[a]	8.7[a]	0.7[a]	10.2[a]	1.3[a]	18.1[a]	1.7[a]	76.1[a]	28.2[a]
	±11.3	±6.9	±11.0	±0.8	±7.8	±1.9	±13.9	±2.5	±13.5	±15.4
1962-72	20.0[a]	8.2[ab]	13.9[a]	1.2[ab]	7.9[a]	2.0[a]	20.9[a]	2.9[a]	82.1[a]	38.4[ab]
	±13.4	±8.7	±14.4	±1.0	±4.6	±2.5	±17.3	±3.4	±12.0	±14.6
1973-83	20.8[a]	2.7[ab]	4.0[a]	0.2[ab]	12.2[a]	0.6[a]	15.5[a]	0.7[a]	70.6[a]	19.0[ab]
	±9.1	±1.5	±2.5	±0.1	±9.6	±0.5	±10.2	±0.5	±12.8	±9.2

*Average females per light-trap night are computed as follows: total number of females divided by the number of collections. It can be safely assumed that the majority of the species represented by this data are salt-marsh species.

a. Mean values are significantly different from one another at the 5% level across areas, using a two-tailed *t*-test.

b. Mean values are significantly different from one another at the 5% level across time periods (1962-72 vs. 1973-83) within areas using a two-tailed *t*-test.

Source: Chatham County Mosquito Control Commission Monthly Adult Density Surveys, 1962-1983.

different at the 5% level (*t*-test). Comparison of mean densities across time periods (pre- versus post-1973) showed that mean densities were significantly different across both areas at the 5% level and that for Isle of Hope only, these mean densities were significantly different at the 5% level across pre-1973 versus post-1973 periods (*t*-test).

Additional examination of the light-trap data for the two primary target salt-marsh species, *Aedes sollicitans* (Walker) and *Ae. taeniorhynchus* (Wied.) identified by the CCMCC director proved interesting. Comparison of observed mean values of annual female densities per light-trap night showed that: 1) mean values were significantly different across areas at the 5% level for all time periods (1962–83, 1962–72, 1973–83), individual species and both species combined; and 2) mean values associated with *Ae. sollicitans* were significantly different at the 5% level across pre-1973 and post-1973 periods (1962–72 versus 1973–83) for Isle of Hope (*t*-test). Considering the proportion (or mix) of *Ae. sollicitans* and *Ae. taeniorhynchus* combined relative to total species per light-trap night indicated: 1) the observed mean proportion for the 1962–83 period for Thunderbolt (76.1%) versus Isle of Hope (28.2%) was significantly different at the 5% level as well as for pre-1973 and post-1973 periods across areas; but 2) the mean proportion of these primary target species differed significantly prior to 1973 (1962–72) versus post-1973 (1973–83) at the 5% level only for Isle of Hope (*t*-test).

This study suggests that permanent control was a contributing factor in the reduction of ground adulticide applications and quantities, adult densities of female mosquitoes per light-trap night and the proportion of primary target salt-marsh species relative to total species per light-trap night. Although the temporary control project associated with Thunderbolt was less costly when compared to the permanent control project associated with Isle of Hope, it appears that it was less effective in controlling adult densities of female mosquitoes as measured by light-trap data. Limitations of any analysis must be addressed and those germane to the present study are: 1) the assumption of similar weather and tidal conditions could not be formally examined; 2) data concerning other control activities such as larviciding were not available for use in the present study and it is not known if these control activities differed across both areas; and 3) historical mosquito densities as measured by light-trap data of both areas before control started is unknown, and hence, the premise that mosquito densities across both areas prior to control are similar could not be tested. If these assumptions hold the findings would not change.

In conclusion, if one were to view this case study from an ex-post view, clearly one should address the fact that the project outcomes (level of control) differed. Arguing that these outcomes were attributable to the projects, one could compare cost-effectiveness of both projects on the basis of mosquito densities per light-trap night killed or the percent reduction in mosquito densities compared to the level of infestation prior to both projects. Because data of this nature are not commonly available, the researcher has little choice but to use a similar approach as in this paper. An alternative approach could be based on the WIP concept. If residents of Thunderbolt and Isle of Hope recognize that control effectiveness differed across areas and act rationally, then it is clear that amounts they would be willing to pay for mosquito control would reflect this difference. Hence, benefit measures would reflect the differences of control effectiveness and the present value of net benefits could then be used to compare both projects. Rigorous testing of these concepts was beyond the primary scope of this paper and awaits further investigation.

ACKNOWLEDGMENTS

The authors graciously acknowledge the Chatham County Mosquito Control Commission, Savannah, GA, especially T. Oscar Fultz for providing the data and valuable assistance concerning the actual case study. In addition, special thanks are extended to Dr. Ronald A. Ward (editor, JAMCA) for suggesting this research topic and to Dr. J. C. Headley (University of Missouri-Columbia), Dr. Arnold L. Aspelin, Chief (Economic Analysis Branch, OPP, U.S. EPA) and Dr. Al McGartland (Economic Analysis Branch, OPP, U.S. EPA) for reviewing the manuscript and providing exceedingly helpful suggestions. Any remaining errors are the sole responsibility of the authors.

References Cited

Bohm, P. 1976. Social efficiency: A concise introduction to welfare economics. Macmillan Press Ltd., Surrey, Great Britain, 150 pp.

Eckstein, O. 1958. Water resource development—The economics of project evaluation. Harvard Univ. Press, Cambridge, MA, 300 pp.

Gittinger, J. P. 1972. Economic analysis of agricultural projects. Johns Hopkins Univ. Press, Baltimore, MD, 221 pp.

Herfindahl, O. C. and A. V. Kneese. 1974. Economic theory of natural resources. Charles E. Merrill Publ. Co., Columbus, OH, 405 pp.

Just, R. E., D. L. Hueth and, A. Schmitz. 1982. Applied welfare economics and public policy. Prentice-Hall, Inc., Englewood Cliffs, NJ, 491 pp.

Kneese, A. V. 1984. Measuring the benefits of clean air and water. Resources for the Future, Inc., Washington, DC, 159 pp.

Margolis, J. 1959. The economic evaluation of federal water resource development. Am. Econ. Rev. 49(1):96–111.

Mishan, E. J. 1976. Cost-benefit analysis. Praeger Publ., New York, NY, 454 pp.

Prest, A. R. and R. Turvey. 1965. Cost-benefit analysis: A survey. The Econ. J. 75:683–705.

Randall, A. 1981. Resource economics: An economic approach to natural resource and environmental policy. Grid Publ., Inc., Columbus, OH.

Steiner, P. O. 1966. The role of alternative cost in project design and selection, pp. 33–47. *In:* A. V. Kneese and S. C. Smith (Eds.). Water research. Johns Hopkins Univ. Press, Baltimore, MD.

U.S. Department of Commerce. 1980. Business statistics, 1979. A supplement to the survey of current business. Bur. of Econ. Anal., Washington, DC, 75 p.

U.S. Department of Commerce. 1983. Business statistics, 1982. A supplement to the survey of current business. Bur. of Econ. Anal., Washington, DC, 27–28, 57 pp.

U.S. Department of Commerce. 1984. The survey of current business. Bur. of Econ. Anal., Washington, DC, S–5, 6 and 12 p.