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AN IMPACT ASSESSMENT OF MALARIA CONTROL THROUGH ENVIRONMENTAL AND IRRIGATION WATER MANAGEMENT

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ABSTRACT

Malaria is a major public health challenge in much of the developing world and inflicts tremendous social and economic cost:. Current research concentrates largely on the development of new drugs and vaccines, but there is simultaneously renewed interest in examining agro-ecological and environmental options to control malaria. This paper presents the results and ex-post impacts of an action research project in Sri Lanka aimed at testing the viability of environmental and water control strategies to reduce the incidence of malaria and thereby improve the overall well-being and welfare of affected communities. The study relied on multiple sources of data including monitoring and evaluation exercises during project implementation, other secondary data sources, as well as primary data collected through structured questionnaire surveys. Two methods were employed to determine the economic benefits of malaria control to the households: the traditional cost of illness method and the willingness to pay approach based on contingent valuation method. The results of the study suggest the potential of irrigation water and environmental management as a viable alternative or complementary to ongoing malaria control and eradication practices in Sri Lanka, and possibly elsewhere.

Key words: Malaria control, Irrigation Management, Willingness to Pay, Health Economics, Sri Lanka

INTRODUCTION

Malaria is one of the most important diseases in tropical, developing countries. According to the World Health Organization, approximately 40% of the world's population is at risk of malaria, with the majority of the cases found in the developing world (WHO, 2007). Each year over 500 million people become ill with the disease and between 700,000 and 2.7 million people, mostly children, die as a result. In addition to the human health toll, the disease is also associated with significant economic losses, estimated at some US$12 billion annually for sub-Saharan Africa alone (WHO, 2000; Gallup and Sachs, 2001; Amerasinghe, 2006; WHO, 2007).

Global initiatives for malaria control

To combat the disease, a range of eradication and control strategies have been suggested. For example, Roll Back Malaria (RBM), which is a partnership between the World Health Organization (WHO), the United Nations Children's Fund (UNICEF), the United Nations Development Programme (UNDP) and the World Bank launched in 1998 to provide a coordinated global approach to fighting malaria, suggests that the most effective and evidence-based control interventions are i) prompt access to effective treatment, ii) promotion of insecticide-treated bed nets and improved vector control, iii) prevention and management of malaria in pregnancy, and iv) improved management of malaria in complex emergencies (RBM, 2001a). Probably the most effective malaria control would be achieved through a combination of these interventions, applied at the right time and at the right place (Matsuno *et al.*, 1999). These interventions suggested by RBM can be categorized into

curative and preventive interventions strategies. Curative measure'; involve diagnosis and treatment of malaria. Preventive measures include residual spraying, bed net impregnation, larviciding, and environmental and/or irrigation management measures. Environmental and/or irrigation management imterventions include, for example, covering wells and filling in ditches, keeping irrigation channels fast flowing, changing irrigation water levels in the irrigation canals, and ensuring proper drainage.

While access to treatment (curative) and bed nets (preventative) have been the primary tools used in practice (RBM 2001b), environmental control measures have shown to have a profound effect on the prevalence of immature mosquitoes and larvae (WHO, 1982; Coosemans and Barutwanayo, 1989). While environmental management techniques were relatively common up until the mid-20th century, the discovery of DDT in the 1940s changed the focus of malaria control measures. More recently, however, renewed attention has been placed on malaria control through environment and water management (Konradsen *et al.*, 2004; Keiser *et al.*, 2005b; Townscn *et al.*, 2005). Since the decline in DDT use, the health sector has once again become interested in environmental management as a part of integrated disease control approaches (Boelee, 2003). Most of the recommendations are focused on preventive measures that can be incorporated into the design of new irrigation systems (Yohannes *et al.*, 2005). Canals with the right elevation, size and slope require less water, reduce stagnant breeding sites, are less prone to erosion, and can convey water at higher velocities without overtopping. Apart from improvec irrigation infrastructure, the location of the irrigation sites vis-a-vis villages are also important factors in reducing malaria risk (Keiser *et al.*, 2005a).

IWMI's research on malaria control, and outreach activities in Sri Lanka

For the long-tenn sustainability of malaria control, research is needled that simultaneously addresses the agro-ecological, economic and social dimensions of the disease that are on-the-ground realities (Amerasinghe, 2006). Since the 1990s it is this gap that IWMI research has attempted to fill through its projects and programs in Africa and Asia, focusing on an integrated water-land-people based agricultural system management perspective. IWMI's overarching hypothesis is that malaria-agriculture linkages lend themselves to agro-ecosystem management interventions that can contribute to a substantial reduction of disease incidence, especially in areas of unstable transmission. Within this larger program of research, IWMI undertook the study presented here to test the efficacy of water management interventions on malaria control in a site in North Central Province, Sri Lanka, where a 6 year multidisciplinary research study, had set the stage for intervention and action research activities.

MATERIALS AND METHODS

Study site

The study site was an area comprising six villages (Asirigama, Eppawela, Mahameegaswewa, Madawela, Siyambaladmana, Hamillewa and Rambewa, in the Palugaswewa and Kekirawa administrative divisions of the Anuradhapura district) along the Upper Yan Oya catchment, in the Huruluwewa watershed (North Central Province) of Sri Lanka, where IWMI researchers had carried out multidisciplinary research studies on malaria transmission dynamics, malaria risk factors, household treatment seeking behaviour, and feasibility of environmental and water management interventions (Amerasinghe *et al.*, 1997,1999, 2001; Amerasinghe 2006, Konradsen *et al.*, 1997a,b, 2000a,b, 2003a; vander Hoek *et al.*, 1998,2003)

A review of the multidisciplinary studies

The multidisciplinary research studies commenced, in the mid-1990s when malaria was a major health problem for a farming community of about 3000 people that lived within these villages and inflicted significant health, social as well as financial costs. During late 1994 to early 1995, an outbreak of malaria occurred in the area with 46 percent of the study site population experiencing at least one episode of malaria.

The results of the studies confirmed the following:

- *Anopheles culicifacies* was the primary vector associated with the outbreak of malaria;
- *An. culicifacies* was found to breed in the slow flowing stream and or clear sunlit stream bed pools, and later spread to other habitats such as the tanks in the tank cascade irrigation system, which led to rapid spread of the disease;

- The adult population dynamics of *An. culicifacies* was linked to the breeding sites that were created preceding the heavy showers of the main monsoonal rains of October -December;
- Villagers living within 750 m **of** the river were 500% more at risk of contracting malaria than those who lived further away;
- Direct costs of treatment averaged 1% of net family income per episode of malaria, while families with multiple episodes spent up to 10% of income per annum;
- Indirect costs (loss of agricultural work days, labour substitution costs etc.) averaged *6%* of family income per year; and
- From the standpoint of national costs for malaria control, a comparative analysis indicated that where feasible, vector control through water management would be the cheapest option followed by larviciding of breeding habitats. Other methods such as indoor residual spraying, treatment at hospital clinics, local level treatment centers, and mobile clinics were more expensive.

The study also analyzed the association between water levels in the stream and the breeding of *An. culicifacies* and tested the feasibility of different water management strategies to reduce the larval abundance. The strategies tested included temporal changes in upstream water allocations as well as modifications to agricultural practices and physical maintenance of the reservoirs while ensuring the availability of water for fortnightly releases into the stream during the dry season. The results demonstrated the potential for effective vector control through feasible changes in irrigation management (Konradsen *et al.,* 1997a; Konradsen *et al.,* 1998; Amerasinghe et al. 1999, Amerasinghe *et al.*, 1997, van der Hoek *et al.*, 1998). Further hydrological modelling was done to more specifically determine the effectiveness of water management measures on larval abundance, with results suggesting that larval abundance could be reduced by 84 percent when the water level in the stream was increased from pooling level to 50 cm (Matsuno *et al.*, 1999). Following from these initial assessments, the project partners hypothesized that environmental control measures has the potential to significantly reduce malaria incidence in the study area, and thereby reduce the use of insecticides for both larval and adult mosquitoes and thus the costs incurred by the government and the community.

Action Research on Water and environmental management interventions for malaria control

Based on the findings and understandings obtained from the above studies, a follow-up action research project was formulated and implemented over a three year period from January 2000 to December 2002 with the following specific objectives:

(1) To implement environmental management (water releases and other engineering measures) strategies along the Yan Oya that will be effective in controlling the breeding of the major vector of malaria in the area and thereby reduce disease incidence; and

(2) To develop institutional arrangements with stakeholders that would serve as the basis for a policy framework for the wider implementation of this approach to malaria control in Sri Lanka.

The activities of the action research project took place in a critical 8 km stretch of the Yan Oya between Asirigama and Siyambaladamana, where mosquito breeding was associated with outbreaks of malaria in the past. Research studies commenced with a stakeholder (farmers and engineers of the MASL) centred participatory diagnosis of the options for environmental control based on the over all research finings. The final project approach involved the testing **of** water management options and infrastructural modifications to the irrigation system. In brief, the project interventions included:

- Rehabilitation of three reservoirs immediately upstream of the stream, including the Habarana tank—with its dam, spillway and two outlets—a small tank to farmers' fields, and a relatively large tank into the Yan Oya to allow water releases to downstream irrigation systems at Huruluwewa
- Clearing of trees, sand banks and man-made dams blocking the stream to correspond with the findings of the earlier studies that proposed the need to maintain a water depth that was less conducive for malaria vector breeding
- Levelling the streambed and straightening curves to enable a smoother and faster water flow. All dead trees and trunks lying across the stream were cut-up using a chain saw and smaller axes. A team of farmers from

Mahameegaswewa was employed to cut all branches and bushes overhanging the stream. The logs were then removed with heavy machinery. All overhanging branches along the stream were removed. The parts of the vegetation obstructing the water flow was cut back, but the overall canopy remained largely in place to provide shade over the stream bed. Finally, shallow inner bends were excavated with a bulldozer. The machine crawled along the stream bed, straightening the inner bends, removing dead logs and rocks. The final result was a level stream bed.

These project interventions were planned for and carried out in the first nine months of 2001. Following the interventions, the project continued to monitor water levels, mosquito breeding and malaria transmission through the end of the project in December **2002.** The research activities were complemented with the development of brochures and posters, a video and community workshops (IWMI, 2003).

In the following sections of this paper we describe the background, methodology and results of an ex-post impact assessment of the action research project. The aim of the assessment is to determine 1) the extent to which the project interventions contributed to a decline in malaria incidence in the study site and overall improvement in community welfare and **2)** the viability of water management practices for malaria control.

Methodology for impact analysis

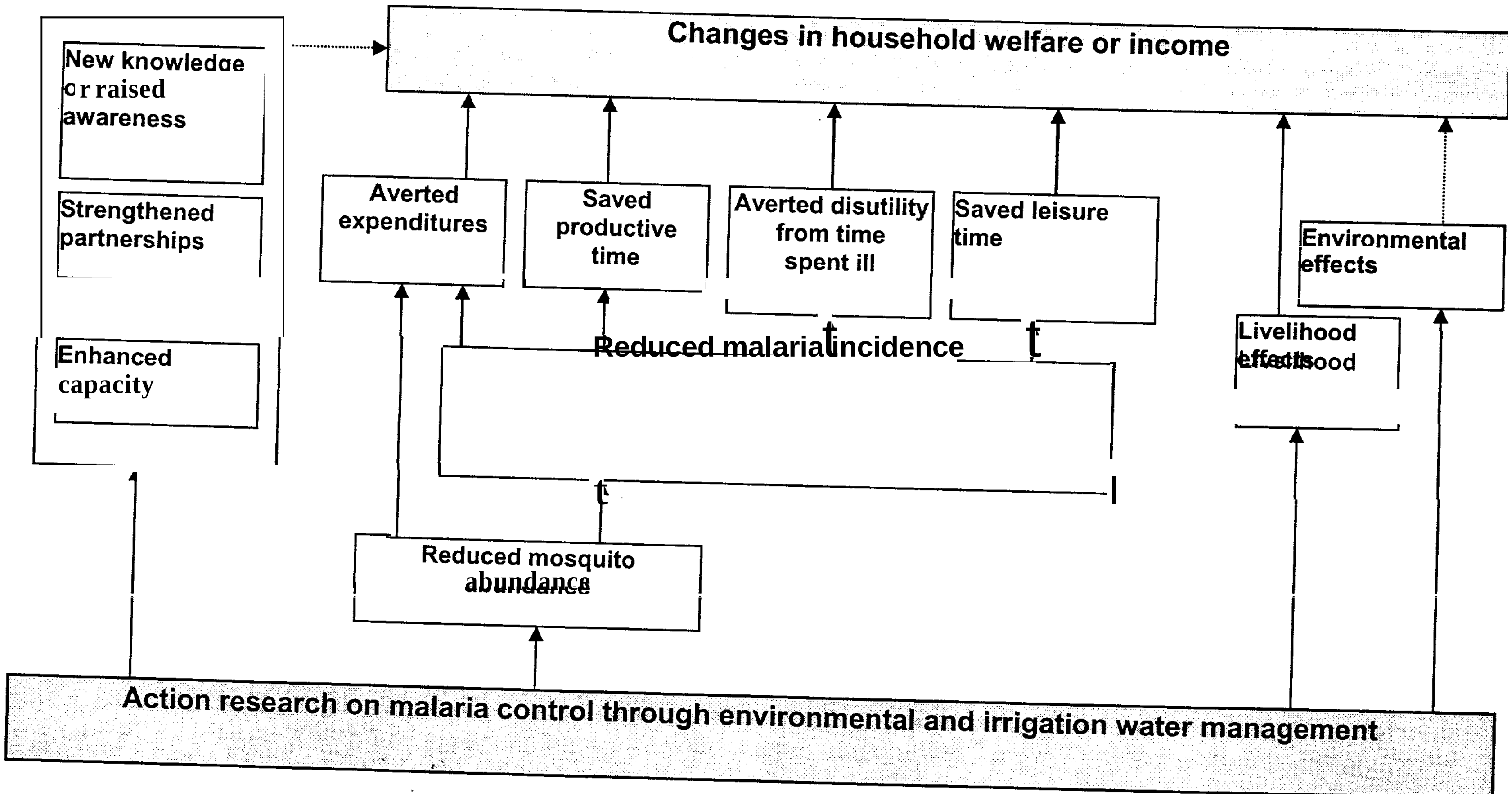
Conceptual framework of the impact analyses: impact pathways and indicators

Impact evaluation assesses the extent to which an intervention has caused desired changes in the intended audience. It is concerned with the net impact of an intervention on households and institutions, attributable only and exclusively to that intervention (Ezemenari *et al.*, 1999). The impacts of the malaria control through environmental and irrigation water management is conceptualized in Fig. 1. The impact pathway depicted in Fig. 1 is a modification of **IWMI** Impact typology conceptualized by Giordano *et al.* (2006).

The malaria control project effects can be seen at three related or sequential levels, namely outputs, outcomes and impacts. The outputs are the immediate or direct results of the activities undertaken by the project (i.e., the development and testing of new or adapted technologies). The outcomes refer to what happened as a result of project outputs (i.e., reduction in malaria incidence) while the impacts refer to the eventual attainment of the project goal (i.e., changes in household welfare or income).

The outcome/impacts of the malaria control project can also be conceptualized as quantitative or qualitative, direct or indirect, and short or long term. Some of the outcomes, such as reduction in vector population and malaria incidence, which have direct welfare impacts on households, can be quantitatively measured (Philips *et al.*, 1993). For example, reductions in mosquito abundance influence household welfare in two ways. First, reduction in nuisance mosquito population irrespective of whether they carry malaria or not, contributes to the household welfare by reducing the demand for spraying. Second, the reduction in the malaria carrying mosquito population reduces the risk of contracting malaria with subsequent effects on household wellbeing and welfare. Other outcomes such as enhanced capacity are more difficult to measure but can be equally important in achieving project goals in the medium and long term. This paper concentrates on the assessment of quantifiable impacts (e.g., increased welfare in the study location through a reduction in malaria incidence) of the project, but includes a description, to the extent possible, of qualitative outcomes, including several indirect influences attributed to the action research project.

Figure 1. Impact pathways and indicators



Data sources, sampling procedure and sample size

The assessment of the impact of the project relied on multiple sources of primary and secondary data including literature reviews, information obtained through project monitoring and evaluation exercises and data collected through follow-on surveys.

The most relevant secondary information used to assess the impact of the project included estimated economic cost of malaria to Sri Lankan households (Konradsen, *et al.*, 1997a), households' responses to malaria and their costs (Konradsen *et al.*, 1997b), and the cost of malaria control to government and households. This information was generated based on a survey undertaken to assess the cost of malaria to the households in the project villages in 1995. The costs were estimated based on treatment, blood tests, transport, meals on the day of treatment, special diet at home and other related costs (e.g., costs associated with a person accompanying the patient for treatment and the need for hired labor during the patient's recovery period).

In addition to these secondary sources, a significant amount of data was collected before and during project implementation. Starting from the beginning of the action research project in 2000, the impact of the project on vector abundance and malaria incidence was monitored. For example, entomological monitoring was carried out through the fortnightly collection of *anopheline* larvae using a standard dipping technique while malaria incidence monitoring was carried out in collaboration with a malaria clinic located at Mahamcegaswewa village along the Yan Oya and the Kekirawa hospital which serves the study village community.

While useful in assessing baseline information, secondary data sources only provide indications of intermediate project impacts. Around the start of the action research project, a secular decline in malaria incidence occurred throughout Sri Lanka, making it difficult to attribute the observed decline in malaria incidence in the project area to the project intervention alone. Thus, for the purposes of quantifying the community level welfare impacts of the project, a representative sample survey was carried out in 2004 in both the intervention villages and a set of control villages. The control villages were drawn from the Galewela area (Matale Distirct), specifically from two stream systems called Malava Oya and Velamitiya Oya. The control and the intervention areas were comparable with respect to the likelihood of occurrence of malaria, and socioeconomic background of the communities. Moreover, the control villages were among those villages where the normal government malaria control practices were undertaken.

The survey sampling design used a two-stage stratified random sampling procedure. In the first stage the villages were categorized into two strata based on proximity to the rivers (Table 1). These are villages located more than 1 km away from the stream and villages situated within 1 km distance from the streams.

Two villages were selected from each strata using Probability Proportionai to Size sampling design. In the second stage households were sampled using Simple Random Sampling design from both the intervention and control areas. Finally, we selected 50 households from each selected village. The total sample size was 402 households, about 200 each from the intervention and control villages.

Table **1. Numbers of** households sampled in **2004 for** the questionnaire survey on malaria in **7** villages in Central Sri **Lanka**

Village name	Distance from river	
	> **1** km	<**1** km
Control villages		
Rathmalgahaelagama	103	
Kalogahaela		50
Yakkuragala North		49
Sub total	103	99
Intervention villages		
Asirigama	50	
Maha Meegaswewa		50
Madawala	50	
Hamillewa		50
Sub total	100	100
Grand total	203	199

Methods to determine the value of malaria prevention

To determine the value of preventing malaria, two techniques, namely the Cost Of Illness (COI) and the Contingent Valuation or Willingness To Pay (WTP), were employed. The value of preventing malaria has typically been equated with the economic losses ("cost of illness") associated with the disease, which is the value of lost productivity plus medical costs. Economic losses, however, fail to capture the pain and sufferings associated with malaria, and tend to place a low value on preventing the disease in children and the elderly. Previous studies suggest that the value of preventing malaria, what people are willing to pay to prevent the disease, may be larger than the economic losses associated with malaria (Whittington *et al.*, 1996; Cropper *et al.*, 2003).

To measure the COI, respondents were asked a series of questions about their most recent episode of malaria. These included questions about the length and severity of the illness as well as questions about treatment sought and costs of treatment. It also included questions about the time others spent caring for the respondent when he/she was ill and about intra-household labour substitution in response to the respondents lost work time. Similarly, to measure COI for children and teenagers, respondents were asked about the most recent malaria episode experienced by either a child or a teenager in the household. This was followed by questions about treatment, treatment costs, caretakers' time, and intra-household labour substitution. In the medical economics literature the COI is the sum of the costs of medical treatment (the direct costs of illness) and the value of productive time lost due to illness (the indirect cost of illness). Depending on the context, costs may be computed as either private costs or social costs. Private medical costs, for example, would include only costs actually incurred by the sick person. These might fall short of social costs if, for example, the government subsidized the costs of medical care. We computed a per episode cost of illness that reflects the costs of the most recent malaria episode experienced during the past two years for the respondent and a child/teenager in his/her household. We then multiply these costs by the number of episodes experienced by all family members during the last two years (and then divide by two) to derive the annual household cost of illness.

WTP was elicited using the Contingent Valuation method. The contingent valuation studies simulate a market for a non-marketed good. The objective is to elicit the maximum amount a non-priced good is worth to the respondent. The respondent was presented with a hypothetical vaccine scenario. The hypothetical vaccine scenario began by emphasizing that such a vaccine is not currently available and might never be available. The enumerator described a hypothetical vaccine to the respondent, which would prevent the recipient from contracting malaria for one year. The scenario checked the respondents' understanding of the benefits of the vaccine, and provided reminders of substitute goods and the budget constraint. It was also emphasized that a separate vaccine would need to be purchased for each member of the household in order to protect them from getting malaria for one year. The respondent was asked whether he would purchase one or more of the hypothetical vaccines at one of the five randomly assigned prices (*i.e.*, 100, 200, 300, 400, and 500 Rupees). If the respondent answered 'yes' to the original choice, he was then asked how many hypothetical vaccines would be purchased and to whom they would be given (e.g., adults, teenagers, children). Enumerators were selected from among Peradeniya university students and trained to administer the questions to the farmers.

Derivation of household demand for malaria vaccine:

A formal model of household demand for preventive medical care that is standard in the health economics literature is useful to derive a demand function for a hypothetical malaria vaccine, which can then be used to estimate a household's willingness to pay for malaria prevention. Following Lampietti et al. 1999, we present here a theoretical model of the demand for health related goods. The model assumes a household receives utility from consumption **(X),** leisure time **(L),** disutility from time spent ill ***(S)*** and a vector of decision makers characteristics **(Z)** such as education, age, and gender. Assuming n family members utility is given by

$$U = u(X_1,\ldots,X_n, L_1,\ldots,L_n, S_1,\ldots,S_n, Z) \quad (1)$$

The time spent ill (S_i) with malaria by each individual is a function of preventive care such as vaccines (A_i) and treatment such as chloroquine (Mi). How effective these inputs are depends on individual health characteristics (Hi) and, in the case of malaria, on the prevalence of mosquitoes (which transmit malaria), E.

$$S_i = s(A_i, M_i, H_i, E) \quad (2)$$

The amount of preventive care, medical care and other goods that each person consumes are constrained by the household's budget. Specifically, total expenditure on these three goods can not exceed the household's income,

$$\sum_{i=1}^{n} I_i + \sum_{i=1}^{n} w_i (T - L_i - S_i) = \sum_{i=1}^{n} X_i + p_a \sum_{i=1}^{n} A_i + p_m \sum_{i=1}^{n} M_i \quad (3)$$

where $\sum_{i=1}^{n} I_i$ is the sum of each individual's non-earned income (I) and $\sum_{i=1}^{n} w_i (T - L_i - S_i)$ is earned income, which is equal to the sum of each individual's wages (w) times total time available for work (T) minus leisure time (L) and time spent sick *(S)* with malaria.

The first term on the right hand side is household expenditure on non health goods, whose price is set equal to 1. The second term represents expenditures on preventive care, with price P_a, and the last term represents expenditure on medical care, whose prices is p_m. The sum of these equals total household consumption. This budget constraint indicates that household expenditures on consumption, prevention, and treatment can not exceed household income.

The head of the household selects values of vector X, L, **A,** and M to maximize household utility subject to the budget constraint and to the health production functions. This yields a household demand function for preventive care $A^* = \sum A_i$ that in general depends on non-wage income, wages, prices, household characteristics, health characteristics of family members, and prevalence of malaria,

$$A^* = g(I, W, P_a, P_m, Z, H, E) \quad (4)$$

The value of protecting n household members with hypothetical vaccines is the maximum amount of income that can be taken away from the decision maker while giving him or her **A*** vaccines and keeping utility constant. Formally, this is the area under the decision makers income compensated demand (also known as Hicksian demand) curve for vaccines. This can be approximated using the equation. The total values the decision maker places on preventing malaria in themselves and members of their household or Willingness to Pay (WTP) for prevention is the area under the demand curve and to the left of the household size. This can be written as:

$$WTP = \int_0^n g(I, W, p_a, p_b, Z, H, E) dA \quad (5)$$

The theoretical model relates the number of hypothetical vaccines a respondent agrees to purchase to a vector of explanatory variables. The discrete nature of the dependent variable and the large number of zeroes and small values suggests that a poison regression model is appropriate. The probability density function, however, is modified so that the household size is an upper bound for each observation. In the case of Poison model this implies,

$$P[A_i^* = k_i | A_i^* \le n_i] = \frac{e^{\lambda_i} \lambda_i^k | k_i!}{pr[A_i^* \le n_i]}$$

$$\text{where } K_i = 1 \text{ to } n_i \quad (6)$$

This is a Truncated Poisson model. This model yields convenient expressions for WTP for prevention, which is the area under the household demand curve between zero and n. More formally:

$$WTP, = -\frac{}{\beta_p} \text{ if } p_{ni} \le 0 \text{ and}$$

$$WTP_i = \frac{}{-\beta_p} + p_{ni} n_i \text{ otherwise} \quad (7)$$

where p_{ni} is the price at which the decision maker buys vaccines for all household members. Within this framework, the willingness,to pay values to be collected through the survey are considered as approximations for the theoretical values represented in equations 1 to **7.**

Calculation of Cost Benefit Ratio, Net Present Value, and Internal Rate of Return

The mean willingness to pay and cost of illness values, information on differential malaria incidence rates between the control and intervention sites, information on mean differences in malaria incidence rates in the intervention villages before and post-intervention, and the project costs were used to evaluate the costs and benefits of the project. Specifically, the discounted cash flow technique is used to drive indicators **of** project worth such as Net Present Value (NPV), Internal Rate of Return (IRR) and Benefit-Cost Ratio (B/C).

Two approaches were followed to effect the cost benefit calculations, namely the with and

without and before and after scenarios. The following variables were determined to undertake the calculations. These are:

- Malaria incidence rate in the control villages (a)
- Malaria incidence rate in the intervention villages (b)
- Reduction in malaria incidence rate due to the project-with/without scenario (a-b=c)
- Mean malaria incidence rate in the intervention villages before the project (d)
- Mean malaria incidence rate in the intervention villages post intervention (e)
- Reduction in malaria ncidence rate attributable to the project –before/after scenario (d-e=f)
- Mean per capita willingness to pay for malaria protection (WTP)
- Mean per capita annual cost of illness (COI)
- Estimated size of the population in the intervention villages in different years(Pt)
- Annual cost of the project (Ct)

Given these information, the annual gross project benefit (Bt) based on with/without scenario was calculated as follows;

$B_t = C * P_t * WTP$ based on willingness to pay value or

$= C * P_t * COI$ based on cost of illness value (8)

$$NPV = \sum_{t=0}^{n} \frac{C * P_t * WTP}{(1+r)^t} - \sum_{t=0}^{n} \frac{C_t}{(1+r)^t} \text{ or}$$

$$\sum_{t=0}^{n} \frac{C * P_t * COI}{(1+r)^t} - \sum \frac{C_t}{(1+r)^t} \quad (9)$$

$$B/C = \frac{\sum_{t=0}^{n} \frac{C * P_t * WTP}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \text{ or}$$

$$\frac{\sum_{t=0}^{n} \frac{C * P_t * COI}{(1+r)^t}}{\sum_{t=0}^{n} \frac{C_t}{(1+r)^t}} \quad (10)$$

IRR is a discount rate r, which drives the NPV to 0.

The annual gross benefit (Bt), NPV, B/C, and IRR for the before/after scenario are calculated in similar fashion as above except that in this case the variable c is replaced by f.

RESULTS AND DISCUSSION

Changes in mosquito abundance

The farmers in the control and intervention villages were asked to subjectively assess the trend in mosquito population during the years 2000 to 2003. The farmers' responses are summarized in Table 2. There is statistically significant association (χ^2=6.170, df=2, p=0.046) between the households' location relative to the stream and his/her perception of mosquito abundance in the control villages. On average, a relatively higher proportion of farmers situated within a kilo-meter from a stream in the control villages reported either no change or high mosquito abundance during the study period.

Conversely, no significant association between farmers' perceptions of mosquito abundance and distance from stream was found in the intervention villages suggesting a positive impact of the project. This view is further corroborated by the pattern of association depicted in the pooled columns of Table 2: a significantly higher proportion of sample households from the intervention village reported low mosquito prevalence, while a significantly lower proportion reported no change or higher mosquito abundance (χ^2 =35.067,df=4,p<0.001).

Empirical evidence collected during the course of the project further supports the survey findings. As noted above, during the project period fortnightly collections of Anopheline larvae were carried out using the dipping technique in the study site. Samples were collected from three monitoring sites along the Yan Oya stream situated in the vicinity of the Puwakpitiya, Asirigama and Mahameegaswewa, villages. The sample results showed that abundance of *Anopheles varuna,* which is not a major vector in the area but in the past often preceded increased breeding of *An. culicifacies,* increased between March and October in 2000, 2001 and 2002 in all sampling sites (Figures 2 and 3), with measurements at times exceeding 500 larvae per 1000 dips. During the project period, however, increased breeding of *An. culicifacies* did not follow the *An. varuna* peaks. Though at one of the sampling sites a brief peak, in *An. culicifacies* occurred late in September to early October 2001, abundance was never more than 45 larvae per 1000 dips. This peak was associated with increased sand mining in the dry stream bed

shortly after the rehabilitation, which causes pooling. When the water flow for Huruluwewa was released in Yan Oya again, ***An.*** *culicifacies* breeding decreased, and in the period October 2001 through March 2002 no vector larvae were found.

Table **2.** Farmers' perception **of** mosquito prevalence during **2000** to **2003**

Mosquito prevalence	Control villages		Intervention villages		Pooled by village type	
	< 1 km	>1 km	< 1 km	>1km	Control	Intervention
Lower	55.6	65.0	83.0	90.0	60.4	86.5
No Change	37.4	22.3	14.0	6.0	29.7	10.0
Higher	**7.1**	12.6	3.0	4.0	9.9	3.5
Chi-square test	6.170 (df=2, p=0.046)		3.626 (df=2, p=0.163)		35.067 (df=2, p<0.001)	

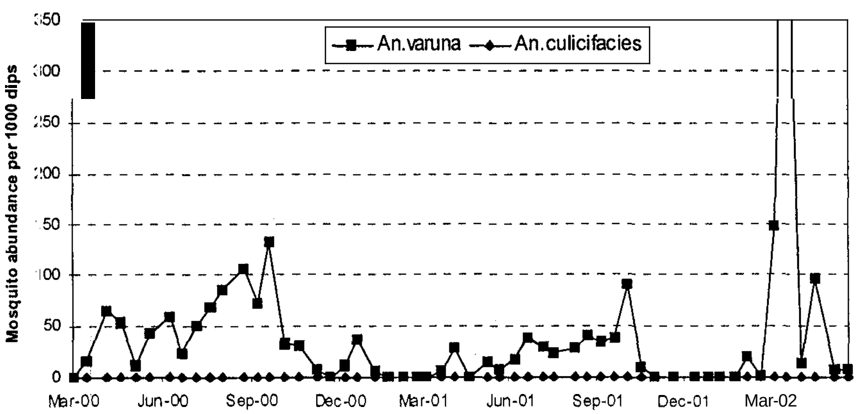


Figure **2.** Larval mosquito abundance at Asirigama between March **2000** and May **2002.**

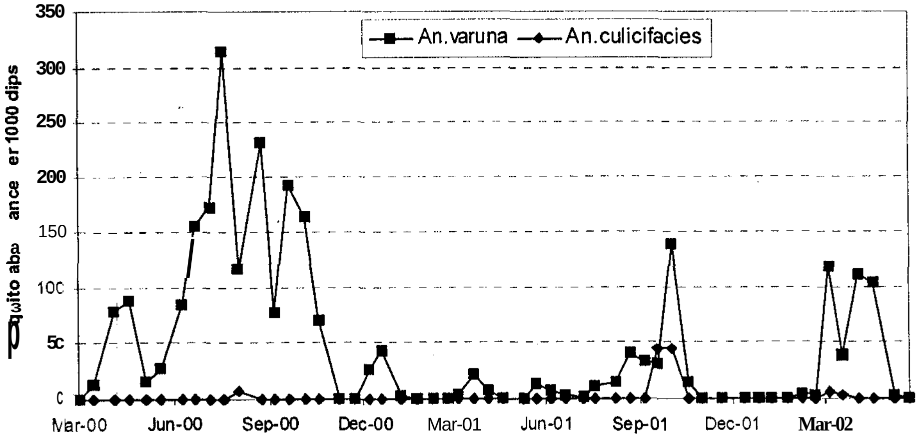


Figure **3.** Larval mosquito abundance at Mahameegaswewa between March **2000** and May **2002.**

Changes in malaria incidence

As noted above, in the mid-1990s over 40% of the people in the intervention villages experienced at least one malaria episode. While malaria cases dropped dramatically in the latter 1990s both within the study villages and in the surrounding region, the study villages appeared to experience even fewer episodes.

The empirical evidence collected during the project period from the malaria clinic located at Mahameegaswewa village, which drew patients from 9 villages in the vicinity, reported no cases of malaria between January 2001 and November 2002 for the study villages. For the same period the Kekirawa hospital reported only 9/266 microscopically confirmed malaria cases from our study area (4 were positive for *P vivax* and 5 for *P falciparum*).

It was not surprising, that the survey respondents in the study villages reported a significantly lower perception of malaria incidence post intervention. However, while the control villagers also reported a decline in malaria incidence, the pattern of farmers' perception of malaria incidence during 2000 to 2003 varies between the control and intervention villages and it appeared to relate to the proximity of the respondent's house to a water body. In both control and intervention villages, a relatively lower proportion of the farmers residing within a kilometre distance from a stream reported a low to very low situation of malaria during 2000 to 2003 compared to those located further away from the stream. This relationship, however, is statistically significant *only* in the control villages. This finding suggests a positive influence of the project interventions on malaria incidences within the intervention villages, in particular, those villages located in close proximity to the Yan Oya. The pattern of relationship between farmers' malaria perception and the type of village (see the pooled columns in Table 3) strengthens this conclusion.

Furthermore, there was significant association between farmers' perceptions of mosquito prevalence, described above, and their perception of malaria incidence during the year 2000 to 2003 ($r=0.359$, $p<0.01$).The farmer survey was also used to assess the number of malaria affected individuals during the project period in both the intervention and control villages. Out of the total of 1737 sample household members, only 25 individuals (2 children and 23 adults) recalled a malaria case during the years 2000 to 2003 (Table 4, column b), with more individuals from the control villages than from the intervention villages. The total number of malaria episodes (or infections) for the individuals who reported malaria case is depicted in Table 4, Column c. The total malaria episodes for the individuals from control villages are about triple that of the intervention villages. Hence, the malaria incidence rate among individuals belonging to the control villages is substantially higher than that for the intervention villages (Table 4, column d) suggesting that the project reduced malaria transmission in the intervention villages.

In summary, the empirical data collected during the project as well as the ex-post survey results suggest an overall positive impact of the project on larval mosquito abundance and malaria incidence. Mosquito abundance was significantly lower in the intervention villages than in the control villages with no notable influence of household location vis-a-vis the Yan Oya irrigation conveyance channel. Distance from stream was, however, a significant variable in the control villages, with a higher proportion of households located within a kilometre of the water source reporting no change or higher mosquito abundance. Similarly, while malaria incidences declined nation-wide over the period 2000 to 2003, the survey results found a statistically significant higher incidence rate of nialaria in the control village than in the intervention villages.

Table **3.** Farmers' perceptions **of** malaria incidence during **2000 to 2003** compared **with** pre-intervention period.

Malaria incidence	Control villages		Intervention villages		Pooled by village type	
	<1 km	>1 km	<1 km	>1 km	Control	Intervention
Much lower	17.2	43.7	63.0	70.0	30.7	66.5
Lower	75.8	52.4	29.0	28.0	63.9	28.5
No change	5.1	3.9	8.0	2.0	4.5	5.0
Higher	2.0	0.0	0.0	0.0	1.0	0.0
Chi-square	18.103 (df=3,p<0.001)		3.986 (df=2, p=0.136)		55.766 (df=3, p<0.001)	

Table 4. Malaria incidence (2000 to 2003) as per 2004 survey

Age group	(a) Population		(b) Malaria affected individuals		(c) Malaria episodes or infections*		(d) Incidence rate**	
	Control	Intervention	Control	Intervention	Control	Intervention	Control	Intervention
Adults	608	633	14	9	30	9	0.0500	0.0142
Children/Teen	246	250	1	1	1	1	0.0041	0.0040
Total	854	**883**	15	10	31	10	0.0363	0.0113

Notes:
* Malaria episode or infection as reported by the respondent and as confirmed through blood test. No attempt has been made to distinguish between relapse and re-infection. However, Gunawardena et al. (1998) states that relapses are exceptional in Sri Lanka due to routine use of Primaquine.
**The incidence rates for the control and intervention villages (column d) were defined as the number of infections per person in the population at risk. These rates were arrived at by dividing values in column c by their corresponding values in column a.

Economic value of malaria prevention through irrigation water management

The economic value of malaria prevention: The Cost of Illness Approach

The estimated per episode per annum cost of malaria illness in the study villages is presented in Table 5. The Table presents the findings from two sources, a 1995 IWMI socio-economic survey of the economic costs of malaria in the Yan Oya watershed (Konradsen *et* al., 1997a) and the results of the present survey. The results are divided into two groups: direct and indirect cost of illness. The direct costs of illness are out of the pocket expenditures for doctors' fees, medicine, and transportation to receive health care, The indirect costs of illness include the productive time (number of workdays) lost by malaria patients and their caregivers (e.g., the total number of workdays lost by the malaria patient and the care giver due to the malaria incidence).

The per episode economic cost of malaria estimated from our sample survey is about Rs. 1,670, while the estimate from Konradsen et al. (1997a), which was based on a detailed 1995 epidemiological study, was Rs. 1541 (applying appropriate inflation conversions, see Table *6)*. These values only take into account the direct and indirect costs incurred by the patients and not the public sector costs of malaria treatment, which according to Attanayake et al. (2000) accounts for 25% of the total cost of malaria treatment in Sri Lanka. The interpretation of this is that any successful malaria prevention program would allow a beneficiary to avert an economic loss of between Rs 1,541 and 1,670 per episode (or approximately 10% of average monthly household income in the study region). As per the 2005 Central Bank of Sri Lanka Consumer Finances and Socio Economic Survey Report 2003104 Part 1, average 2004 monthly household income for the North Central Province, the province in which the study site is located, was Rs. 15,624.

The econonzic value of malaria prevention: the Willingness to Pay Approach

In addition to the traditional cost of illness method, we also calculated the economic value of' malaria prevention via modelling the willingness, to pay by fitting the sample households demand function for total protection against malaria using their response to the hypothetical vaccine questions. Two demand functions were fitted *to* the sample data relating the number of hypothetical malaria vaccines that the respondent would purchase to protect his/her family members from malaria for a year and the bid values or prices of the hypothetical vaccine, and other relevant variables hypothesized to influence the respondents demand for malaria vaccine. The two estimated demand functions were: one for the whole sample and the other one for the sub-sample who responded yes to the willingness to pay question. The model for the yes sub sample excludes those who were not willing to purchase any hypothetical vaccines at the bid values provided (*i.e.*, 100 to 500). Excluded from this model are those either protesting the idea of paying for a vaccine altogether (or are assuming

that the provision of vaccines is the responsibility of the state) or they are only willing to pay less than 100 rupees.

Before detailing the results of the econometric analyses, we first present a descriptive analysis of the model variables as a basis for understanding the results of the econometric analyses (see Table 6). The number of hypothetical malaria vaccines demanded increases as the family size, years of schooling, and proportion of children in the household increases. The results indicate that a significantly higher number of farmers in the intervention village reported they would not buy a vaccine at any of the bid values provided.

The correlation matrix for non-dummy variables is presented in Table 7. Significant correlations were observed between some variables. However, the absolute values of the correlation coefficients are quite small.

Table 5. Total Cost of illness (COI) per episode per annum (2004) in Sri Lankan Rupees.

Category	**Household level costs** Present survey	**Average cost per episode (Note 1)** Present survey (Note 2)	Konradsen *et al.* 1997a (Note 2)
Direct costs of illness			
Treatment and medicine costs	64.0	21.3	39.5
Transport costs	240.0	80.0	59.0
Special food	426.7	142.2	143.1
Indirect cost of illness			
Value of patient lost labor days (Note 3)	2902.5 (11.6)	967.5	947.1 (7.8)
Value of caretaker lost labor days (Note 3)	1375.0 (5.5)	458.3	352.2 (2.9)
Total	5008.2 (US$ 49.10)	1669.3 (US$ 16.40)	1541.0 (US$ 15.10)

Note 1: Average cost per episode calculated by dividing household level values by the number of malaria episodes.
Note 2: 1US$=102 Sri Lankan Rupees
**The numbers in the bracket are the productive time lost in person days

Table 6. Description of the variables used in the WTP study.

Variables	Unit	Number of vaccines demanded 0	1-3	4-6	7-9	Statistics[a]
Family size	Number	4 4	3.8	5.1	7.5	***
Age	Year	48.5	45.5	48.0	52 5	Ns
Years of schooling	Year	6.7	8.1	8.2	7.8	***
Proportion of teenage-s	Percentage	16.1	17.7	12.7	13.6	Ns
Proportion of children	Percentage	13.5	13.8	17.9	18.6	Ns
Site: Control	Percentage	24.8	41.1	32.7	1.5	***
Intervention	Percentage	49.5	21.0	27.5	2.0	
Distance from stream: >1km	Percentage	24.6	41.9	33.5	0.0	***
<1km	Percentage	49.7	20.1	26.6	3.5	
Gender: Male	Percentage	35.5	31.1	32.0	1.5	Ns
Female	Percentage	43.4	32.1	22.6	1.9	

ns= statistically not significant
****= significant at $p<0.001$
[a] The statistics used was Analysis of Variance (ANOVA) for ratio variables and chi-square for nominal variables.

The results for the hypothetical vaccine models are generally consistent with economic theory. The number of vaccines that the respondents agree to purchase decreases with price, respondents' age and location (Table 8). Most of the variables included in the truncated poisson hypothetical

malaria vaccine demand function had significant effects.

The coefficients for the bid values or prices are also in line with expectation: as the bid values increase, the willingness to pay decreases. This relationship can also be inferred from figures 4 and 5 below. Figure 6 shows that as the hypothetical malaria vaccine price increases, the proportion of households willing to pay for full prevention of malaria decreases. This observation is also further corroborated by the pattern of relationship exhibited in Figure 7 below, which shows the relationship between bid values and the mean number of vaccines that the sample households are willing to pay. As the bid prices increase, the numbers of vaccines the households are willing to pay decreases.

A more complete picture of the relationship between bid values and willingness to pay is depicted in Table 10. At lower bid values, more of the sample farmers have indicated their willingness to purchase more of the vaccines or alternatively willing to protect more of their family members against malaria. On the other hand, at higher bid values more of the sample households are willing to buy less of the vaccines.

The coefficient for the site dummy (indicating whether the household is from a control village or from the intervention village) is negative. This might indicate the difference in the perceived chance of getting malaria between the two groups. Since the farmers' perception is based on the relative occurrence of malaria in their villages, it can be inferred that the project has effectively reduced the chance of malaria infection in the intervention village. Thus, the farmers in the intervention village are on average willing to pay less for malaria protection than the farmers in the control village. The willingness to purchase hypothetical malaria vaccine is also influenced by the gender of the household head. On average, female headed households are willing *to* purchase more malaria vaccine to protect their family members from the disease.

Table **7.** Pearson's correlation matrix for continuous variables.

	FMSIZE	HHAGE	HHEDU	PROTEEN	PROCHILD
Family Size (FMSIZE)	1.000				
Age of the HH (HHAGE)	.026	1.000			
Level ofeducation of the HH (HHEDU)	.018	-.287**	1.000		
Proportion of teenagers (PROTEEN)	-.059	-.011	.035	1.000	
Proportion of children (PRQCHILD)	.113*	.078	-.052	-.163**	1.000

* Correlation is significant at the 0.05 level (2-tailed)

** Correlation is significant at the 0.01 level (2-tailed)

Table **8.** Coefficients of the truncated poisson model or parameter estimates for a hypothetical vaccine model.

Variable	Whole sample (n=402)	Sub-sample with yes response (n=254)
Intercept	1.0930***	1.0274***
Bid value or price	-.0027***	-.0008***
Site (=1 if intervention site)	-.3188***	-.0007
Distance from stream (=1 if less than 1km)	-.0715	0.0100
Family size	0.1140***	0.1001***
Number of teenagers	-.0028**	-.0005
Number of children	0.0029**	0.0004
Gender (=1 if male)	-.1558***	-.1084***
Age	-.0019	0.0008
Years of schooling	0.0430***	0.0071

Note: ***significant at 1% level, ** significant at 5% level

Table 9. Relationship between number of vaccines demanded and vaccine prices.

Number of vaccines	Bid values in rupees				
	100	200	300	400	500
1	1	3	3	3	7
2	5	7	6	8	3
3	19	8	39	8	5
4	13	17	10	4	6
5	28	7	12	7	1
6	7	4	3	2	1
7	4	0	0	1	1
9	1	0	0	0	0
Total	78	46	73	33	24

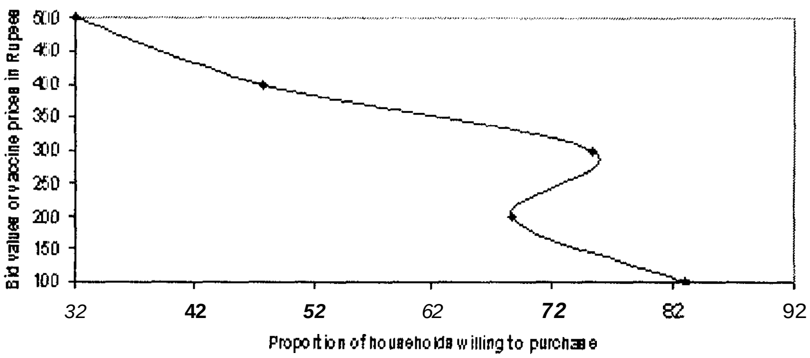


Figure 4. Observed relationship between vaccine prices and number of people willing to buy.

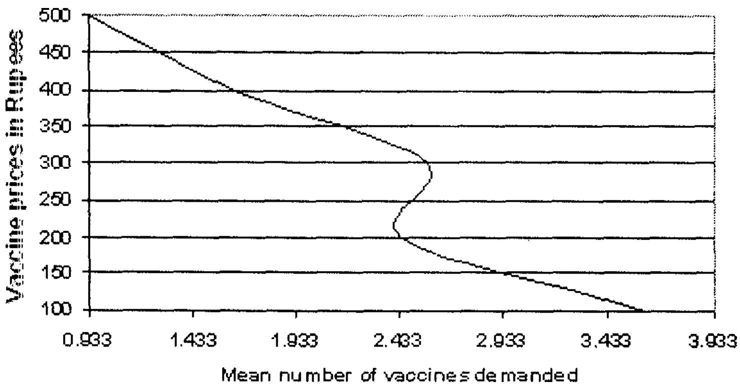


Figure 5. Relationship between number of vaccines demanded and vaccine prices.

Model derived willingness to pay values

Table 10 shows the implications of the truncated poisson model for household willingness to pay for total prevention. There are significant difference: in the estimated household WTP based on the whole sample and sub-sample. For the whole sample, the mean WTP is approximately Rs. 2,010, with a median value of Rupees **1,926.** The figures for the sub-sample of yes responses is double that for the whole sample. If we base our evaluation on the results for the sub sample with yes response to the range of bid values provided, mean household's willingness to pay calculated as the area under the households demand curve between 0 and n vaccines is on average about Rs. 5,597 per annum. Of course the value varies from household to household, with a minimum value of Rs. 1,375 and the maximum value of Rs. 12,429 per annum.

As noted above, there is a significant difference between the study locations with respect to willingness to pay, particularly for the model involving the whole sample (Table 11). The

households sampled from the intervention villages felt relatively safer with respect to malaria risk as compared to the farmers from the control villages, and this has been manifested in the amount of income they are willing to forgo in order to shield themselves against malaria.

When we compare the per episode values estimated through traditional cost of illness method (ranging between Rs 1,670 and 1,541) with the per capita va'ues given in Table 12 using willingness to pay approach, the cost of illness approach yields slightly higher values than those obtained from the sub sample with yes response using the willingness to pay approach. In other studies, the willingness to pay values are triple that of the cost of illness approach (Whittington et al., 1996; Cropper et a . 2003). We believe that the drastic decline in malaria incidence rate (both in the intervention area and control sites) might have influenced the opinion of the respondents regarding malaria threat.

Aggregate value of malaria protection in the intervention area

The total population with potential risk of malaria attack in the study villages is about 3800 people. The total population of the project villages in 1994 was about 3000 people. The current population of the villages was estimated by projecting the 1994 base figure using a growth rate of 1.5 %. The annual economic value of the project is derived from the reductions in the malaria incidence rate observed in the intervention areas only attributable to the project. There was a general reduction in malaria incidence rate in Sri Lanka starting at about the same time as the project. Thus, we estimated the changes in malaria incidence rate attributable exclusively to the project by comparing the incidence rate of malaria in the control villages and the intervention villages among our sample farmers (i.e., with and without project scenario). For comparative purposes we also use as a proxy for malaria incidence rate reduction attributable to the project by the changes in malaria incidence rate between the start of the project and after the project completion (i.e., the before and after scenario). Ideally. a double difference impact measurement approach would have been applied. However, the lack of baseline information for the control villages prevented us from using this method.

The malaria incidence rate calculated from our sample households from the intervention villages was 0.0142; the corresponding figure for the control villages was 0.0500 resulting in a difference of 0.0358. Thus. the malaria incidence in the control area is about 3.5 times higher than in the intervention area (Table 12). When we look at the longitudinal change in malaria incidence rate in the intervention area alone, the reduction in the incidence rate is substantial. During the mid-1990s outbreak 46% of the village population in the project area experienced at least one episode of malaria. Between January 2001 and November 2002. a total of 1634 fever cases from the project area were reported to the malaria clinic located in Mahameegaswewa village and to Kekirawa hospital. Out of all these fever cases only nine were confirmed positive for malaria. In general, the mean malaria incidence rate before the project (1994 to 2000) in the intervention villages was 0.0846, which declined to 0.00088 after the project (see Table 13). The difference in mean malaria incidence rate between pre- and post intervention (0.08373) was taken as the effect potentially attributable to the project.

Based on with and without project scenario qr cross-sectional comparison, the gross undiscounted economic value of protecting people against malaria based on the estimated mean willingness to pay is Sri Lankan Rupees 1.581.962. The corresponding figure when valuing it using the estimated cost of illness value is Sri Lankan Rupees 1,967,957 (see Table 13).

Table 10. Willingness to pay **for the** hypothetical vaccine **in Sri Lankan** Rupees.

Willingness to Pav	Whole sample		Sub-sample withyes resoonses	
	Per household	Per capita	Per household	Per capita
Mean	2007.7	482.9	5597.3	1323.7
Median	1925.8	321.0	5502.2	1222.7
SD	842.9	206.7	2128.4	467.6
Minimum	470.0	81.4	1375.6	210.8
Maximum	6089.7	2009.9	12428.9	4726.7

Table **11.** Comparison **of** mean willingness to pay by location in Sri **Lankan** rupees.

	Sub sample with yes response		Whole sample	
Location	Per household	Per capita	Per household	Per capita
Intervention site	5784.3	1258.6	1880.2	430.7
Control site	5471.9	1366.0	2123.4	532.2
T-test	-1.147	1.780*	2.793***	4.985***

Table **12. Estimates of** changes in malaria incidence rates.

Methods	Item	Values	Source
With and without scenario	Malaria incidence rate in intervention villages	0.0142	Present study carried out in 2004
	Malaria incidence rate in control villages	0.0500	
	Change in incidence rate due to the project	0.0358	
Before and after scenario	Mean malaria incidence rate before the project	0.0846	Konradsen *et al.*, 1997
	Mean malaria incidence rate after the project	0.00088	Boelee ***et** al.*, 2003
	Change in incidence rate due to the project	0.08373	

Table **13.** The aggregate economic value **of** malaria protection through environmental management.

Scenarios	Based on WTP approach (Rs)	Based on COI Approach (Rs)
With and without project scenario	1,581,962.4	1,967,957.0
Before and alter project scenario	3,699,956.0	4,602,735.0

Returns to tlie action research project:

The value of inputs mobilized to carry out the project interventions is summarized in Table 14. Based these figures, the returns to the project investment were calculated using with and without and before and after scenarios (Table 15). As with the calculation of the aggregate economic value of malaria protection, the values for the indicators of project worth presented in Table 15 are consistently lower for the with/without scenario as compared to the before/after scenario.

The with/without scenario indicates a negative or slightly positive return on investment while the before/after scenario gives returns that exceed the expectations of most investors. Had we obtained the before intervention estimates of malaria incidence rate for control villages we would have used the double. difference method impact assessment, which would have been more robust.

The "true" return is likely to be somewhere in between the two results. While we attempted to isolate the project effects on malaria incidence from the natural decline, the before and after scenario is likely to be overstated. Conversely, the with-and-without scenario is likely underestimated due to the secular decline in malaria nation-wide since the late 1990s. In addition, the benefits of the malaria control intervention tested here may even be higher when looked at from a societal perspective as 1) the calculations above only consider the savings to the patient from malaria avoidance and do not take into account the public sector treatment costs, estimated at 25% of total malaria treatment cost in one study (Attanayake ***et** al.*, 2000); 2) the environmental control techniques may reduce the need for insecticides resulting in increased public and private savings; and 3) water management intervention may avoid the environmental degradation of some of the alternative preventive practices such as residual spraying and larviciding. Other benefits are the reduced use of insecticides reduces the development of vector resistance. Reduced drug use. reduces that parasite resistance. Taken as a whole. the results seem to suggest the potential of irrigation water and environmental management as a viable alternative or complement to ongoing malaria control and eradication practices in Sri Lanka, and possibly elsewhere.

Table **14. Inputs** mobilized for the rehabilitation of Yan Oya **(8** km).

Item	Grant (US$)	IWMI (US$)	Total	%
Heavy machinery	3,700	8,200	11,900	**67**
Research supplies	800	350	1150	**7**
Casual wages	450	1,200	1650	9
Sub contractors	0	1650	I650	9
Travel and accommodation	1,050	400	1450	**8**
Total	**6,000**	**11,800**	**17,800**	**100**

Source: Boelee ***et** al.,* 2003

Table **15.** Returns to investment.

Items	With/without scenario	Before/ after scenario
Based on WTP values		
NPV (RS)	451,939.04	1,212,639.0
IRR (%)	3	24
B/C	0.73	**1.72**
Based on COI values		
NPV (RS)	148,557.71	1,922,152.5

Other impacts

In addition to the quantifiable direct impacts of the project described above, several indirect impacts have also been reported through interviews undertaken in preparation of a video documenting the project and its results. First. the removal of large trees and rock boulders from the Yan Oya stream bed resulted in uninterrupted vehicular transport over the Meegawewa bridge which previously was submerged for a minimum of 3 weeks during the North East Monsoons. Secondly, project interventions, which increased the flow of water in the Yan Oya, dramatically shortened the water transport time between the Mahaweli diversion outlet to Huruluwewa from 4 to 5 weeks to a maximum of 10 days. Finally, and perhaps most importantly, the project alterations were readily accepted and endorsed by the stakeholders interviewed and offers were made to voluntarily maintain the new improvements to the Yan Oya.

Conversely, the project has had a negative impact on sand miners. Project interventions reduced the amount of sand available to local sand miners. However, the numbers involved in this practice were small at the time and have continued to decrease due to more recent nation-wide restrictions imposed on sand mining and transportation.

Finally, prior to the project interventions, there was some concern that straightening the natural stream would increase erosion on the Yan Oya embankments. Studies were conducted to ascertain any significant increment in the magnitude of suspended particles in Yan Oya waters following the project interventions. Sampling was conducted at both improved and non-improved sections of Yan Oya. The results found no significant difference between the sampled sections, which may be because, the project maintained the natural slope of the stream bed.

CONCLUSION

Malaria is **a** major public health challenge in much of the developing world and inflicts tremendous social and economic costs. Research has concentrated on the developmen of new drugs and vaccines, but there i simultaneously renewed interest in examinin agro-ecological options to control malaria. Thi paper presented the results and ex-post impact of an action research project in Sri Lanka aimed at testing the viability of en ironmental and

water control strategies to reduce the incidence of malaria and thereby improve the overall well-being and welfare of affected communities. The paper specifically examined the effects of the project on mosquito abundance, malaria incidence and community welfare following the water management interventions in 2000. As Sri Lanka experienced a secular nationwide reduction in malaria beginning in the late 1990s, a specific methodological challenge of the ex-post Impact Assessment (epIA) was to determine if the project interventions made a significant contribution to malaria control beyond the natural trend. The epIA drew on both primary and secondary data sources, including an io-depth questionnaire survey in the intervention villages and nearby control villages, with similar malaria patterns where traditional malaria control practices were utilized. In addition to assessing the disease reduction and welfare effects of the project, epIA also attempted to quantify and methodologically compare the economic value of malaria prevention using the Cost of Illness and Contingent Valuation approaches. Finally, the impact assessment calculated the returns to project intervention using before and after and with and without scenarios.

In terms of project impacts, the ex post impact assessment suggests an overall positive project influence on malaria control in the intervention villages. Farmer perceptions and primary data sources both suggest significantly larger declines in mosquito abundance and malaria incidence rate in the intervention villages over control villages. Presumably as a result of this reduced risk of contracting malaria post-project, the epIA found that farmers in the intervention villages, where malaria risks are now lower, are on average willing to pay less for malaria protection than farmers in the control village. The economic value of malaria control for the community is noi insignificant either. Using the Cost of Illness approach, the private savings (direct and indirect) of malaria avoidance is between Rs. 1540 and 1670 per episode, a substantial savings for farmers in region. At an aggregate level, the gross undiscounted value of malaria protection from water management interventions is conservatively between Rs. 1,572,000 and 1,968,000, applying the Willingness to Pay and Cost of Illness approaches, respectively under the with and without project scenario. Finally, the returns on investment using the with and without scenario ranged from marginally negative to marginally positive while the before and after scenario, used for comparison reasons, indicated returns from 24-35%. We believe the "true" return is somewhere in between the two scenarios. The before and after scenario, despite the methodological efforts to isolate project impacts, likely still overstated to some degree the returns due to the natural declines in malaria incidence in Sri Lanka. Conversely, we hypothesize that the results of the with and without scenario would have been significantly higher had it not been for the overall secular decline in malaria incidences nation-wide beginning in the late 1990s, and had we been able to incorporate the broader public sector savings due to reduced treatment and prevention costs. Other indirect impacts were not quantified, and future studies could be improved by building in additional baseline analyses to capture broader social, economic and environmental impacts.

In conclusion, the epIA study presented here highlights the potential of agro-ecological interventions in malaria control. Further studies that incorporate the broader socio-economic costs and benefits of the tested technique are required to more accurately assess the full impacts of the environmental interventions described in this paper. In addition, research is required to assess the replicability of the engineering water control measures in similar agro-ecological settings. However, initial indications suggest that these interventions can be implemented in other arid and semi-arid environments such as in southeast India and East Africa.

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