Cannot afford to apply the methods to every inhabitant of for every infected person in an endemic area. Consequently, there is a need to evaluate the cost and effectiveness of judicious combinations of different degrees of levels below complete treatment of the endemic zone. For example, if it is too expensive to give oxamniquine, the new single-dose drug to all infected people in an endemic area, the cost-effectiveness should be evaluated for treating only infected children or only those with high excretion rates. Another possibility is to evaluate the cost-effectiveness of eradicating 75% of the snail habitats and giving chemotherapy to the 25% most heavily infected people, compared with eradicating 25% of the snail habitats and treating the 75% most heavily infected persons. Before attempting field studies to compare various levels and expenses to conduct, a simulation should be made to estimate the amount of expensive and long-range field studies required. This report presents the necessary theoretical analyses for Puerto Rico as a basis for planning such operational studies.

The methodology is simple; calculations can be performed with a small handheld calculator and mathematical procedures involved are limited. The amount of data involved in a single case study is analogous to ledger values, thus they can easily be done and be recorded on one large page from a book. A computer was not needed for this by most technical personnel in the headquarters of a schistosomiasis control program. The methods of control evaluated by this theoretical approach were the drug oxamniquine, snail control by ditching and bayluscide, and the provision of water supply with adequate health education to interrupt transmission. The parameter used to measure effectiveness of control was the calculated decrease in disease prevalence by the number of years over which the effects were eliminated. To be more precise, effectiveness in a theoretical community was calculated in terms of the reduction in area under the worm population curve during and after the initiation of control, assuming a stable, equilibrium worm population at the start.

Figure 0 highlights the somewhat arbitrary use of the "number of worm-years prevented". This is an improvement over measuring the number of infections prevented in individuals since it includes a measure of the intensity of the infections. Recent unpublished notes and communications suggest that this parameter is proportional to the severity of the infection, thus its use as a measure of effectiveness is probably a rough quantitative measure of the amount of disease prevented. Worm-years of infection are also likely proportional to the number of schistosome eggs embedded in an infected individual, thus proportional to the damage caused by the infection.

5. NUMBER OF SCHISTOSOME WORMS IN A COMMUNITY AFTER INITIATION OF CONTROL
NUMBER OF WORMS IN THOUSANDS
YEARS OF CONTROL EFFORT
Figure 2

METHODS FOR CALCULATING NUMBER OF SCHISTOSOME WORMS

A simple calculation scheme was developed, in which worm deaths were subtracted from the existing rates of transmission. The assumptions used in the calculation scheme were: a life span of 5-6 years, a cercarial population, and a variation in the number of new worms from 1 to 10 without affecting the comparative effectiveness of the control strategies evaluated. Worm populations are strongly clumped in people, so single-sex infections are neglected. Reductions in the rate of worms in a community result from treatment.

Based on the above assumptions, the following rationale was used in calculating the yearly changes in the worm population. The reduction in worms was due to natural deaths at the rate of 10% per year, and deaths due to drugs at the expected mortality rate of the drugs, assuming a clumped distribution of worms in people. Worm deaths due to death of the host and the number of new worms were a result of transmission, which occurred only in areas outside of a designated control zone. The pre-control transmission rate was equal to the pre-control death rate of the worm (20%), assuming a stable worm population. During control efforts, the marginal

The transmission rate was reduced as a result of an improved water supply by 0.9, a reduction in water contact, and by the proportion of people provided with piped water. As the total worm population decreased, the transmission rate also decreased in direct proportion due to lower environmental and cercarial populations. The number of worms killed by drugs was ExW, where E was the drug efficiency (proportional reduction in worm population in the treated community) and W was the number of worms in the treated people. The W was calculated from the number of infected people given the drug, assuming the clumped distribution of worms. The initial clumped worm burden was assumed to exist in people until the entire population was treated, then a new uniform worm distribution was calculated for subsequent cycles of treatment. These calculations were carried out separately for the zone with snail control and for 1.

The initial worm population in the endemic zone of Puerto Rico was calculated from data supplied by the USPHS-CDT from their study in Coqueron when indicated. It was arbitrarily assumed that this corresponds to a mean worm load of 3 worm pairs per infected person, the equivalent of 1 egg per gram per worm. This assumption agrees with autopsy data from Brazil (Cheever, 1968). Since 189,000 infected people thus harbored 6 worms each, the number of schistosome worms in Puerto Rico before starting the control program was 1,134,000, and it was assumed that 75% (142,000 people) were in the endemic area (Figure 2). More recent estimates give lower numbers of infected people in Puerto Rico, but the example reported here was not changed since the conclusions are not sensitive to small changes in population sizes.

10 - TREATMENT REGIMEN FOR APPLICATION OF VARIOUS CONTROL METHODS

The control methods analyzed are well known, but the concept of reduced levels or degrees of control is somewhat new and is detailed herein.

The analysis here involved infected people. The proportion of infected people to be treated depended on budget constraints. A budget ratio of 2:1 for expenditures for diagnostics to treatment was initially followed in these analyses, and as the prevalence decreased, excess funds occurred in the drug treatment budget. These excess funds were then diverted to the diagnosis budget, keeping the total for chemotherapy constant.

Water supply is quite expensive and for practical reasons, this analysis assumed an even pace of construction over the first few years, reaching a stable number of people served when the operation and maintenance costs consumed the entire annual budget.

Figures for water supply were taken from annual reports of the aqueduct and sewer authority which serves both rural and urban populations (Table 2). Since its creation in 1945, the Puerto Rico Sewer Authority has constructed potable water systems with $450 million dollars and which serve 2.04 million people as of 1976 (Annual Report 1977, ASA). This includes all costs of a system which gives chemical treatment (filtration, chlorination, and fluoridation) to water supplying 11 urban areas, and partial treatment to water serving many rural areas. The construction cost of $180 per capita is thus much higher than necessary to simply prevent bilharzia, which can be accomplished by avoiding the use of contaminated surface water. Additional treatment gives protection against typhoid and diarrheal diseases as well.

Table 2: COSTS OF CONSTRUCTION, OPERATION, AND MAINTENANCE FOR PUERTO RICO AQUEDUCT AND SEWER AUTHORITY AS OF JUNE 30, 1977, FROM STATISTICAL REPORT OF ASA, 1977.

	Water Supply	Sewage Services	Disposal Fees
Construction cost of facilities in service:	$438,269,867	$191,714,540	$26,571,536
Annual operation costs:	$1,468,896	$2,609,040	
Annual Maintenance Costs:	$549,930	$6,876,470	
Persons Served:	2,899,476	1,496,287	

DISTRIBUTION OF SCHISTOSOME WORM POPULATION AMONG INFECTED PEOPLE FROM SOQUERON, PUERTO RICO, 1972 CALCULATED FROM DATA SUPPLIED

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The Baral Aqueduct program in Puerto Rico was budgeted separately and more closely approximates the type of system which would be sufficient to eliminate previous dependence on polluted surface waters. Construction costs by 1950 averaged $14 per capita. By 1960, they were $30 per capita and by 1966 a total of $39 million had been invested to serve 836,000 people, a mean construction cost of $499 per person (Cuma, 1966).

The rise in cost over the 20 years reported was due to inflation and also because the easiest systems were constructed first, leaving difficult systems serving only a few people to be constructed during the later years. Even this lower construction cost, estimated $50 per capita by 1976, can only be partially charged against Bilharzia control.

Operation and maintenance costs for 1976 were $22 million for the 2.04 million people served, or $8 per capita per year (Annual Report ASA 1977). Again, this cost was for operating a fully developed urban water supply system, far beyond the needs for Bilharzia control.

The overall water consumption figure for both urban and rural systems was 47 cubic meters per family per month by 1976, or 990 liters per capita per day (Statistical Report by the Executive Director, July 1977 ASA). This is much greater than the amount required for effective Bilharzia control, which was about 50 liters per person (Cuman, 1975). Thus, less than 5/39, or about 15% of the costs should be charged to Bilharzia control.

Since the provision of piped water has many benefits in addition to the prevention of schistosomiasis, only part of the costs were attributed to the control program. Thus, the construction cost used in these analyses was $10 per capita and operation and maintenance cost was $1 per capita per year. The necessary cost of health education was assumed to...

Included in the annual $1 per capita cost, it was assumed that the water systems were highly effective, reducing 90% of the water contact and thus 90% of transmission. Sanitary disposal of excreta by the construction of latrines or septic tanks was not evaluated here since it appears to be relatively ineffective (Dhajen et al, 1978). The strategies evaluated included 4 different budget schedules where 1 to 5 control methods were used simultaneously, but with 4 different strategies compared, concentrating 80% of the money on each method in turn, and also dividing the money equally between the three methods (Table 2). It follows then that the endemic zone was divided into 2 parts, one with snail control and one without. In the area with snail control, transmission was completely interrupted but in the area without it, transmission was only decreased by the provision of water supply in proportion to the number of people served and the 90% reduction in their water.

Table 3, Distribution of Funds on Various Strategies: Water systems, drugs, and snails each received different percentages of the budget, varying from 1% to 33.9%.

Evaluation of Several Strategies for Puerto Rico: A comparison was made of several alternate strategies for disease control in Puerto Rico with an annual budget of US $1 per capita in the endemic zone. This equates to a total of $1,500. Funds were based on the three control methods, either individually (Strategy B), or water supply with sanitation (Strategy C), but always including all 3 methods in some division, mostly among the three methods (Strategy D). An estimate of both the population corresponds closely to prevalence determined by five-fold prevalence counts at all ages, during three years. Thus, the water population of Puerto Rico was estimated at 0.07 x 2,700,000 or around 189,000. It was arbitrarily decided that about 75% of the infected persons were monitored, and a total population of 1.5 million. Thus, the mean prevalence rate of disease in the endemic zone was 9.4.

Approving a total of $786,000 for chemotherapy and $364,000 for snail control.

For the ASLE 4, YIROT year, reduced allocation for doctor's costs was introduced. Dr. FUEEZD AICO MINH allocated a total budget of UG 41 per person in the home store, or about $1,500,000 in 1976 prices (preliminary estimate 2).

For diagnosis and treatment, the following amounts were set: $800,000 for drugs, $400,000 for water, and $150,000 each for snail control and other units. For snail control, $524,000 was allocated, with $262,000 for water, $60,000 for drugs, and $350,000 for other units. For water, $100,000 was set, with $50,000 for drugs and $150,000 for snail control. For other units, $333,000 was allocated, with $167,000 for drugs and $500,000 for water.

In a balanced strategy, about $500,000 would be available for snail control, just enough to cover the endemic zone. In Strategy B, when the surplus snail control funds were diverted to chemotherapy, a total of $524,000 would be available each year for diagnosis, covering the entire population in 3 years.

According to this budget plan ($1,500,000), the total budget distribution was calculated (Table 0). A distribution system was implemented, allocating $1 for each person in the endemic zone. From this budget distribution, slight adjustments were made for cases where the budget allocated to a certain method exceeded the amount needed for that method (Tables 4 and 5).

For the water supply program, construction would be evenly distributed throughout the disease-free zone outside of the snail control area. When the entire endemic zone was covered by snail control, water supply had a very noticeable effect. This occurred for Strategies B and D. The water supply program would include both construction and the annual cost of operation, maintenance, and health education.

The first year, all the funds would be used for construction but as more units were added the operations cost would increase until all funds were used for operation. The eventual, stable number of persons supplied with piped water was calculated by assuming all funds were used for operations maintenance and health education, for each of the strategies (Table 5).

In 1970, only 10% of the population in Puerto Rico did not have piped water, so the total population to be served is...

The endemic zone (if we ignore changes occurring from 1970 to 1976) was 150,000. Reduction in water contact due to this water supply program is thus the fraction of this 150,000 which is supplied with piped water (Table 9).

No relevant or understandable information is provided in this section.

Table 6, sample calculations for model reprising snail control (restated as strategy 18). See snail control budget = $564,000 covers entire endemic zone, thus no new infections after the first year. Water supply budget = $130,000. Chemotherapy: Eradication budget = $524,000. Treatment budget = $262,000.

Number of worm deaths due to drug program:
Prevalence in examined population, 0.096.
People examined: 326,000, 824,000, 596,000, 524,000.
Cumulative people examined: 524,000, 1,048,000, 1,500,000.
Infected people located: 49,000.

Mean worm load in infected people: 60.
Worms located: 296,000.
People treated: 26,000.
Proportion of worms treated: 0.97.
Worms treated: 287,000.
Worms killed by drug (90%): 258,000, 258,000, 258,000, 258,000, 59,000, 28,000, 238,000, 258,000, 120,000, 100,000.

Prevalence rate:
Initial infected persons: 141,000, 118,000, 95,000, 72,000.
Number of persons treated: 26,000, 28,000, 26,000, 25,000.
Number cured: 23,000, 23,000, 23,000, 22,000.
Persons treated but not killed (30,000 worms left each year).

A second set of strategies was evaluated, based on an annual budget of $750,000 which was the actual 1976 expenditure of the Health Department on schistosomiasis control. This represents an annual expense of $0.50 per person in the endemic zone. Funds were again allocated according to four possible alternatives, emphasizing either drugs, snail control, water supply, or else a balanced division of the funds between the three methods (Table 2). Spending $1 per capita annually.

"Separately emphasizing the use of drugs was clearly more effective than the other three strategies (Figure 3). Preliminary calculations showed that this was true for many other endemic areas as well, such as St. Lucia, Brazil, Egypt, and Tanzania. A second set of strategies utilizing the smaller annual budget also demonstrated the advantage of emphasizing chemotherapy, and snail control again ranked second (Figure 6). A balanced approach was the least cost-effective of the four strategies evaluated.

A more precise evaluation of cost-effectiveness was made by calculating the program cost per reduction in worm-years during the first four years of control and dividing by the total four-year budget, again demonstrating the ranking of drugs, snail control, water supply, and a balanced program, in that order (Table 8). Preliminary calculations for other endemic areas showed that the cost-effectiveness increased with increased worm burden as one would expect. Thus priority for international programs should be given to areas with high worm-burdens, such as northeastern Brazil or the Nile River valley.

A reduced budget of $0.50 per person was evaluated for Puerto Rico and no advantage was indicated by the cost-effectiveness analysis, in fact it was more cost-effective to use the higher budget (Table 8).

Table 7. FIRST YEAR BUDGET ALLOCATION FOR SCHISTOSOMIASIS CONTROL IN PUERTO RICO WITH A TOTAL ANNUAL BUDGET OF $0.50 PER PERSON IN THE WHOLE OF, OR $750, 000 PER YEAR, 1976 methods (scenario 2). Methods of allocation: Snail control, Drugs = $400,000, $200,000, $75,000, $75,000 respectively.

Figure 5. PREDICTED EFFECTIVENESS OF SCHISTOSOMIASIS CONTROL IN PUERTO RICO WITH AN ANNUAL BUDGET OF $1,500,000. NUMBER OF SCHISTOSOME WORMS IN

THOUSANDS.

Figure 6. PREDICTED EFFECTIVENESS OF SCHISTOSOMIASIS CONTROL IN PUERTO RICO WITH AN ANNUAL BUDGET OF $750,000.

Table 8."

COMPARISON OF COST-EFFECTIVENESS FOR SEVERAL STRATEGIES OF SCHISTOSOMIASIS CONTROL IN PUERTO RICO, 1976 COSTS. Cost per Year Control Strategy - Effectiveness in Infection Years Prevented 'Expense per Year Prevented' 1976 US $ per Infection-Year. 'Total Budget for years' Stratification drugs - 14 238 $252 US 3.05 Sterilizer = 10 18 3.6 Balanced = 10 132 3.93 Total Budget for 8 years $3 million Dosage 2 1.60 35 scenarios = 28 0.8 4.69

A comparison of all possible strategies for schistosomiasis control in Puerto Rico showed that emphasis on the new drug oxamniquine would be much more effective than continued efforts with the present strategy emphasizing snail control. The analysis also indicated that an intensive program of a few years duration would remain of low intensity.

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