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9. ABSTRACT

A model of how schistosomiasis is transmitted was developed and verified in Iran, using 13 years of data supplied from the Bilharziasis Control Project and the Dez Pilot Irrigation Project, Iran. The advantage of the model is that it requires fewer data inputs than prior models. A good fit was obtained between predicted and observed levels of infection. Values for meters of accessible snail habitats (those in contact with people) and the numbers of infected people were corrected to account for control measures used. The results indicated that a combination of chemotherapy, mollusciciding, and engineering is most cost-effective over the long term. The model is an effective instrument for analyzing the cost-effectiveness of various control strategies for eradicating the disease for certain periods of time or maintaining it at below some given percentage of the population.

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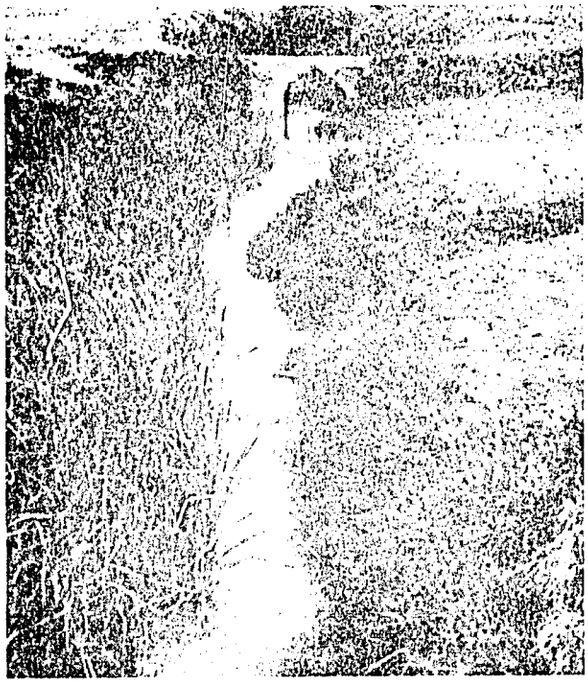

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DEVELOPMENT AND VERIFICATION
OF A
SCHISTOSOMIASIS TRANSMISSION MODEL

With Data From
Bilharziasis Control Project
and
Dez Pilot Irrigation Project
Khuzestan Province, Iran

by

Patricia L. Rosenfield

A dissertation submitted to the Johns Hopkins University in conformity with the requirements for the degree of Doctor of Philosophy

Baltimore, Maryland

1975

Frontispiece

IN

KHUZESTAN PROVINCE

IRAN , 1974

" ... any habitat more than one kilometer from a village was not considered as contributing to the transmission cycle since villagers generally did not go that far away from their areas ..."

(Chapter II)

Photograph by P.L.R.

ABSTRACT

A schistosomiasis transmission model is developed and verified using thirteen years of data supplied by the Bilharziasis Control Project and the Dez Pilot Irrigation Project, Iran. The procedure draws upon existing models to provide a practical field model involving the interaction of the meters of accessible snail habitats and numbers of infected persons. An advantage of the model, consciously sought, is that data requirements are fewer than those demanded in prior disease control models. Values for meters of accessible snail habitats (habitat actually visited by the population) and numbers of infected people were corrected to account for control measures used. Thus, meters of accessible snail habitats included only those not molluscicided nor improved by engineering measures, and numbers of people infected was corrected for the effect of chemotherapy. A good fit was obtained between predicted and observed levels of prevalence. Sensitivity analyses indicate that model predictions of prevalence are sensitive to high values of the de-infection rate when observed prevalence is high and to low values of the incidence rate when observed prevalence is low. Special attention to accuracy is warranted in the collection of data on de-infection rates in high prevalence areas and in the collection of incidence rate data where prevalence is low.

The Iranian effort to expand agricultural development through

increased water availability illustrates problems faced by all developing areas where schistosomiasis is endemic or a possible threat. From the standpoint of disease transmission the major impact of the irrigation project in Iran was to increase the meters of accessible snail habitats.

To demonstrate the use of the model in evaluating the cost-effectiveness of alternative disease control strategies, the Bilharziasis Control Project program of combining several control measures was compared with alternative strategies using one control measure at a time. Costs were determined for three types of control measures used by the Bilharziasis Control Project based on records of expenditures for labor, equipment, materials, and transportation. Average total costs calculated from the first year of control use through the last year of available data, 1964 through 1973, were 5 rials per meter of accessible snail habitats for mollusciciding, 17 rials per meter of accessible snail habitats for engineering measures, and 10,000 rials per chemotherapy treatment.* Three analyses of control measure effectiveness were considered. In the first, assuming an annual allocation equivalent to the total annual cost actually expended in each successive year, the model was used to compare alternative control strategies for the years of Bilharziasis Control Project expenditures and for ten hypothetical years without treatment to evaluate the long-term effects of different controls. In the second, assuming a high

* at 1974 exchange rates, the costs equal 0.07 US$, 0.25US$,and 148.00 US$, respectively.

constant annual expenditure, three separate control measures were compared for their effectiveness in reducing prevalence for years of project expenditures and for 22 years following hypothetical cessation of control assuming a low constant level of expenditures, equal to less than half of the Bilharziasis Control Project's average annual rate of expenditures. In the third, the Bilharziasis Control Project's combined control program was examined for its effectiveness in maintaining low levels of prevalence over time. The results indicated that a combination of controls used consistently over a period of years was the most cost-effectiveness strategy. In the first two analyses, chemotherapy, mollusciciding, and engineering showed the same results. Chemotherapy, used alone, was dramatically effective as long as it continued, but once stopped the model indicated that prevalence rose rapidly to values higher than the initial one. Mollusciciding used alone, in the first case did not decrease prevalence below the level at the start of treatment, in the second case reduced prevalence only slightly, and when stopped in the model, prevalence rose to the same high level reached when chemotherapy ceased. Engineering measures, used alone, also did not reduce prevalence in the first analysis below the level at the start of treatment but did reduce prevalence with the higher expenditures in the second analysis. In both tests, when engineering measures were stopped in the model, prevalence continued to fall for four years then rose slowly to

level off at values of prevalence slightly below those obtained after cessation in the model of the other control strategies. The third analysis indicated that low constant level of expenditure was not sufficient to maintain low prevalence levels; prevalence began to rise after the first year of low expenditure.

The conclusion drawn from these analyses is that, in addition to the combined controls program demonstrating the most success in reducing prevalence, in order to maintain low levels of prevalence it would be necessary to continue the combined program at a higher rate of expenditure than considered. An alternative design for a combined control program requiring initial high expenditures for engineering measures coupled with concomitant chemotherapy and the use of mollusciciding as a maintenance measure to achieve and to maintain low prevalence levels in a fixed period of time is suggested.

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Photograph A. *Bulinus truncatus*
The snail vector for
Schistosoma haematobium

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CHAPTER ONE

The schistosomiasis transmission model developed and verified in this study is based on data from Khuzestan Province, Iran where only urinary schistosomiasis, caused by *Schistosoma haematobium*, is found. Th following chapter describes the essential elements of the life cycle and pathology of *S. haematobium*, and measures used to control the disease in order to assist in understanding the model.

Background and Transmission of Schistosomiasis

Schistosomiasis, known also as Bilharziasis[1], is an ancient disease which depends upon water for transmission. Increased water availability, due to irrigation or impoundment schemes, increases prevalence of the disease. Therefore, economic development projects, such as large scale agricultural ones, are likely to increase the spread of schistosomiasis by providing more habitats for the intermediate snail hosts of the disease. This is particularly true in areas with low levels of economic development where inadequacies of human waste disposal facilities, deficiencies in domestic water supplies, and lack of health education in rural villages of tropical and subtropical developing countries are conducive to the spread of schistosomiasis. At

---

[1] Unofficially so-called in honor of Dr. Theodor Bilharz, 1825-1862, a German physician, who isolated the organism that caused the disease during a post mortem in 1851. In 1966, the World Health Organization officially designated the name as schistosomiasis in the interest of uniformity.

present, schistosomiasis is one of the world's leading health problems, "coming next to malaria as a parasitic disease" (Vogel, 1973, p. xvii). It affects over 200 milion people in countries of the Far East, Middle East, Africa, and Latin America (Figure 1) and it is "growing in seriousness in just those largely rural nations that are struggling to improve ..." (Weir, 1969, p. 7).

There are three species of schistosomes, each with its own snail host[2], and with a variety of areas suitable for development of the snail population. All three species follow a similar life cycle. A particular species, *Schistosoma haematobium*, in a particular type of water project, irrigation, illustrates the essential elements of the disease.

Successful transmission and completion of the many-staged cycle of schistosomiasis depends on the presence of shallow water areas in which snail vectors can thrive and which man uses and contaminates (Figure 2). Such areas include swamps and ponds where weeds and algae often grow. In the Dez Project area described in this study, snails also thrive in canals and drains. Eggs of the schistosomes (Table 1) are passed along with human urine* into waters. When the water temperature ranges between 10°C and 32°C, the eggs hatch into the first larval stage, miracidia, approximately 500 microns in length. The free swimming miracidia must

---

[2] *Schistosoma mansoni* - snail : *Biomphalaria*
Schistosoma haematobium - snail : *Bulinus*
Schistosoma japonicum - snail : *Onocomelania*

* for *S. haematobium* the eggs of *S. mansoni* and *S. japonicum* are passed in human feces.

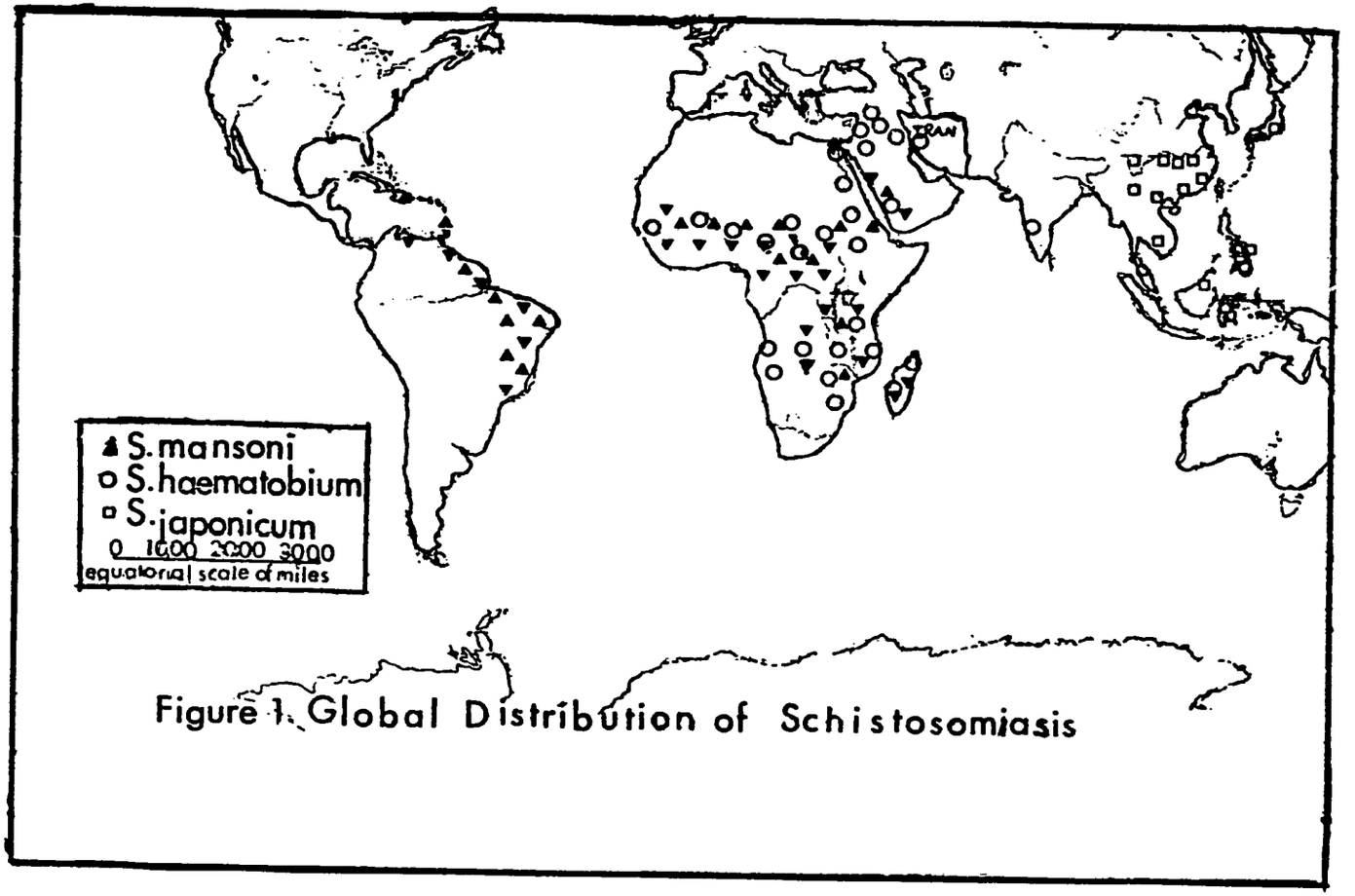


Figure 1. Global Distribution of Schistosomiasis

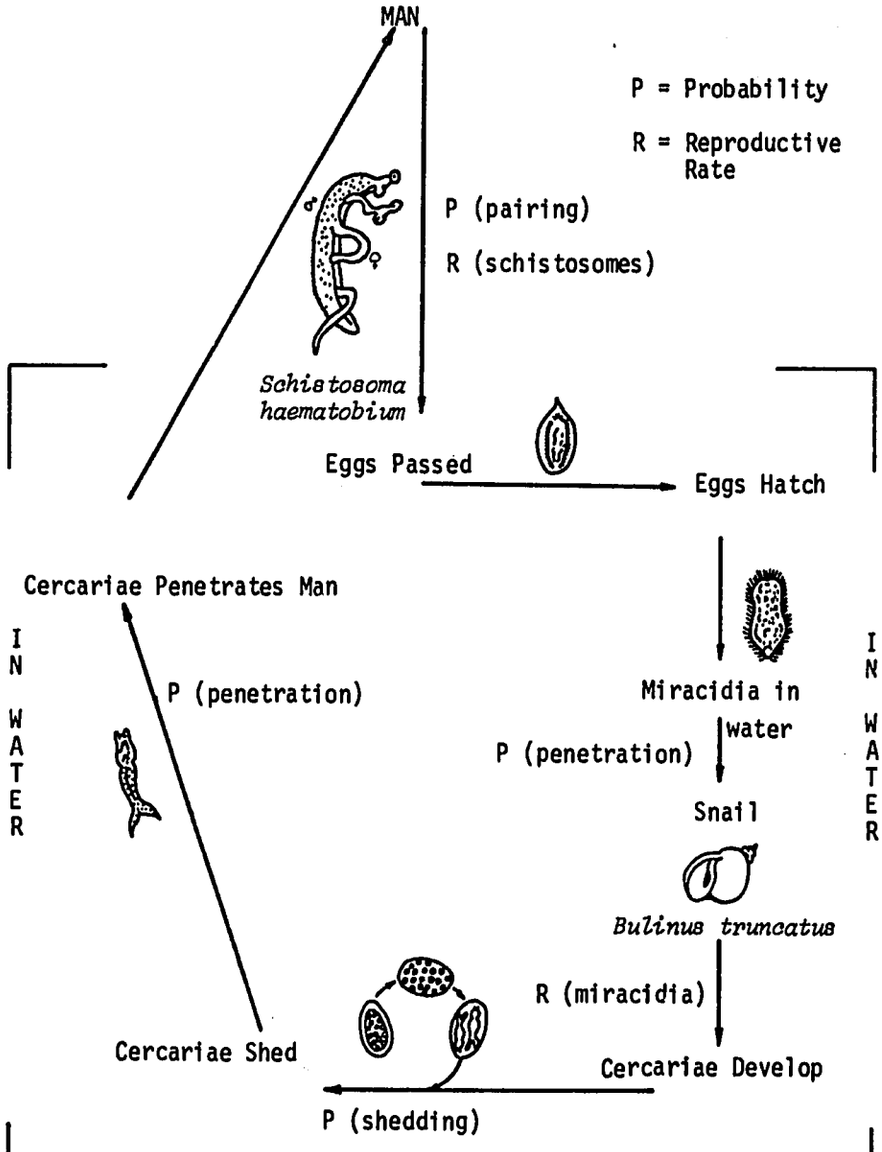


Figure 2. Life Cycle of *Schistosoma haematobium*

reach appropriate snail hosts within 8 to 32 hours. After penetrating the soft tissue of the snail's foot, miracidia, by means of asexual reproduction, become mother then daughter sporocysts. The latter develop into cercariae, the second larval stage in the schistosome cycle. From one infestation in a snail, " ... many thousands" (Wright, 1967, p. 5) of whitish, motile, sexually differentiated cercariae emerge, each covered with little hairs. Bright light stimulates the release of the cercariae from the snail. In Iran, as in many other countries, most emerge between 10 a.m. and 2 p.m., a time which corresponds in that area to the period of time when most people have contact with the water.

Table 1: *S. haematobium* Life Cycle Data

Schistosoma haematobium		*Bulinus truncatus*
adult, male :	1.3 x .09 cm.	range in size :
adult, female :	2 x .025 cm.	1 - 14 mm.
eggs :	140 x 60 microns	
egg production :	20-290 per day	
cercariae :	500 x 60 microns	

The fork-tailed cercariae are attracted to humans and can penetrate any part of the body — foot, finger, or throat when water is ingested. They do not need an open sore or orifice to enter. Upon entrance, the cercariae lose their tails and are known as schistosomules. These move easily through sub-cutaneous tissues to the veins in a complicated migration involving heart, lungs, liver, and bladder. The schistosomules develop into adult

male and female worms in the liver where mating also occurs. Unlike most parasites, schistosomes reproduce sexually; thus, for the disease to be transmitted, an individual must be infected by both sexes. After fertilization in the liver, females migrate to the bladder and deposit eggs in the blood vessels of the submucosa of the human bladder. Miracidia develop within the eggs. As they become ready to hatch, a substance is released which causes the bladder to contract, which, in turn, forces the eggs into the lumen (passageway) of the bladder . From there, the eggs are passed during urination. The eggs are usually passed 10 to 12 weeks after the initial infection (Jordan and Webbe, 1969, p. 38-67).

Pathology of Schistosomiasis

Harm to the human host results from the incomplete excretion of the eggs and worms:

> The excretion of eggs by an individual constitutes a public health menace rather than a hazard to the patient and if all eggs produced by the female worm were excreted serious pathological consequences of schistosomiasis would be rare. Regrettably, however, nature has decreed that many eggs remain in the tissues of the host and, apart from adult worms in aberrant situations, these are responsible for the pathological changes associated with *S. haematobium.*
>
> (Jordan and Webbe, 1969, p. 68).

Changes result from accumulations of eggs over years of re-infection; while rarely fatal, the physiological changes produce chronic debilitating symptoms. Eggs which are not expelled from the bladder become calcified as they accumulate in the submucosa

and lower ends of the ureters. Other changes produced by trapped eggs include lesions and sandy patches on organ walls and fibrosis. These create distortions of organs and difficulties in urination. Usually surgery is necessary to alleviate suffering and to prevent kidney failure (Jordan and Webbe, 1969, p. 76). Other systems of the body are also affected by worms laying eggs in atypical places. This can cause inflammations, or possibly malignancies, of the appendix, spinal cord, and lungs. Migrating worms sometimes settle in these same atypical, sensitive areas and can cause death; however, schistosomiasis is not usually directly fatal. It is more often an indirect cause of death.

The dramatic destruction of tissues and organs of the body receives medical attention where such is available, or sought, but the real problem of the disease is the insidious malaise it produces. Effects such as edema, lung infections, micturation, cramps, and feelings of weakness are not dramatic. They result, however, in:

> chronic debility with under-estimated overt morbidity and mortality; ... the damage done to the individual and the community is much more than meets the eye ... (Farooq, 1973, p. 422).

It must also be noted that with infections of *S. haematobium* spontaneous cures occur naturally. Although the reasons for this are uncertain, it is thought that the *S. haematobium* worms have a shorter life span in the human host than worms of the other species of schistosomiasis. If re-infection could be stopped, this species

of the disease would be less serious. Some people, also for reasons not clearly understood, develop resistance to the disease after several years of re-infection.

Control of Schistosomiasis

Successful control of schistosomiasis depends upon interrupting the cycle of disease. This is tried in many ways with specific techniques used separately or in combinations to eradicate areas of snail vector infestation, to eliminate parasite infections in humans, and/or to eliminate contacts between man and snail. Control measures tried all over the world are:

1) Molluscicidng - eradication of snail populations by means of chemicals

2) Engineering measures - drainage of swampy areas and maintenance of canals and drains - e.g., elimination of weed growth

3) Biological control - use of predators of the snail such as flies, fish, and ducks, and competitors such as other snail species

4) Chemotherapy - elimination or significant reduction of parasites in humans by means of schistosomicidal drugs

5) Sanitary improvements - introduction of plumbing into dwellings including drinking water provisions, latrines, waste disposal facilities, and water for bathing and laundering

6) Health education - instruction about health and disease prevention, concentrating on fundamentals, such as the use of sanitary facilities and avoidance of polluted water

Difficulties are associated with applications of each control

measure.

Mollusciciding which attempts to eliminate snail populations is ineffective because of the snail's ability to reproduce asexually. A single snail which survives a siege of mollusciciding can produce new generations within a few months (Jordan and Webbe, 1969, p. 192). Molluscicides now used are evidently non-toxic to humans and to most aquatic life. There is, however, a lack of studies about the different toxicities of molluscicides and possible chemical interactions between molluscicides and fertilizers used in adjacent fields. Shiff (1972, p. 325) has suggested that residual molluscicides in the water may be directly dangerous to human health or upset the aquatic ecological balance.

Engineering measures have major drawbacks which include high costs for heavy equipment, materials, and semi-skilled labor. These measures involve one large expenditure or capital cost with relatively minor maintenance costs. They can at the same time, however, offer permanent elimination of infested waters either by changing swamps to cultivated fields or through weed clearance of canals and drains (McJunkin, 1971, p. 34-35). The largest problem involved in the use of this effective control measure is the necessity for routine surveillance by trained labor crews.

Biological controls may have unpredictable effects which may be far reaching in their ecological impacts (Ferguson, 1972, p. 85). Until these controls are better understood, more extensive field

testing is necessary. For instance, sciomizid fly larvae which destroy adult snails by burrowing into and devouring them have proved successful in laboratory testing (Knutson, personal communication, 1973). However, they have not yet received adequate field testing to demonstrate that the adult flies are not disease carriers to villagers. Other snail predators, parasites, and competitors have been tried, but each has had distinctive drawbacks. One effective control snail, *Tarebia granifera,* is a snail host for lung flukes of the genus, *Paragonimus,* which infect man (Jordan and Webbe, 1969, p. 182). Biological control has had varying degrees of support. In the early 1930's, when it was observed that ducks in the Thames River, London, ate snails, ducks were imported as a control measure in the Sudan. The experiment failed when the ducks were stolen by field workers (Humphreys, 1932, p. 249). In 1974, the Dez Project in Iran, imported a special species of fish with an appetite for vegetation. Presumably these fish will not only eliminate the snail's food supply but will also provide protein for people in the area. Effectiveness of the fish, however, remains to be seen as vector snails for schistosomiasis can exist on micro-organisms and any algae that the fish cannot eat.

Chemotherapy is effective in killing adult worms in the human host. To date, however, no drug tried has been able to confer immunity; as a result the frequency of reinfection in endemic

areas is high. Most of the drugs cause serious side-effects such as nausea, dizziness, and depression. Sometimes certain drugs induce worm migration to vital areas such as the brain or heart. In some cases, the drugs are hallucinagenic, mutagenic, teratogenic, and/or carcinogenic.

All of the above measures, even when effectively controlling schistosomiasis, have undesirable consequences which particularly disturb environmentalists. Sanitary improvements and health education have only desirable consequences to their primary goal of reducing the number of cases of schistosomiasis. Most health scientists agree that these measures are beneficial and important (Wolman, 1953, p. 557; Jordan and Webbe, 1969, p. 173; Howard, 1972, p. 10). Other researchers have noted the variety of difficulties (McJunkin, 1971, p. 16) involved in introducing them. Weir (1969, p. 7) notes that many villagers consider urinating in the fields a way of keeping their homes clean. Thus, even when latrines are provided, there is a reluctance to use them. This is a special problem for *S. haematobium*, since it is spread by urination. Hesitation to use sanitary improvements and health education for control measures is thus based on the belief that changes involving sanitation and drinking water require attitudinal changes in tradition bound populations and may take generations to implement (Scott and Barlow, 1938, p. 646). There is room for argument. In the Dez Project, for instance, Goodell

(personal communication, 1974) reports that the population is receptive to change and welcomes changes that will improve their living conditions and health. Dez may not be an isolated phenomena. In the People's Republic of China, in Japan, and in Puerto Rico, where schistosomiasis reportedly has been controlled, sanitation improvements and health education have received major emphasis among control measures and have not been rejected by their tradition-respecting peoples (Horn, 1970, p. 70; Yokogawa, 1972, p. 508; Cline, 1972, p. 98, respectively).

Since the effectiveness of control measures such as molluscicidings, engineering, and chemotherapy is not difficult to evaluate, these controls are generally used. A basic reason for lack of emphasis on social measures of sanitation and health education as control measures appears to be the difficulty of quantifying results in specific projects and thus providing a basis upon which to obtain financial support. Such cost considerations are discussed in Chapters IV and V.

CHAPTER TWO

The Need for Models

The potential for increased transmission of schistosomiasis becomes greater as more irrigated acreage is required to increase food production. Thus irrigation projects threaten as well as benefit unless parasitic disease dangers are considered *ab initio*.

Irrigation planners do in fact recognize that their projects will have an impact on the transmission of schistosomiasis. What they need to know is how to incorporate in design and operation the most effective disease control measures. A simple methodology is needed to estimate reliably the transmission of schistosomiasis which will result from a particular project within a particular area.

To be most useful models must concentrate on the specific goal of disease control, preferably with minimum data demands or involved mathematical concepts. In fact, the more straightforward such estimation methods are, the more likely they are to be used. However, certain minimum criteria are required in an analytical model to be used in estimating the possible spread of schistosomiasis in an irrigated area:

1) the model must be dynamic, not static, reflecting changes within an area over a period of time

2) the model must be selective, not obfuscative, utilizing the critical elements of the transmission cycle.

Appropriate mathematical models can illustrate the impact of an irrigation project on people and their environments. In addition, they may also illustrate which control measures among many possibilities are likely to be the most cost effective under specified conditions.

Existing Schistosomiasis Models

Mathematical models have been developed to analyze the dynamics of the transmission of schistosomiasis. Major characteristics of representative models are summarized with particular emphasis on field utility in Table 2. The models have been grouped into three generic categories: population ecology models; catalytic models; mathematical epidemiology models. The first type is based on life table constructions for the snail and human populations and, except for Jobin's model (1972), require the limiting assumption of steady-state disease conditions. The catalytic models are developed from the theories and equations derived by Muench (1959). They, too, assume steady-state disease conditions. The published mathematical epidemiological models involve highly complicated mathematical expressions and expertise. They have not been tested with any field data. The two unpublished mathematical epidemiological models are less complicated mathematically. The first, Kodlin's (1971), again applies to steady-state disease conditions, while the second, Fagan's (1973),

TABLE 2 — REPRESENTATIVE SCHISTOSOMIASIS TRANSMISSION MODELS

Model Type and Author	Contributions of Author	Limitations of Model
	POPULATION - ECOLOGY MODELS	
George MACDONALD 1965	Established importance of special nature of schistosomiasis: probability of worm - pairing... mean worm load ... critical worm load	Actual probabilities and mean load are difficult to estimate in field
Nelson G. HAIRSTON 1962, 1965a, 1973	Developed and solved ecological life table equations for 4 stages of life cycle of schistosomes for all species with field data from Egypt, Syria, Philipp. Established that superinfections are wasted in snails ...	Assumption of steady-state conditions is crucial Requires detailed information on mammal and snail populations
Gerald WEBBE 1965a,b	First to explicitly include environmental conditions: weather and climate in population model ... Through detailed fieldwork established cercarial infection rate was not directly proportional to prevalence rate ...	Specifically designed for snail population ...
William JOBIN 1967, 1970, 1972	Developed and verified with field data dynamic simulation model for aquatic snail population - established effects of: resources (food-water), crowding, weather, desiccation, molluscicidings on snail populations in laboratory and in field work ... Snail-based simulation model used to estimate costs and benefits of different control measures for Egypt ...	Requires detailed information on mammal and snail populations ... Assumes intense disease transmission ...

TABLE 2 — REPRESENTATIVE SCHISTOSOMIASIS TRANSMISSION MODELS (Continued)

Model Type and Author	Contributions of Author	Limitations of Model
	CATALYTIC MODELS	
Nelson G. HAIRSTON 1965b	First to apply Muench's catalytic models to schistosomiasis .. Established good fit between 2-stage (infection and permanent loss of disease) catalytic model and age/prevalence data from Egypt, Syria... Demonstrated importance of natural loss rate of disease ... Discussed possible uses of infection and loss constants in analyzing immunological tests... Reduction of necessary data: good fit for 0-15 yr. olds.	Assumes steady-state epidemiological situations Assumes immunity occurs in older ages (death not a factor of disease loss, in model) ...
R. F. STURROCK & Gerald WEBBE 1971	Fit age-prevalence curves of 3 snail species by simple, modified simple, 2-stages catalytic curves (Determined last most appropriate) Established by age-specific prevalence curve: infection is result of number of effective miracidium contacts per 1000-snails per week and loss force is expression of differential death rate of infected and uninfected snails - not immunity - and is equal to number of deaths per 1000-snails per week ...	Assumes steady-state situation Assumes age of each snail can be determined ... Does not consider human aspect of transmission cycle ...
Joel F. COHEN 1973	Improved catalytic model by addition of human mortality and emigration terms (constant over age) plus snail mortality terms ... If mortality is ignored, force of defection overestimates the true rate of loss of infection by half.	Linear independence of susceptible population and infected population ... Assumes immunity Assumes steady-state

TABLE 2 — REPRESENTATIVE SCHISTOSOMIASIS TRANSMISSION MODELS (Continued)

Model Type and Author	Contributions of Author	Limitations of Model
	MATHEMATICAL EPIDEMIOLOGY MODELS	
G. M. TALLIS & M. K. LEYTON 1966, 1968 (Leyton) 1969	1st Random-model ... Developed stochastic parasite-population model based on additive "antigenic information trajectory" (host's body responds to parasite) ... Paper #2: Refined model for pairing probability of schistosomes: Paper #3: Refined model for size of parasite population (death and immigration rates)	Disregards: --death of host (human)... --host (human) resistance... --seasonal variations... --competitor effects on parasite... --life cycle of intermediate host (snail)...
William GOFFMAN & Kenneth S. WARREN 1970	Applied Kermack-McKendrick epidemiology theory to schistosomiasis with expressions for all 4-stages of life cycle... Established: --threshold density of susceptibles (human and snail) --critical level (breakpoint) of density of snails crucial for epidemic... --total eradication of snails not necessary for control of disease (mathematically)...	Assumes: recovery rate of those with disease is zero... Assumes: rates of infection, removal, and influx constant for all ages (human/snail) Requires: field-testing (Macdonald and Hairston) to determine reliability... Data difficult to collect and estimate in field
Ingemar NASELL & Warren M. HIRSCH 1971	Developed deterministic and stochastic models for schistosomiasis with threshold effect Established: (where no disease exists) for few, new cases-disease dies out; for many, new	Assumes: --human and snail populations constant over time.. --constant rate of worm-egg

TABLE 2 — REPRESENTATIVE SCHISTOSOMIASIS TRANSMISSION MODELS (Continued)

Model Type and Author	Contributions of Author	Limitations of Model
Ingemar NASELL & Warren M. HIRSCH 1971 (Cont'd.)	cases-disease becomes endemic.. Rank of efficiency of control measures (based on model): mollusciciding, chemotherapy, chemotherapy and sanitation..	output.. --death rate of adult parasites independe of age, sex.. --snail begins cercariae shedding as soon as infection --no immunity in humans.. Requires extensive data and math background to apply...
MATHEMATICAL EPIDEMIOLOGY MODELS ... UNPUBLISHED (1974)		
Dankward KODLIN 1971 (A.I.D.)	Simulation model (Iran and Egypt data: mass-chemotherapy most effective control measure... (Cf. Chap. IV) Cost-benefit analysis: snail control plus mass chemotherapy preferred...	Assumes: --critical density not important for eradication goal... --no seasonal variations... --no immunity... Re-infection of humans not explicit - i.e., mass chemotherapy overstated for long-term effectiveness
A. FAGAN 1973 (L.Knutson)	Simulation model for biological control of snails by sciomyzid flies: Sensitive variables are: --snail and fly fecundity; snail and fly egg survival... Important variables: infection rate of snails; mortality of pupae and adult flies; number of snails killed per fly larvae application..(Based on laboratory data)	Assumes: constant input of miracidia from humans; (other human factors not included).. Requires: detailed data on snail and fly populations; field-testing...

examines one particular control method. The one dynamic model by Jobin (1972) requires extensive information on both snail and human populations.

Table 3 contains the data requirements for most of the transmission models in Table 2. All of the data are essential for understanding disease conditions in a particular area. Many control projects continue to collect this information beyond the time necessary for its useful application in utilitarian models. At the same time, such projects often do not collect information that has practical significance due to a lack of appreciation of the criteria necessary for practical models.

In addition to these problems for modelers of the disease, peculiarities in the life cycle of the schistosomes create complications. Unlike other parasitic diseases such as malaria, schistosomiasis requires the presence of both male and female worms inside the human host for parasite reproduction to take place in order to continue the transmission cycle. Extensive work has been done in modeling malaria, lucidly described by Bailey (1957), but schistosomiasis modeling would be helped by field information on the probabilities of pairing of worms within the human host and of penetration by male and female cercariae. With such additional information (extremely unlikely to be available) this peculiar characteristic of schistosomiasis could be included in a stochastic model that uses probability terms. Some data are

TABLE 3 — DATA NECESSARY FOR REPRESENTATIVE TRANSMISSION MODELS

Data Requirements Re HUMANS

Population:
- Age / sex distribution
- Birth rate/ age class
- Death rate / age class
- Prevalence / age class
- Incidence / age class

Environment:
- Proximity of homes to water
- Sanitary conditions
- Frequency of contact with infected water / age class
- Nutritional and health level / age class
- Health facilities

Data Requirements Re SNAILS

Population:
- Age distribution
- Birth rate / age class
- Death Rate / age class
- Species
- Density of infected snails

Environment:
- Dimensions of available habitats
- Food supply
- Velocity of water
- Light conditions
- Pollution of water (degree and kinds)
- Chemical conditions of water
- Seasonal variations of population

Data Requirements Re SCHISTOSOMES

Population:
- Probabilities of pairing, egg hatching, miracidia and cercariae penetration
- Mean worm load in humans / related to number of eggs passed
- Reproductive rate in humans
- Reproductive rate in snails

TABLE 3 — DATA NECESSARY FOR REPRESENTATIVE TRANSMISSION MODELS (Continued)

Date Requirements Re SCHISTOSOMES (Cont'd.)

Population:	Existence of compensatory mortality* Species in humans and reservoir hosts
Environment:	Effects of chemotherapy / immunity in humans Effects of mollusciciding / immunity in snails Existence of break - point - below which the probability of parasites mating is so low that the disease cycle is broken

* Reaction of parasite population to environmental changes, if control measures eliminate large numbers of parasites through eradication of snails compensatory mechanisms may result in higher reproduction rates of the parasite in man. Thus, the disease may be as prevalent as before controls. This reaction, however, has yet to be demonstrated for schistosomes, although it does occur in other animals.

available from Cheever's (1968) work and from that of Goldsmith et al (1967) from examining *S. mansoni* worms in post-mortem and surgical studies, but there is not enough to calculate probabilities required for population ecology models. There is some debate on the importance of this information. Macdonald (1965) considers that the probability of pairing constitutes a, "significant factor" (p. 492). Olivier, on the other hand, (personal communication, 1973) believes that it is sufficient to assume a probability of pairing equal to one if a person is passing eggs. Since this kind of information has not yet been collected in an irrigated area, surrogate measures are used in the model developed in this study.

Another major complication in the modeling of the disease is the existence of intermediate snail hosts. Unlike tuberculosis, influenza, or syphilis for which detailed mathematical models exist (Grundy and Reinke, 1973; ReVelle, 1967), schistosomiasis is not a directly contagious disease. Without man, snail, and water as the source of contact, the disease would not be transmitted.

To account for the man-water-snail-water-man interaction, previous modelers have emphasized the need for reasonable estimates of snail population density and the frequency-duration of human contact with snail habitats. In addition, evaluations of the probabilities of infection have been attempted for the different stages of the parasite in relation to its two hosts, e.g., the probabilities of eggs hatching upon release from humans and of

cercariae penetrating upon release from snails (Figure 2). Unfortunately, such information is rarely collected in sufficient detail because of the large number of manhours and elaborate effort required. Along with probability factors, snail density and extent of human water contact are frequently estimated on the basis of few or no observations in the models described above. For reliable estimates, extensive field observations are necessary. Thus, in the model developed below surrogate terms are examined.

Schistosomiasis Transmission Simulation Model

The models discussed and outlined in Table 2 have been useful in clarifying the essential parameters in the disease transmission cycle. Because of the meticulous work done on them, they are considered springboards for new possibilities. Their usefulness as practical tools for decision making is, however, limited by two major considerations. Most of the models apply only to steady-state or endemic conditions; thus, they cannot account for the effects of environmental changes. All of the models, moreover, require for reliable results such detailed snail and human population information that they may be considered too data-dependent for practical use. The model described below has been developed to circumvent some of these needs and requirements.

Although the development of the schistosomiasis transmission simulation model (STS) is problem-specific, broader applications

of the model are discussed in Chapter IV. These include uses of the model to predict the impact of irrigation projects on the transmission of schistosomiasis and to estimate cost-effective strategies for control of the disease. The structure of the model is presented below by discussion of the equations, with a table of notation (Table 4), verification of the model, and sensitivity analysis.

Basic Transmission Equations

The two fundamental processes of infection and de-infection of schistosomiasis may be expressed as one simple rate process by the following equation (Muench, 1959, p. 45):

$$dY / dt = A(1-Y) - BY \qquad (1)$$

where Y is the fraction of the population infected with schistosomiasis, A is the force of infection, B is the force of de-infection. Equation 1 states that the rate of change in schistosomiasis prevalence is a function of the rate at which healthy people become infected and infected people lose the disease. An important assumption in the equation is that as infected individuals lose the disease, they join the pool of susceptible individuals. In contrast to previous models (Hairston, 1965b), immunity to re-infection is not considered in this model. With *S. haematobium* infections there is reason to doubt that immunity plays a significant role in the disease cycle (Bueding, personal communication,

TABLE 4 — STS EQUATIONS AND NOTATION

$$A = b_0 (H^{b_1} \times P^{b_2}) \qquad \text{(regression)}$$

$$I = \frac{A}{A+B} [1 - e^{-(A+B)}] \qquad \text{(transformation)}$$

$$Y_{t+1} = I (1-Y_t) - BY_t + Y_t \qquad \text{(simulation)}$$

A = force of infection per village.

b_0 = intercept of line of best fit in regression equation.

H = accessible snail habitat (meters per village).

P = people infected (number per village).

b_1 = regression computed exponent of H.

b_2 = regression computed exponent of P.

I = incidence rate per village (fraction of people that becomes positive over one year).

B = force of de-infection per village (natural loss rate).

e = base of natural logarithms.

Y_t = fraction of population positive in year of analysis per village.

Y_{t+1} = fraction of population positive in following year per village.

1974).

A solution for Equation 1 for the boundary conditions Y = 0 at t = 0 has been given by Muench (1959, p. 45):

$$Y = \frac{A}{A+B} [1-e^{-(A+B)t}] \qquad (2)$$

Structure of Schistosomiasis Transmission Simulation Model

The STS model is based on three equations derived from the basic transmission Equations 1 and 2. In the STS model, the numerical values for A have been determined for several villages from 1964 through 1973 from data collected by the Bilharziasis Control Project (BCP) staff through annual examination of a selected group of 0 to 10 year olds initially diagnosed as negative on the basis of 3-day urine tests. These field values of A are directly related in the model to transmission factors of the disease, snail habitats and number of people infected, by regression analysis. After several different trial regressions, the most successful equation for estimating A was found to be the interaction of meters of accessible snail habitats (H) and number of people infected (P):

$$A = b_0(H^{b_1} \times P^{b_2}) \qquad (3)$$

where b_0, b_1, and b_2 are determined in the regression analysis.

The force of de-infection, B, is the natural loss rate of the disease. The value used in the model was estimated from steady-state data to be 0.2, and is considered constant over all ages and years in the model. The value agrees closely with values estimated by Hairston (1965b) for *S. haematobium* in Syria and Egypt.

Estimates of the forces of infection and de-infection are used in the simulation of changes in prevalence over time. The time unit for the model is one year because that is the unit of time the BCP used for their data collections. Simulation of prevalence is accomplished with iterative use of the following equation:

$$Y_{t+1} = I\ (1-Y_t) - BY_t + Y_t \qquad (4)$$

where Y_t is the fraction positive in the beginning of year t, B is the force of de-infection, and Y_{t+1} is the fraction positive predicted for the end of year t or beginning of year t+1. I is the fraction of uninfected people who become positive at the end of one year. I can be expressed as a function of A and B by solving Equation 2 for Y_t when t = 1:

$$I = Y_1 - Y_0 = \frac{A}{A+B}\,[1 - e^{-(A+B)}] \qquad (5)$$

Discussion of Regression Equation

In the STS model, by means of regression analysis, values of A from 14 Dez Pilot Irrigation Project (DPIP) villages are

quantitatively related to the most important environmental variables involved in the transmission of the disease. The choice of these variables was derived from careful analysis of the data available from the different villages in the project area.

Two essential elements in transmission models are: 1) transmission of the disease from snails to people, and 2) transmission of the disease from people to snails. With regard to the first, researchers have usually considered it essential to measure the number of snails per meter of habitat. In the BCP area, Chu, the Project Malacologist, had established that the number of infected snails in any given snail habitat was low, generally less than one percent of the total snail population (1967, p. 9). Thus, the BCP staff concentrated on controlling the disease without making further density measurements.

Certain snail information, however, is meticulously recorded in the Quarterly Reports and files of the BCP. This includes:

1. location of habitats infested by *Bulinus truncatus*
2. area, perimeter, and (sometimes) volume of habitats
3. degree of human contact with habitats
4. control measures used to eliminate habitats.

The information used for the STS model was verified and expanded by Engineers Mansoori of BCP and Hebert of BCP and the Near East Foundation.

During development of the STS model, each measure of

accessible snail habitat, area, perimeter, and volume, was carefully examined for significance in predicting incidence. Based on discussions held in Iran, any habitat more than one kilometer from a village was not considered as contributing to the transmission cycle since villagers generally did not go that far away from their areas. For this analysis it was possible to determine from BCP maps which habitats were within a one kilometer radius of the villages. Of these, only those habitats that were known sites for human contact, as designated by BCP engineers, were included in the regression analysis. These are referred to in the following discussions as "accessible snail habitats" or H. In addition, only those habitats that were not treated during force of infection measurement periods for each year were included in the regression analysis. The most significant data in the trial correlations proved to be the perimeter of accessible snail habitats, such as swamps and ponds, and the lengths of canals or drains nearest to a village within the one kilometer radius.

The most desirable variable to represent the transmission of the parasites from people to snails is the number of eggs reaching snail-infested waters. Unfortunately, few egg counts were made by BCP. Thus, the number of people infected in a village over time was used as a surrogate for egg counts.

Regression equations were examined using different units of the above variables to determine the most valid predictors of A.

The variables were used separately, together, and in combination with an interaction variable. In every trial correlation, the most successful term for predicting infection force has been the interaction of the two independent variables, meters of accessible snail habitats and numbers of people infected as expressed in Equation 3. Because the regression equation is non-linear, it was necessary to use logarithmic forms of the data in the analysis. The regression results, using information from the Dez project, discussed in more detail in Chapter III and Appendix I, are:

$$A = 5.675 \times 10^{-6} \left(H^{1.109} \times P^{.455}\right) \qquad (6)$$

$$t=4.421 \quad t=5.125$$

$$R^2 = 0.69$$

$$F = 21.54 \quad \text{(degrees of freedom = 2,19)}$$

A = force of infection

H = accessible snail habitat, in meters

P = number of people infected

The values of t and the F ratio for the regression are highly significant ($P < .01$).

Using the number of infected people to predict the rate of people becoming infected is possible and plausible due to the cyclical nature of schistosomiasis. In addition, the two independent variables are highly uncorrelated, $r^2 = 0.081$. In an endemic,

steady-state situation, one might expect the two to be related; but, since chemotherapy has altered the number of people infected, the relationship is less direct.

The above regression equation has been tested with data collected independently — i.e., before the BCP and the Dez Project began. These early data, collected by Gremliza (1962), include specific distributions by age of the disease in the population and snail habitats from each village in the Dez Pilot Project area. The data were assumed to be representative of steady-state disease situations (Gremliza, 1962, p. 133). For this reason, measures of force of infection could be calculated using the techniques of Hairston (1965b) based on those of Muench (1959). The fit between predicted and observed values as determined by Equation 4 for the Gremliza data is good as shown in Figure 3. The correlation coefficient between the two is 0.7. The graph (Figure 3) includes, 1) post-project data used in the regression analysis, and 2) the Gremliza pre-project data. Because the regression equation is non-linear, logarithms of the data, used in the analysis, are plotted.

Operation of the Model

The STS model simulates changes in levels of prevalence over time. A flow diagram which schematically represents use of the model is given in Figure 4 . With values of A (from Equation 6),

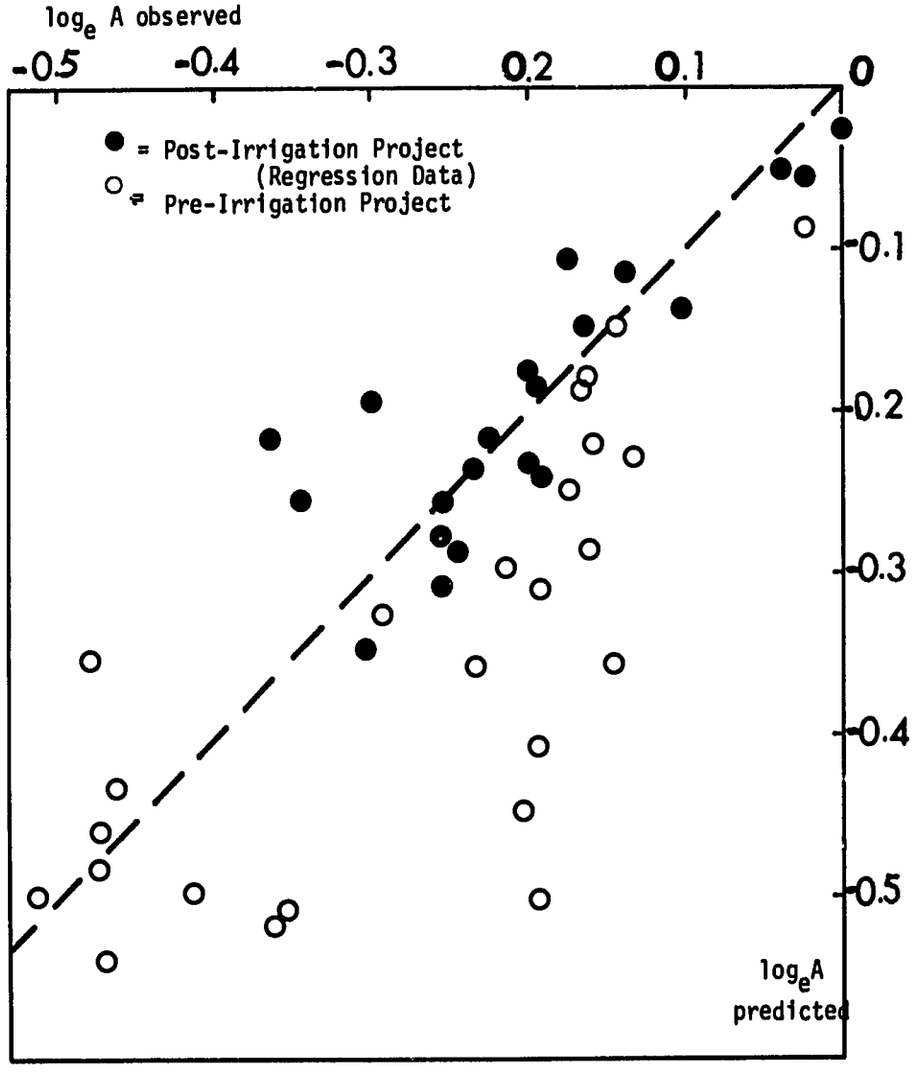
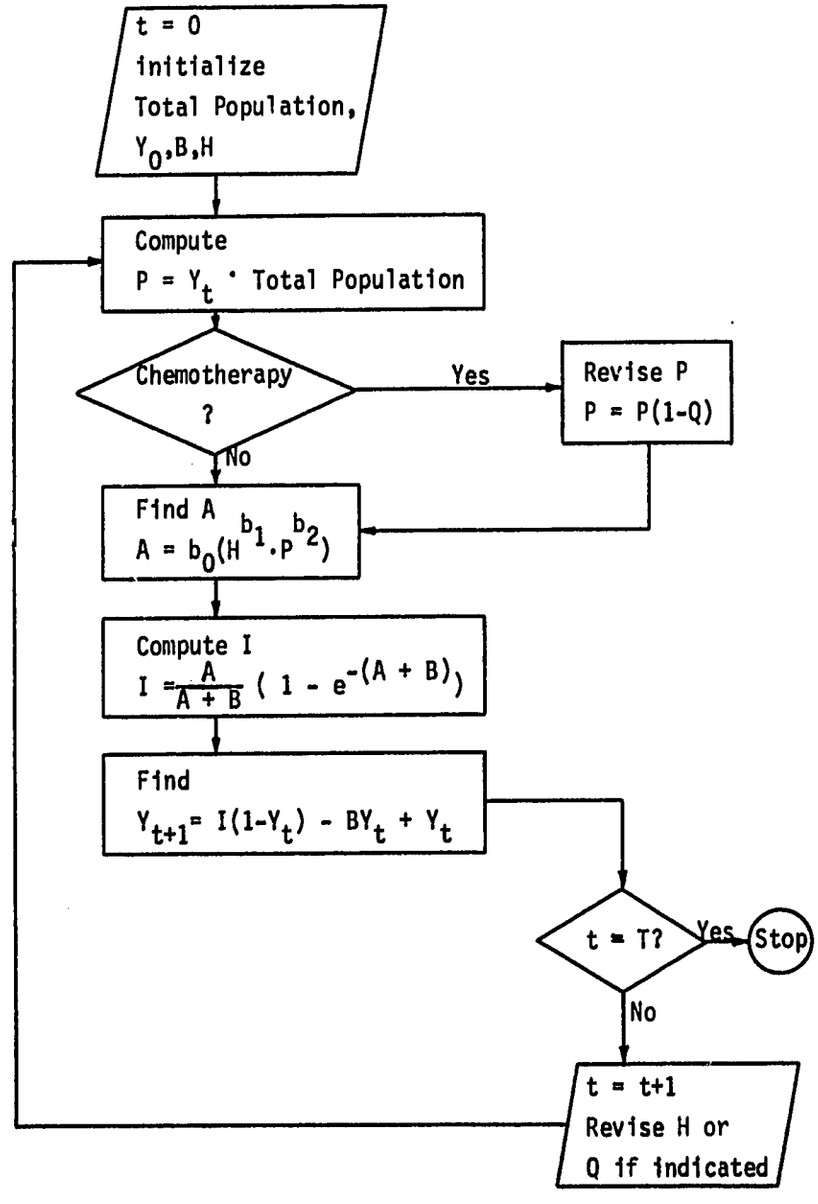


Figure 3. Regression Analysis Results
Predicted versus Observed Values of Log$_e$ Force of Infection (A) obtained from Equation 6.

Figure 4. Flow Diagram of STS Model

Demonstrates model operation.
Notation matches that in Table 4
except that Y_0 is baseline prevalence.

Flow Diagram for Operation of STS Model



B,I (from Equation 5), and Y_0 a model run is accomplished by solving for Y_1, Y_2, ..., Y_T, where T is the number of years in the planning period, by successive application of Equation 4.

Data on prevalence (Y_0) are required for the initial year of operation. Data required for each year include meters of accessible snail habitats (H) and total population. The data used in the model are corrected to account for actual events that occurred during the year of analysis. For this reason, only meters of accessible snail habitats not molluscicided nor improved by engineering measures are included. A chemotherapy correction factor (Q), the fraction of total number of infected people treated over total number infected, is applied when appropriate. In addition, because of the nature of difference equations, assumptions must be made about at what time to apply such events during the year of analysis. These assumptions are described in the section on verification.

As shown in Figure 4 , the initial step, the value for prevalence (Y_t) is multiplied by the total population to obtain total number infected. If chemotherapy occurred, the chemotherapy correction factor (Q) is multiplied times the total number infected. This product is subtracted from the total number infected. The difference is the value used for P in the regression equation with accessible snail habitats to compute a new force of infection (A). The estimated A's are then converted to incidence values (I).

The incidence values are used, along with the constant B value of 0.2, to calculate the fraction positive for the next year. The new fraction positive is used to reiterate the calculations. The procedure is repeated for all years in the planning period. Appendix I contains the computer program for the model.

Verification of the Model

The STS model has been verified with data from 54 villages in the Dez Pilot Irrigation Project. Changes in fraction of the population infected with schistosomiasis are simulated over a thirteen year period. The model reflects construction and operation effects from the irrigation project (such as increased meters of accessible snail habitats) and disease control measures applied in each year within that time period.

Model verification is based on the use of the iterative solution procedure described in the previous section. Data used for model verification include the baseline values of fraction positive for each village, total meters of accessible snail habitats for each village for each year of analysis, and total population for each village for each year. Baseline data were obtained from Gremliza's 1959-1961 survey and data for subsequent years from the BCP files and reports. Appendix I contains the data used in verification of the model.

The results from the model for the available data are shown

in Figure 5 where the predicted fraction positive is compared to observed values for each of the thirteen years. The points on the graph represent the sum of observed values of prevalence reported for each year. The model predictions compare favorably with the observed data. The effects of the irrigation project are shown on the graph by the increase in prevalence in the years following 1965. Similarly, the dramatic effects of treatment are faithfully reproduced by the simulation model.

One aspect of difference equations is that the results predicted from their use apply to one point in time. To account for this in verifying the model, it is necessary to assign the number of infected people and accessible snail habitats, plus any correction factors such as the one for chemotherapy, to the year where they will be correctly used in the model. The model is designed so that accessible snail habitats found in the first and second quarters of the year under consideration are applied to that year, but such habitats found in the third and fourth quarters of that same year under consideration are applied to the following year. This is done on the assumption that newly found accessible snail habitats are not transmission factors previous to their discovery and that the effects of such new habitats on the force of infection, thus prevalence, are delayed. The chemotherapy correction factor is applied in the same manner. First and second quarter treatments correct the number of persons infected that

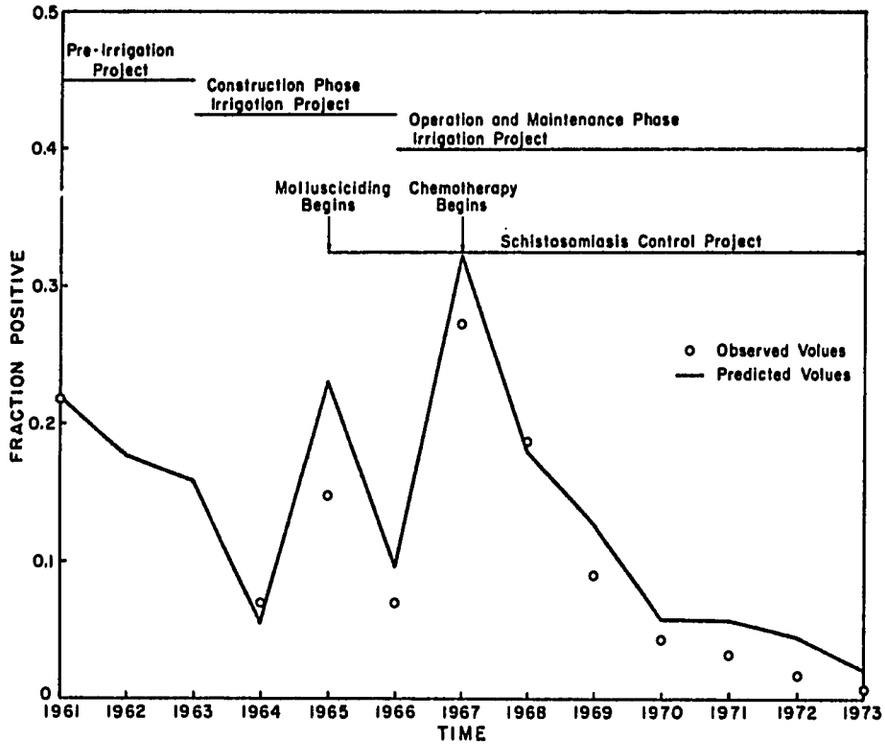


Figure 5. Verification of STS model. The predicted values are compared with observed values of prevalence for years of DPIP construction and operation, and BCP controls.

enter the infection force calculation for the year under consideration. Third and fourth quarter treatments correct the number of infected persons entering the calculation of infection force for the following year. The BCP annual data collection is divided into quarters, the first of which goes from January through March.

Sensitivity Analysis of the Model

The STS model depends upon only three parameters. All of them are necessary for model predictions and each requires careful data collection for reliable model predictions.

It is possible to analyze the sensitivity of model predictions to different magnitudes of the incidence and de-infection rate terms, $I(1-Y_t)$ and BY_t, respectively. This was done by 1) examining different values of incidence rate plus or minus one standard deviation ($I \pm 0.67$) at constant de-infection rate ($B = 0.2$) to predict prevalence from different initial conditions of prevalence ranging from 0.1 to 0.9; and, 2) examining the value of B plus or minus one standard deviation (0.2 ± 0.17) for its effect on predicting prevalence, with constant I and initial conditions of prevalence ranging from 0.1 to 0.9. The results of testing various incidence rates plus or minus one standard deviation to predict prevalence from different initial prevalence conditions are shown in Figures 6a to 6e. In general, the lower the values of prevalence, the more sensitive the predictions are to the magnitude of

the incidence terms. Specifically the model predictions are more sensitive to lower values of incidence than to higher values. The range of percent differences in predicted prevalence by I $\pm$ 0.67 is at low values of initial prevalence from minus 47 percent to 32 percent*(Figures 6b and 6c) and at high values from minus 0.8 percent to plus 2 percent (Figures 6a and 6d-e).

The results of testing the de-infection rate plus or minus one standard deviation to predict prevalence from different initial prevalence conditions are shown in Figures 6f to 6j. These results indicate that the higher the values of prevalence the more sensitive the predictions are to the magnitude of the de-infection rate terms. The range of percent differences in predicted prevalence by B $\pm$ 0.17 is at high values of initial prevalence from plus 21 percent to minus 21 percent (Figures 6f and 6h) and at low values from plus 15 percent to minus 15 percent (Figure 6f).

The combined effects of variation in the incidence and de-infection rate terms on predicting prevalence are shown in Figures 6k to 6o. These show clearly that the widest range in the sensitivity analysis occurs at low levels of initial prevalence where lowest values of incidence result in a difference in prevalence prediction of greater than 30 percent with one exception. At high values of initial prevalence, the percent of difference is 3 percent or less.

From these results, it can be concluded that the level of

* Here and in following paragraphs percentages of variation were calculated but were not shown on the figures.

Figures 6a - 6o. Sensitivity Analyses of STS Model

Figures 6a-6e show results of predicting prevalence from changing Force of Infection plus or minus 1 standard deviation (A±0.67).

Figures 6f-6j show results of predicting prevalence from changing Force of De-infection plus or minus 1 standard deviation (0.2±0.17).

Figures 6k-6o show comparison of both sets of results.

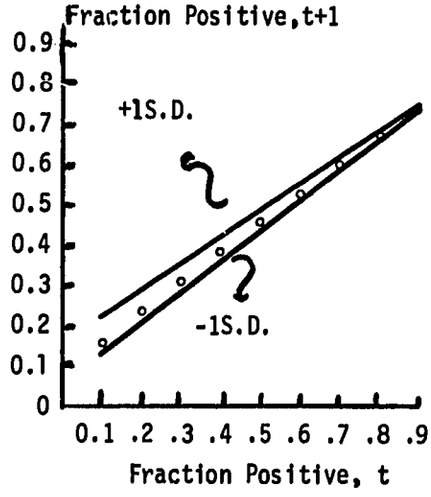


Fig. 6a
I=0.1±1S.D.
B=0.2

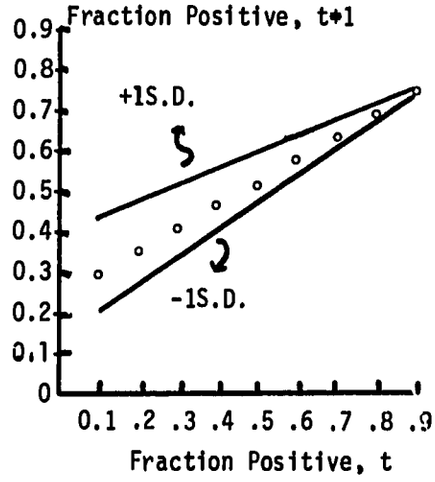


Fig. 6b.
I=0.3±1S.D.
B=0.2

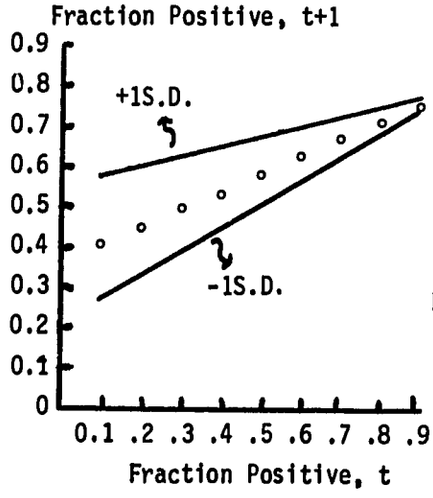


Fig.6c.
I=0.5±1S.D.
B=0.2

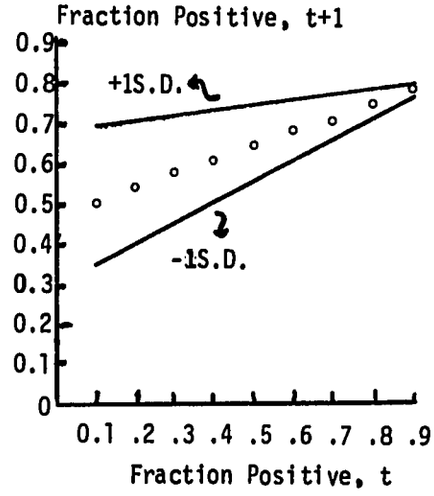


Fig.6d.

I=0.7±1S.D.
B=0.2

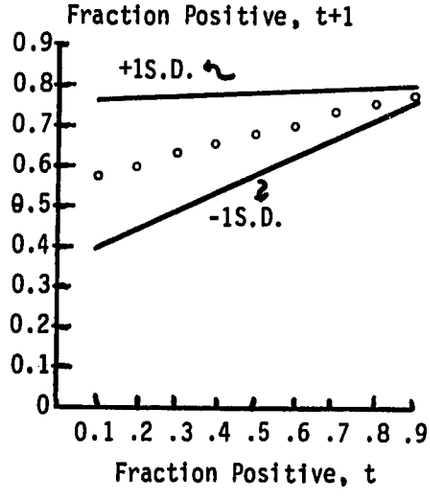


Fig.6e.

I=0.9±1S.D.
B=0.2

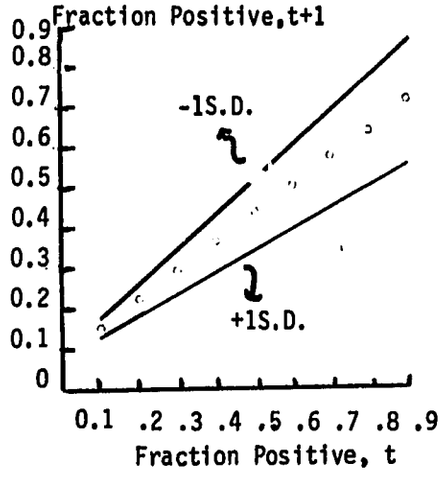


Fig. 6f.
I=0.1
B=0.2±1S.D.

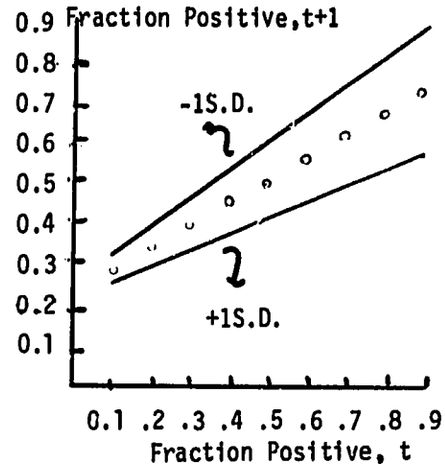


Fig. 6g.
I=0.3
B=0.2±1S.D.

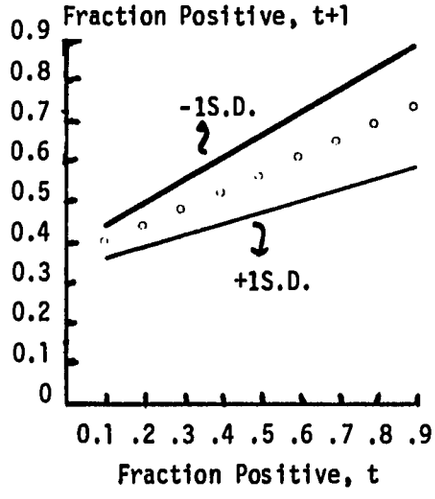


Fig.6h. I=0.5
B=0.2±1S.D.

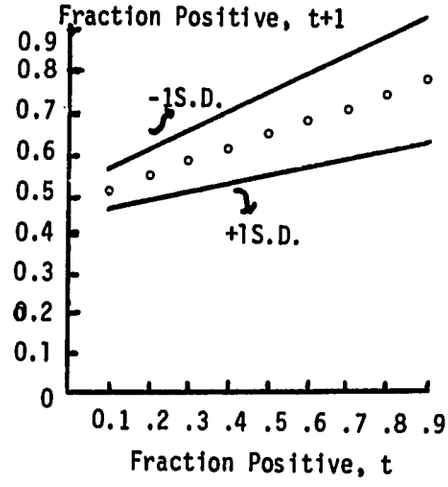


Fig. 6i.
I=0.7
B=0.2±1S.D.

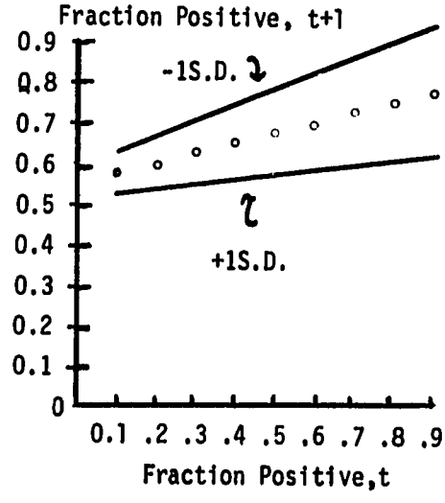


Fig.6j.
I=0.9
B=0.2±1S.D.

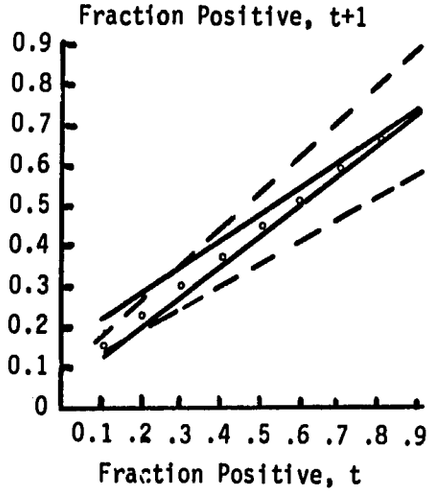


Fig. 6k.
I=0.1±1S.D.
B=0.2±1S.D.

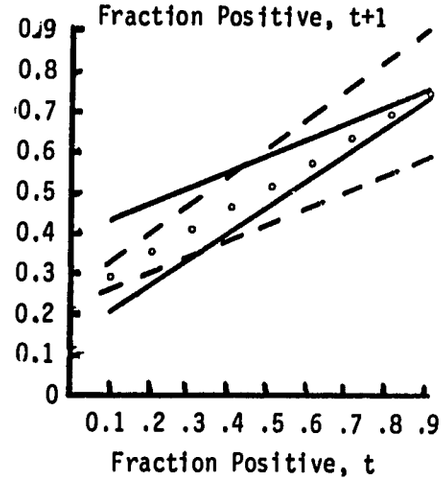


Fig. 6l.
I=0.3±1S.D.
B=0.2±1S.D.

—— = Force of Infection
— — = Force of De-infection

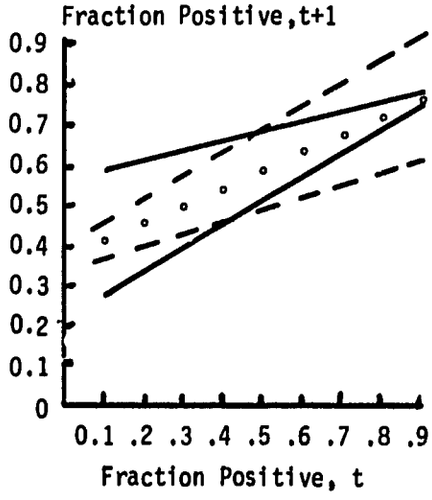


Fig.6m.
I=0.5±1S.D.
B=0.2±1S.D.

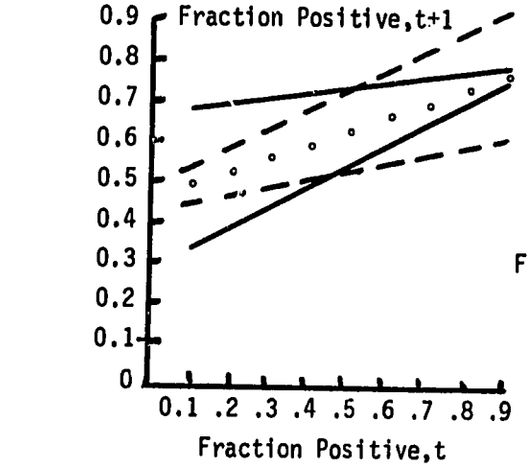


Fig. 6n,

I=0.7±1S.D.
B=0.2±1S.D.

———=Force of Infection
– – –=Force of De-infection

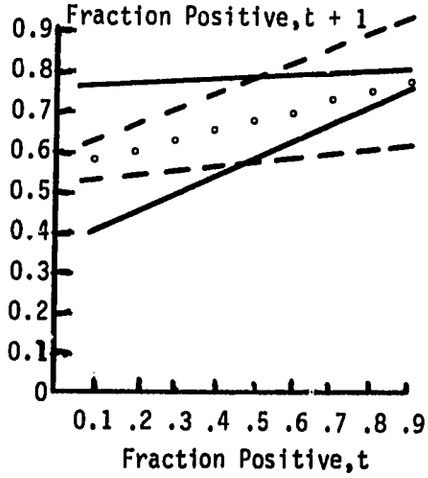


Fig. 6o.

I=0.9±1S.D.
B=0.2±1S.D

initial prevalence in an area should be considered in designing a data collection program. At low values of initial prevalence, incidence term data which include accessible snail habitats and people infected should be carefully determined. Since accessible snail habitats have a lower t-value than number of people infected, special emphasis should be given to accurate snail habitat measurements and observations to improve prevalence predictions. For estimation of the de-infection rate, especially at high values of initial prevalence, field studies can be organized to measure disease de-infection rates as individuals change back to susceptibles over a wide range of incidence rates and environmental conditions.

Remarks

The STS model is presented here as a manageable tool for assessing the impact of environmental changes on a water-related parasitic disease, schistosomiasis. As with all experimental tools, refinements of the model are being contemplated to extend its usefulness to cover a wide range of disease conditions. These refinements are discussed in Chapter V.

CHAPTER THREE

The Dez Pilot Irrigation Project (DPIP) and the Bilharziasis Control Project (BCP), Khuzestan Province of Iran, provided the empirical information used in developing the STS model, as well as the setting in which to suggest some possible uses of the model as a planning tool for testing the potential effectiveness of alternative schemes for mitigating or eliminating the spread of schistosomiasis in new irrigation developments.

The review of the DPIP is not intented to be an overall evaluation of the project and its results. Instead, information on the DPIP is used to facilitate an understanding of the relationship between schistosomiasis and irrigation development.

Historical Background of the Dez Pilot Irrigation Project Area

In 1961, construction of the Dez Pilot Irrigation Project (Figure 7) began with the hope that Khuzestan would again be the fertile bread basket for Iran as it had been centuries before — but, in this era, without widespread disease. Irrigation systems and water transmitted disease are ancient twins in this part of the world. Irrigation systems have been traced back to the Elamites, 3,000 B.C. (Adams, 1962, p. 113), and a recent report notes, " . . . in Khuzestan, as in Iraq, schistosomiasis has been established for centuries." (Development and Resources, 1959A,

Figure 7. Map of IRAN with outlines of Khuzestan Province and Dez Pilot Irrigation Project (DPIP)

National boundary
--- Province boundary
not to scale
after KWPA,1964,p.6

p. E-3). Construction of barrages and canals was begun by Darius in Khuzestan around 520 B.C., to provide food for the emerging Persian Empire (Ghirshman, 1954, p. 182). Undoubtedly the prevalence of schistosomiasis in Persia was substantially increased by Darius' frequent military forays into Egypt where schistosomiasis was a long established problem. Details about schistosomiasis in Egypt come from the discovery of the "Papyrus Ebers" and from examination of mummies:

> Direct evidence of the parasite by one of the foremost pioneers in the field of palaeopathology (Ruffer, 1910) was furnished by the demonstration of a large number of calcified ova of the parasite, situated for the most part among the straight tubules in the kidneys of two Egyptian mummies of the XXth Dynasty (1250 - 1000 B.C.).
>
> (Farooq, 1973, p. 2)

Since schistosomiasis is often transported into new areas by vector snails clinging to animals and clothing as well as by infected persons, such as soldiers who contracted the disease in Egyptian waters, "Khouzistan . . . (as in) Egypte, en Irak et dans d'autres pays de l'Ancien Monde . . . la bilharziose . . . a pris une signification de première importance. . ." (Ansari and Faghih, 1953, p. 515).

The empire established by Darius flourished until it was destroyed by Alexander the Great, in 330 B.C. For the succeeding five centuries, foreign invasions and internal struggles caused widespread destruction and the disintegration of the irrigation

systems. They were reconstructed and reached a new, technically sophisticated stage under the Sassanian kings of the Persian Empire, 226 - 637 A.D. (Adams, 1962, p. 120). Again, Khuzestan was the Persian granary. From then until after the downfall of the Mongols in 1502, Khuzestan continued to provide food for itself and surrounding provinces. And, by then, schistosomiasis was probably endemic.

Slowly, beginning in the 16th Century, the combined effects of unsettled governments, waterlogging of the soil, salinization, primitive farming practices, and lack of soil nutrients reduced the productivity of the area. In 1839, Rawlinson (1839, p. 66) wrote,

> This plain (from Baladrud to Dezful) is at present without water, and uncultivated; but the traces of old canals are to be seen traversing it in all directions, indications of its former fertility.

In 1959, reports described the region as, " . . . a desolated waste largely taken over by silt from the river floods and weird (sic) erosions." (Development and Resources Corporation (D. & R.), 1959B, p. 33).

Shah Mohammed Reza Pahlavi, formally referred to as His Imperial Majesty Aryamehr Shahanshah, (The Shah of all Shahs), under his second seven-year development plan, from 1955 - 1962, turned his attention to the possibilities of restoring Khuzestan to its ancient prominence as food provider. Plans for utilizing

its five large rivers included hydroelectric power plants and irrigation projects for agriculture along each of the river basins. The Multi-Purpose Dez River Project was the first one planned. Now in operation, this project consists of a 203 meter high, thin arch, concrete dam on the Dez River (Photograph 1), with hydroelectric power plant, high-voltage transmission lines, a re-regulating dam on the Dez River (Photograph 2), and the almost completed 125,000 hectare (308,875 acres) Greater Dez Irrigation Project. The Development and Resources Corporation (D & R) of New York City, headed by David Lilienthal and Gordon Clapp, both of Tennessee Valley Authority experience, assisted in developing the plans.

In 1959, the International Bank for Reconstruction and Development (World Bank) was approached by the Iranian Government for a $42 million (U.S.$) loan to finance the entire project. At the time of the request, Iran had not yet realized substantial earnings from her oil industry. The World Bank was hesitant to fund such a large irrigation project under the conditions of the land and the general inexperience of available managerial technicians in Iran. Therefore, an experimental site of 22,000 hectares was decided upon for a pilot irrigation project. Here, new farming practices with aid from the new irrigation system were to be tested and a determination made as to whether, "the projected objective of a three-fold increase in gross agricultural production within

three years and a five-fold increase within ten years could be accomplished" (D. & R., 1959B, p. 33).

Detailed studies and reports had been made by D. & R.; contracts had been awarded to Nederlandsche Heidemaatschappij (Heidemy), to the Food and Agricultural Organization (FAO) of the United Nations, and to other consultants to analyze the Dez area for every possible characteristic from soil conditions in the fields to sanitary conditions within the villages. Increased transmission of schistosomiasis was not ignored as a possible hazard of development; however, either insufficient evidence about its real threat or assumptions about ease of control failed to establish strong guidelines at the outset for control of the disease.

As a result of the surveys and after many meetings with landlords in the area to persuade them to participate in irrigation and agronomic improvements, the World Bank authorized construction of the Dez Pilot Irrigation Project (DPIP) to begin September, 1961. By June 21, 1963, the dam was completed and regulated water flowed into the northern section of the DPIP area. By the end of 1965, the entire DPIP area was receiving regulated water. With the promise of economic development of long fallowed land came the swift reality of increased transmission of schistosomiasis.

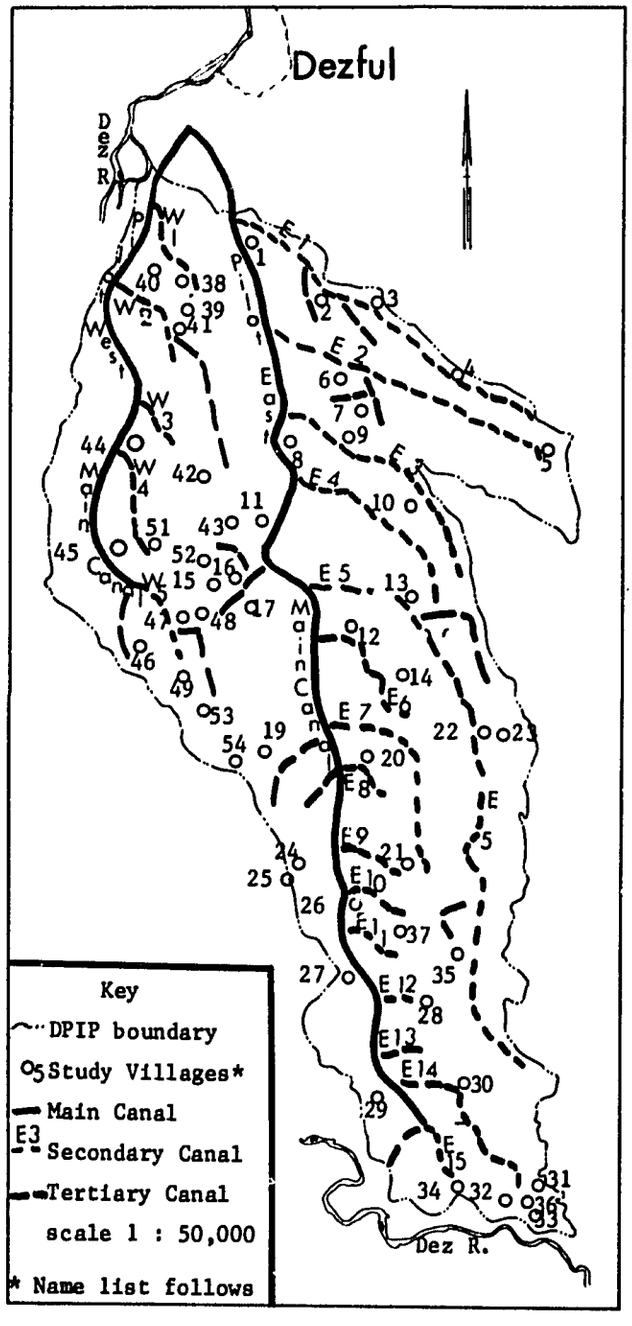
Physical Characteristics of the Project Area

The Dez Pilot Irrigation Project (Figure 8) is located south

Figure 8. Map of Dez Pilot Irrigation Project Area

Villages used for this study are located on the map.

Main, Secondary, and Tertiary Canals in DPIP Area are shown. (Canal capacities and lengths are in Appendix II).


Dezful
Dez R.
Pilot West Main Canal
Pilot East Main Canal
Dez R.
Key
DPIP boundary
Study Villages*
Main Canal
Secondary Canal
Tertiary Canal
scale 1 : 50,000
* Name list follows

List of Villages in Study Area*
For Figure 8.

1. Bande-bal
2. Ghaleh Rob Bandebal
3. Ghaleh Now Shams Abad
4. Boneh Abdol Mohammad
5. Chagha Sorkh
6. Ghaleh Say-yed
7. Shams Abad
8. Anjeerak
9. Khalteh
10. Ghaleh Ghazee
11. Alee Kowlee
12. Koo-tee-yan
13. Khayr Abad
14. Najaf Abad
15. Ghaleh Now Askar
16. Boneh Cheetee
17. Farrash
18. Balangoon
19. Hossay-nee-yeh Balangoon
20. Khosrow Abad
21. Boneh Raheemeh
22. Baya-tee-yoon Arshad
23. Baya-tee-yoon Rafat
24. Ghaleh Abdol Shah
25. Ghaleh Now Sardar Abad
26. Sardar Abad
27. Deylam Olya
28. Sham-oon
29. Deylam Sofla
30. Boneh Say-yed Taher
31. Boneh Nebhan
32. Boneh Khepel
33. Boneh Yoones
34. Boneh Alvan
35. Salar Abad
36. Boneh Charee
37. Azeez Abad
38. Kermalak Tahmasebee
39. Kermalak Alee Abad
40. Ghaleh Shaykh
41. Dehbar
42. Ghaleh Now Beesheh Ney
43. Ghalvand
44. Sharaf Abads (three villages close together)

* keyed to data lines of computer print-out

List of Villages in Study Area (continued)*
For Figure 8.

45. Abbas Abads (two villages close together)

46. Ghaleh Rob Koway-yekh

47. Hajee Abad

48. Ghaleh Rob Jaybar

49. Koway-yekh

50. Ghaleh Abbas

51. Ghaleh Agha Hassanee

52. Jaybar

53. Boneh Teeleh

54. Ameer Abad

* keyed to data lines of computer print-out

of the town of Dezful, latitude 30° (photograph 3 with contrast in photograph 4). It covers an irregular area roughly 25 kilometers on the North-South axis and ~15 km wide; bounded on the north by qanat irrigated land; on the northeast by the Siah Mansur River; on the east by the Abjeerob River; on the south and west by the Dez River. The land is an alluvial plain descending from the Zagros Mountains at a gentle slope of two to three meters per kilometer. Comparable in size to the drainage basin of the Potomac River, above Washington, D.C., the Dez River at the damsite drains 17,000 km^2 with an average annual discharge of 305 cubic meters per second (cms) and minimum annual natural discharge of 50 cms. The minimum annual flow now regulated by the dam is 190 cms.

The climate in this part of Khuzestan Province is seasonal and semi-arid. No rain falls in the summer, but severe floods have occurred during some winters which extend from November through March. Figure 9, a graph of rainfall in the DPIP area from 1961 to 1972, indicates the wide variability in rainfall over the years. Thus, while irrigation is essential for two growing seasons, designs for canal capacity were complicated by the variable rainfall over any year as well as by the geographical variations of rainfall: average annual rainfall measured at Dezful is 365 mm; in the southern part of the DPIP, the average is measured at 330 mm.

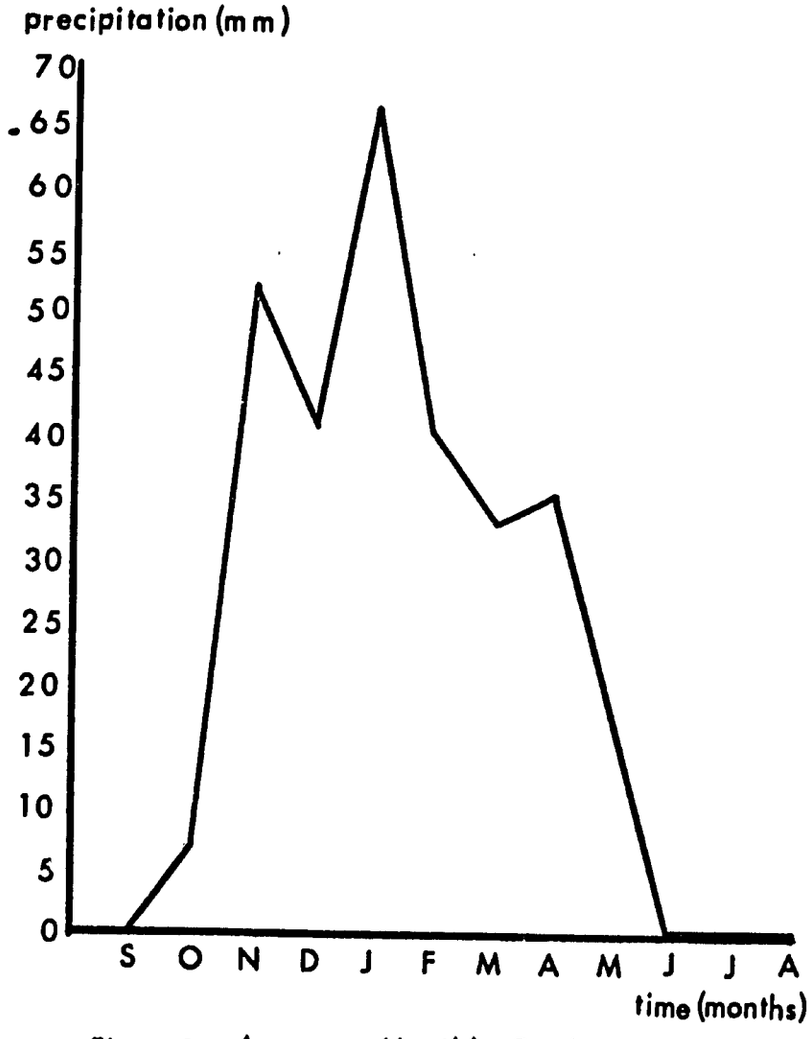


Figure 9. Average Monthly Precipitation
1961 - 1973
Dez Pilot Irrigation Project
(data collected by KWPA
at Safi Abad)

The temperature also ranges widely, from 0°C in the winter months to over 50°C in the summer (Figure 10). The relative humidity is low, less than 50 percent on the average, but depends on wind direction (Arfaa, 1967, p. 359). This makes the temperature tolerable, but increases water evaporation from the soil thus increasing the need for irrigation. According to Thornthwaite (in Fisher, 1968, p.573) the water balance shows an 800 mm water deficit.

The variations of temperature and rainfall do not hinder snail population growth, but soil conditions influence snail habitats. Two types of soil conditions are present in the DPIP area. In the northern part, snail development is restricted due to gravel deposits, at a minimum depth of 4 meters, which guarantee good subsurface drainage under a surface silt layer (D. & R., 1959B, p. 19-20). In the southern half of the project, along the river, marshes abound creating extensive snail habitats with resulting problems of schistosomiasis control along with agricultural problems.

Social Characteristics of the Population Within the Project Area

In 1959, when DPIP plans were completed, the population in the area was estimated to be 13,800, living in 57 villages ranging in size from sixty to six hundred persons per village with an average of 45 families of 5.4 children (D. & R., 1959B, p. 20).

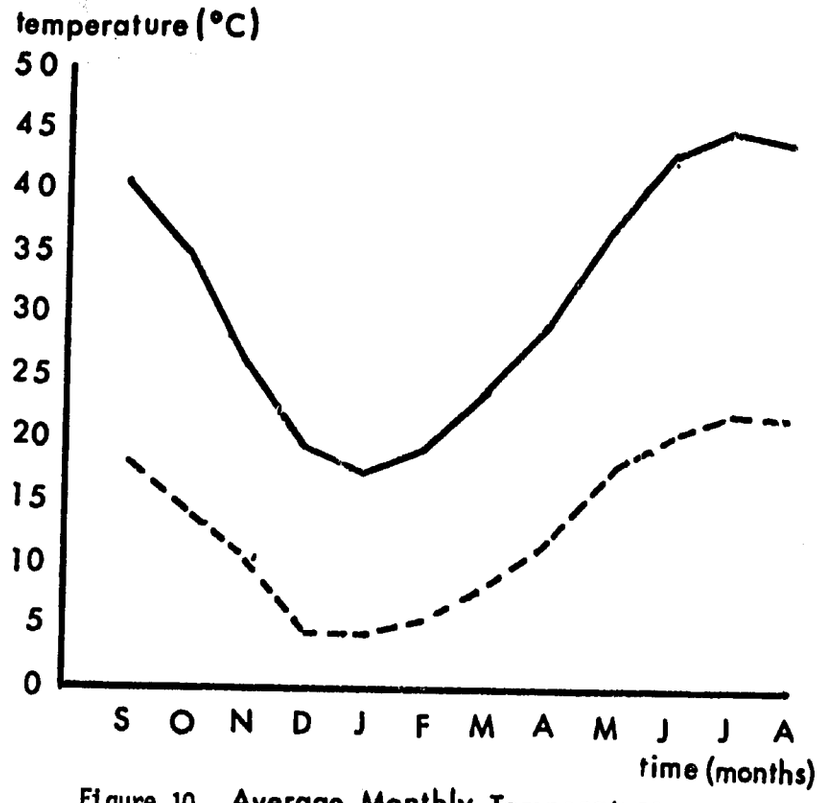


Figure 10. Average Monthly Temperature
1961-1973
Dez Pilot Irrigation Project

— maximum °C
- - minimum °C

(data collected by KWPA at SafiAbad)

Population density was fifty-nine per square kilometer. While the majority of men worked as agricultural laborers or tenant farmers with much seasonal unemployment, during planting and harvesting seasons migrant labor was required. Four elementary schools provided the only formal education. Eighty-five percent of the population was illiterate. Before Land Reform, farming was under a feudal system of powerful landlords who were represented by kadkhoda. Even though landlord holdings averaged only 100 hectares each, this group of men had great authority over the lives of peasants and villagers because of the traditions of fore-selling crops to landlords and because they controlled credit and market organizations. The tenant farmers usually did not receive a fair price for any surplus grains they were able to produce over the amounts owed to the landlords (Smith, 1971, p. 397-413).

Ethnic composition varies geographically today as it has historically. The northern area is inhabited mainly by descendents of the Persians (Dezfulli and Lur tribes), while the southern area is settled mainly by Arabs. The picturesque nomadic Bahktiari tribes live in Khuzestan in the DPIP area during winters, but migrate, as they have for countless centuries beginning before the Christian era, into the mountain pasturelands each summer. The villages, until recently, consisted of members of the same tribes, usually related groups of the same family who lived in the same village for generations. After centuries of unchanging conditions

of human behavior, new ways are feared, with dire superstition surrounding changes as, for example, in matters of human waste elimination. Health educators daily confront this subtle, but persistent problem.

The walled villages of single-story, mudbrick houses built around animal inhabited courtyards have also remained unchanged during the centuries. Domestic water for all purposes is supplied by canals and borrow-pits so-called because when villagers dig up mud for their houses, they say they are "borrowing" it. Before DPIP and BCP, latrines did not exist. Today, even where new latrines have been installed, human waste disposal from the latrines is directed into the natural drains or village streets. In 1959, only two villages in the DPIP area had bathhouses and none had laundry facilities. By 1974, however, work had progressed so that almost every village in the area had at least one bathhouse.

Gremliza (1962), in an extensive pre-irrigation project health survey for D. & R. from 1959-1961, estimated prevalence for the following diseases:

Bejel (endemic syphilis)	1.2%
Favus (2-5 year olds)	15.1%
(all ages)	0.9%
Schistosomiasis	22.0%
Trachoma	34.8%
Tuberculosis (underest.)	2.1%
Typhoid-paratyphoid fever	1.1%

He also discussed the presence of: endemic typhus, leishmania, malaria, nutritional deficiencies, and widespread soil-transmitted helminthic diseases such as hookworm and ascariasis (Gremliza, 1962, compiled). Absence of any health facilities plus the poor standards of sanitation resulted in the high infant mortality of 221 per 1000 live births as contrasted with 131 per 1000 average for Iran in 1970 (Smith, 1971, p. 83). With a birth rate of 57.4 per 1000 persons, the rate of natural increase was 32.5 per 1000 persons, or about 376 people per year for the DPIP area before the Project. D. & R. summarized the village situation in the report of 1959A:

> Living standards are low, with net family farming income estimated to average 18,000 rials (sic)[3] annually. Villages are typically of mudbrick construction . . . Village roads are in bad condition and frequently impassable during the rainy season. The villagers' diet, except for sugar and tea, is based entirely on their own production. The diet consists mostly of cereals, vegetables, milk and eggs, and, occasionally, meat (p. D-5)

Agriculture in the Project Area

The gross agricultural area of the DPIP now includes 20,500 hectares out of a total area of 22,000. Village property roads, grazing land, and holy areas make up the difference.

---

[3] "18,000" is likely to be a misprint. That is a high income, particularly for 1959. D. & R. gives other estimates as between "7500-9000 rials (100-200 U.S. $)" (1959B, p. 37).

Before project construction, primitive fast-flowing, gravity-flow canals and ditches irrigated about 13,500 hectares during the winter and about 6100 hectares during the summer, the acreage directly related to high and low flows of the Dez River. High velocity, greater than one meter per second, prevented snail populations from inhabiting the canals, even though they were in the surrounding swampy areas. Winter crops included wheat, barley, and board beans; summer ones, rice, sesame, and vegetables, along with grazing grasses for cattle, goats, sheep, and water buffalo. The list sounds adequate for good nutrition, but actually:

> The majority of people, including most farmers, live on a simple diet that is deficient in proteins and in certain vitamins . . . Increased crop yields since 1965 improved food supply, but distribution problems, social customs, and traditional food prejudices have hampered efforts to improve the general diet . . . inadequate diet of young children is often rooted in social custom.
>
> (Smith, 1971, p. 153)

The domestic animals which have always lived in close proximity to the villagers also frequent the canals, dispersing vector snails from one area to another as the snails adhere to their hoofs and hides. While not susceptible to *S. haematobium* themselves, these animals are often agents of transmission.

Traditional farming practices included the use of wooden plows drawn by animals, hand threshing, manure for fertilizer, and poor seed varieties. Low yields, combined with traditional marketing practices, resulted in low incomes for farmers.

The Dez Pilot Irrigation Project

The DPIP as the test case for the entire Greater Dez Irrigation Project, provides a manageable illustration of the effects of irrigation projects on the transmission of schistosomiasis. In addition, the Bilharziasis Control Project's (BCP) data on the disease in the area offer additional insights into both the transmission and control of the disease.

The DPIP included canals and irrigation facilities, and establishment of a 200 hectare trial field farm, Safi Abad, to experiment with different seeds and farming practices. Health and sanitation improvements were also begun, as part of the DPIP, in 57 villages. The schedule and projected costs, as furnished by D. & R.'s November 10, 1959 report are compiled in Appendix II. The total estimated DPIP cost was 25,297,000 U.S.$.

Responsibility for water regulation and distribution, operation and maintenance of the canals, implementation of land improvements, as well as supervision of all previously mentioned non-irrigation activities are vested in the Khuzestan Water and Power Authority (KWPA), officially created in 1960. KWPA was, and is today, in charge of electric power distribution, as well as determining and collecting both water and electric power fees. In 1961, agreements were formalized between landlords and the KWPA. Two items had potential effects on the transmission of schistosomiasis: 1) land levelling and preparing would be jointly financed,

and, 2) KWPA and the landlords would share the costs of making improvements for private canals and drains. The last was purposely left vague, but it was understood that the landlords would, "undertake the financial commitments required" (DPIP), 1964, p. 76). The landlords and KWPA also agreed that all irrigation works, except tertiary canals and drains, would be publicly owned.

The irrigation system, which was designed by Heidemy, a Dutch firm, was planned to begin operation as soon as river flow could be regulated upon completion of the Mohammed Reza Shah Pahlavi Dam on the Dez River, 30 kilometers upstream from the town of Dezful. A temporary diversion canal, below the town, served until a second re-regulating dam was completed. Then a main canal with a major distribution system to maintain even flows in the canals was built. The final plan, now in operation, consists of 17.5 kilometers of main canal, of which 3.6 kilometers is lined and 34.3 kilometers of unlined branch canals. Canals were lined depending on soil conditions and grade. Lining is discussed below along with other engineering measures for schistosomiasis control. Drains were scheduled for improvement, but only a few new ones were constructed in the 1960's. It was expected that private canals, outside of farm boundaries, "would be abandoned, though partly used as drains" (D. & R., 1959B, p. 24). The original plan had called for full-scale irrigation by May-June, 1963 so that regulated flow would be available for 1963

summer crops, but the schedule was not met. The entire DPIP did not receive regulated water until December, 1965. Major delays occurred due to difficulties with labor, equipment, and weather encountered by different construction companies.

Delays were due also to the Land Reform Act of 1962, which was passed at the Shah's insistence, and was, "Perhaps the most significant development in the lives of the villagers of the Dez area . . ." (Public Administrative Service, 1971, p. 8). The first phase of the Land Reform Law limited the number of hectares an individual could own; any amount above the maximum had to be sold to the Ministry of Agriculture, which then redistributed the land to farmers who joined the newly established rural cooperatives. Phase Two, beginning in March, 1965, required distribution of lands belonging to smaller landlords in one of three ways: leasing, selling, or share-cropping (Lambton, 1969 has detailed discussion of Land Reform Law). The immediate impact of the law was to make landlords hesitant to cooperate with KWPA for improvements of lands which they feared would not continue to belong to them (Fisher, 1968, Chapter 21; DPIP, 1964, p. 33-34). This was particularly noticeable in regard to irrigation, because the landlords had agreed to pay for canal and drain improvements.

The beneficial aspects of Land Reform outweighed the negative impact of irrigation delay KWPA was able to work successfully, in the beginning, with villagers who bought land. Several whole

villages joined in land-preparation programs which leveled hills and filled in marsh areas.* This, in turn, helped to eliminate snail habitats. By 1969, crop production was beginning to show improvement. Tangible results showed also in the villagers acquisitions of new possessions. People bought bicycles, radios, electric fans; they did not invest in sanitary improvements (Setayesh, personal communication, 1974). Bathrooms were not added to homes unless KWPA provided them. The majority of villagers kept to their established patterns of using swamps, canals, and drains for domestic water purposes, and waste was excreted as before (photographs 5 and 6). The ancient parasitic cycle associated with schistosomiasis was not broken. While the Islamic faith stresses cleanliness and associates ritual washings with holiness, at the same time, many ancient beliefs among villagers also concern gens (singular gen) who have magical control, the evil eye, demons and such which are associated with bodily functions or products. Sanitation is not the problem; superstition and fear are.

Even with the improvements made to agriculture, the Government of Iran decided that farm yields should be higher. Starting in 1969, large-scale agricultural businesses, called agri-business, were invited to invest and to develop the agricultural potential of Iran. From personal observation in Iran, it appears that this action severely restricted the benefits from Land Reform, because,

* reported in DPIP Quarterly Reports to the World Bank

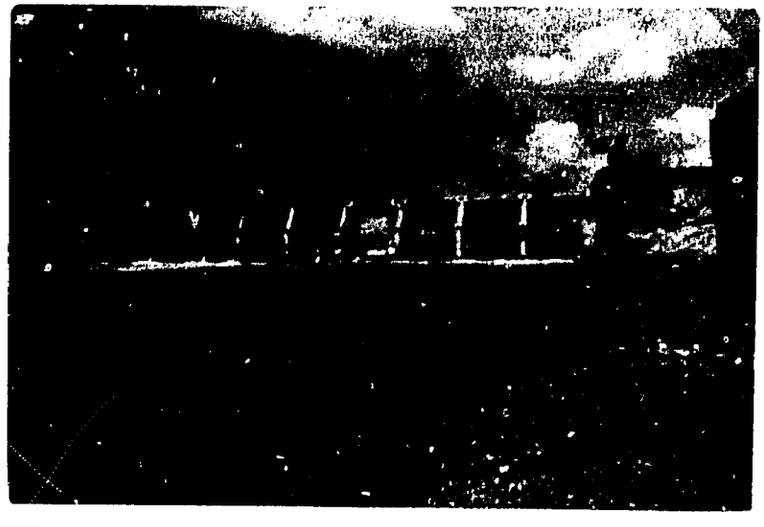
in the DPIP area, land which had shortly before been distributed to farmers was taken from them and rented to agri-businesses. (The only small-farm area remaining was in the farm corporation in the Northwest.) Today, not only has the villagers' incentive derived from ownership of his land been removed because of the agri-businesses, but mechanized farming and restrictions on hiring of the agri-businesses have made unemployment high again (Tabib, personal communication, 1974).

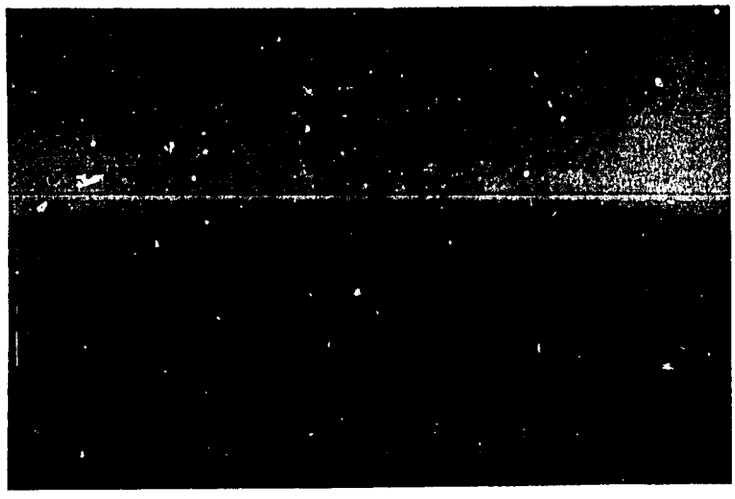
The agri-businesses, however, engaged in extensive land-levelling programs. This should be an effective limitation on the transmission of schistosomiasis. However, two drawbacks could offset any advantages. One is that those who work for the agri-businesses, both male and female, must be between 18-40 years old and healthy. Thus, many villagers with still high levels of parasitic, and other diseases, are not employed. Such people do not generally seek out health facilities, nor are they treated by the agri-businesses, and unless government agencies find them, they remain active in the transmission cycle. A second related disease problem arises because of strict health qualifications for employment of local people by the agri-businesses, which results in their dependence upon migrant workers. While these workers are also examined for health, they come from areas where schistosomiasis is widespread, such as Iraq and can easily bring the disease with them through vector snails clinging to their clothing

Photograph 1.
Mohammed Reza Shah
Pahlavi Dam,
Dez River, Iran

" By June 21, 1963,
the dam was completed.
...203 meters high...
irrigates Khuzestan
Province."
(Chapter III)

Photograph 2.
Re-regulating Dam on
the Dez River





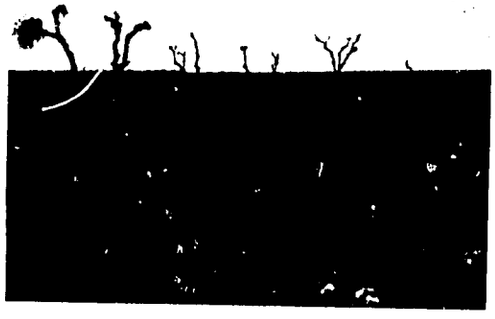
Photograph 3. Dezful from a Dez River bridge looking toward the Zagros Mountains

WITHIN TEN MILES OF EACH OTHER

Photograph 4. Shahabad Village, southeast of Dezful, showing courtyard shared by domestic animal

Photographs 5 and 6. " The majority of villagers kept to their established patterns of using swamps, canals, and drains for domestic water purposes. "
(Chapter III)

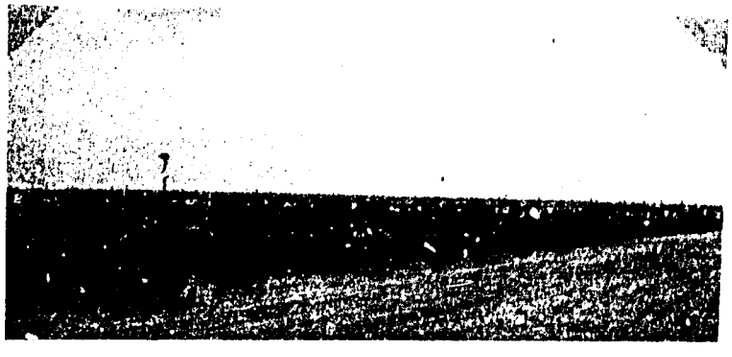
Mother and children washing dishes in snail infested waters, Khuzestan Province



Photograph 7. A plowed under village, Salar Abad, 1974

" ... all of the villagers in the DPIP are being moved to new town developments, shahraks. Old villages are then plowed under...persons from the same village, even from the same family are sent to different shahraks..."
(Chapter III)

Photograph 8. Shahrak built near Dezful, 1974



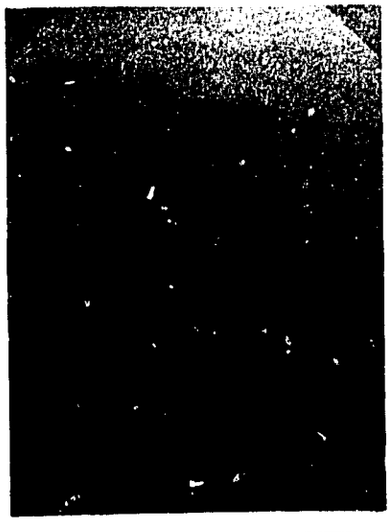
Photograph 9. Cement lined canal

ENGINEERING CONTROL MEASURES in DPIP area

" Seven percent of the canals are lined with a variety of materials ..." (Chapter III)

Photograph 10. Near drain lined with stone and concrete combination, an unlined field drain in back

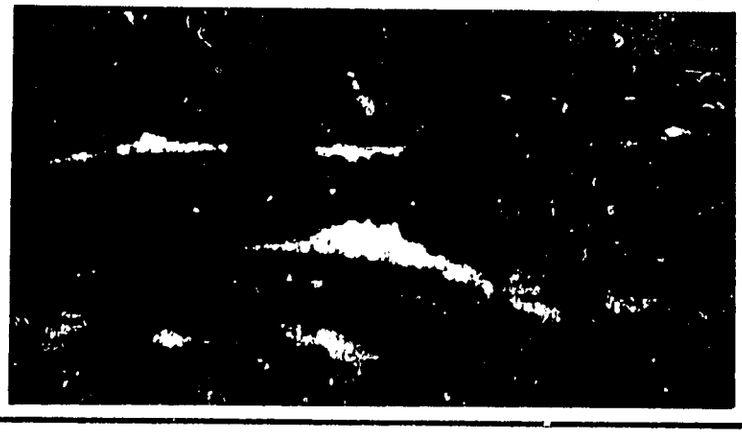
Photograph 11. Improved drain with vegetation removed



Photograph 12.
Old canal now used as a drain in DPIP area

Photograph 13.
Typical accessible snail habitat in swampy area of Abjeerob

" Sidepools from canals and drains served as habitats for the snails ..."
(Chapter III)



Photograph 14. 20 ml. of bloody urine ...

" For prevalence determinations, a (BCP) team of one physician and two technicians set the goal of examining 90% or more of the population in each village in the entire BCP area. Urine samples were taken between 10:00 a.m. and 2:00 p.m. by collecting 20 ml. of urine in a sterile bottle ... each was identified by name, age, sex ... "
(Chapter III)

Photograph 15. Engineer Mansoori and Engineer Hebert doing molluscicide follow up survey in swamp treated six months earlier.

BCP STAFF IN THE FIELD

Photograph 16. Mr. Ardalan during a mass chemotherapy program on a return visit to complete treatment begun earlier the same day.

Photograph 17. This shows a village jube (open drain).

"Today, even when new latrines have been installed, human waste from the latrines is directed into the natural drains or village streets." (Chapter III)

SHAHABAD VILLAGE, KHUZESTAN PROVINCE

Photograph 18. This shows a BCP installed village faucet - with its handle removed.

Photograph 19.
Mr. Iranshahi, BCP staff, on a sanitation survey

Photograph 20. A village father holding his daughter after her treatment for schistosomiasis.

Photograph 21. Cleanest house in Shahabad Village - note covered water supply and clothesline.

or possessions. In many parts of the world migrant laborers are active transmission agents (Ayad, 1956; McMullen, et al, 1962; Foster, 1967; Farooq, 1969).

The agri-businesses have been responsible for an additional limitation to development in the DPIP area. To provide better living conditions for farm laborers, all of the villagers in the DPIP are being moved to new-town developments, shahraks. Old villages are then plowed under (Photograph 7). Traditional, established village relationships have been broken; persons from the same village, even from the same family, are sent to different shahraks (Photograph 8). No matter whom one consults nor how one considers this changing of set patterns of behavior, it is a drastic innovation — particularly in Iran, where the extended family is the basic social organization, performing economic, medical, and religious functions. Engineers on the project consider this mixing of Arab and Persian populations within the shahraks essential for progress. They maintain that it introduces change to people whose daily existence has never varied (Tabib, personal communication, 1974).

Movement and relocation of the Project population in shahraks could have improved living conditions, at least in regard to sanitation and health, if KWPA had not been under stringent financial limitations in building the shahraks. Parasitic diseases thrive in these new towns where no domestic water is supplied except for

single faucet serving two blocks of families. Similarly no waste disposal facilities are provided except for jubes (open drains) which encircle the blocks, and little time or money is spent on health education. Cholera and malaria have recently been reported in the shahraks (Hebert, personal communication, 1974). No cases of these diseases had been reported in Khuzestan for years, and schistosomiasis is increasing again after years of concentrated effort to control its spread (Mansoori, personal communication, 1974)* Because one condition for moving into the shahraks is that no animals are allowed in the homes, the author suspects that the lower nutritional standards may be contributing to the spread of diseases. Restriction of animals is for sanitary purposes, but it may well have the effect of lowering nutritional standards by making milk, yogurt, eggs, and meat unavailable. Other far-reaching effects are being analyzed in a forth-coming work by Grace Goodell of Columbia University (in preparation).

Impact of DPIP on Transmission of Schistosomiasis

From the beginning, the irrigation planners[4] recognized the impact that the project would have on the spread of schistosomiasis:

> The extensive projects which are a part of the Seven Year Plan and which will make possible

---

[4]David Lilienthal was especially aware of the impact of irrigation projects effects on parasitic disease due to his TVA experiences.

* These two statements have been disputed by health personnel in Iran.

> the growing of more than one crop per year, could, unless precautions are taken, spread the infection (schistosomiasis) out of its present pockets with more extensive transmission. More water on the land could result in heavier infections . . .
>
> (D. & R., 1959A, p. E-3)

The potential impact of irrigation projects on the disease is realized primarily through increasing the snail habitats and increasing the number of people infected. Increases in prevalence have been documented for the Gezira Scheme in the Sudan and from information about the Egyptian change from basin to perennial irrigation (Humphreys, 1932, p. 246; Lanoix, 1958, p. 1013).

Increases in the level of infection among humans resulting from the DPIP were greatly mitigated by the simultaneous efforts of the Bilharziasis Control Project:

TABLE 5 — COMPARISON OF PREVALENCE IN DPIP AREA

	Year		Prevalence
Pre-DPIP	1961	BCP Controls Begun - 1964	22.0% **
Early DPIP effects	1965		14.7%***
Later DPIP effects*	1966		7.0%***
Later DPIP effects	1967		27.3%***

* Date when all villages began receiving irrigation water

Even though controls were instituted, the impact of increased

** Gremliza, 1962.
*** Complied from BCP Quarterly Reports for appropriate years

snail habitats resulting from increased water on the landscape is clearly observable from the data. The graph (Figure 11) on the following page shows the development of accessible snail habitats over the years of project construction, and current operation of the irrigation canal systems. Seven percent of the canals were lined, most with concrete, some with asphalt, others with brick and stone, and the remainder with experimental materials (photographs 9, 10 and 11). Although canal lining is usually referred to as an effective engineering control measure for schistosomiasis (McMullen, 1973, p. 565-566), Table 6 shows that there is little or no difference in prevalence levels between villages near lined and unlined canals.

The effectiveness of lined canals as a schistosomiasis control measure is hard to prove. Snails have been found clinging to sides of lined canals (Mobin, personal communication, 1974), vegetation continues to grow in the water providing food for the snails, and spill-overs still occur creating new snail habitats. However, some planners continue to think that lining is effective; hence, in the newly-developing irrigation system in the West Irrigation Project all of the canals are being lined for reasons of disease control as well as to decrease water losses due to seepage. In 1974, schistosomiasis had appeared in previously uninfected areas in the new West Project's lined canal areas. Snails have

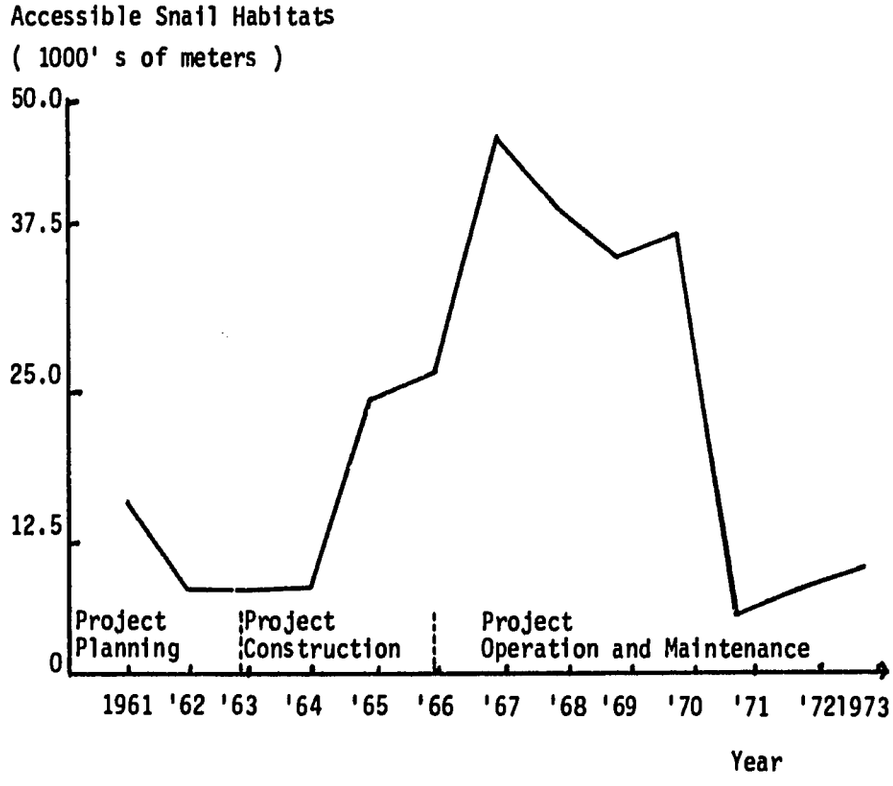


Figure 11. Increases in Snail Habitats resulting from construction and operation of DPIP 1961 - 1973

TABLE 6 — EFFECT OF CANAL LINING ON PREVALENCE LEVELS:

Comparison of Villages Near Lined and Unlined Canals Before and After Installation of Irrigation System

Village Near Lined Canal	Prevalence of population infected Before irrigation	After irrigation	Village Near Unlined Canal	Prevalence of population infected Before irrigation	After irrigation
Bande-bal	0.012	0.008	Chaga Sorkh	0.06	0.013
Anjeerak	0.017	0.008	G. Rob Bandebal	0.157	0.016
Ghaleh Ghazee	0.169	0.0	G. Say-yed	0.111	0.105
G. N. Shams Abad	0.018	0.085	G. Abdol Shah	0.269	0.34
Salar Abad	0.052	0.229	Boneh Alvan	0.391	0.307
Boneh Raheemeh	0.054	0.414	Najaf Abad	0.007	0.005
Shamoon	0.457	0.355	Khosrow Abad	0.02	0.048
Bayateeyon	0.203	0.254	B. Say-yed Taher	0.265	0.016
SardarAbad*	0.435	0.563	Boneh Cheetee	0.021	0.0
Sharaf Abads*	0.005	0.0	Boneh Teeleh	0.035	0.016
Abbas Abads*	0.0	0.0	Ghaleh Shaykh	0.031	0.0
Dehbar*	0.018	0.0	Ghalvand	0.009	0.0
Kermalak Alee Abad	0.0	0.0	Boneh Nebhan	0.265	0.06
			Boneh Khepel	0.333	0.408
			G. Rob Jaybar*	0.015	0.0
			Ghaleh Agha Hassannee	0.042	0.0
			Hossay-nee-yeh Balangoon	0.014	0.007

* Villages in northwest of DPIP area
Compiled from BCP Quarterly Reports, 1961-1967.

been found in both the newly lined canals and in the newly created swamp areas near those canals (personal observation during field trip, 1974).

In addition to the ineffectiveness of canal linings, a primary factor in creating more snail habitats is the lack of adequate drainage. The increase in meters of snail habitats after the completion of the irrigation system has already been indicated. Runoff from irrigated fields entered the old canals and tended to make them marshy and sluggish. Sidepools from canals and drains served as habitats for the snails and washbasins for the villagers (Photographs 12 and 13). McConnell, after working with the Bilharziasis Control Project as an engineer, concluded, that drainage problems were critical ones for schistosomiasis control (1971, p. 19).

KWPA is planning to install new drains both in the DPIP area and along the expanding irrigation system of the West Project while planning to repair existing ones in the DPIP (McCulloch, personal communication, 1974). With adequate maintenance, these measures should be effective in preventing the spread of schistosomiasis and in improving agriculture.

The Bilharziasis Control Project

Ansari and Faghih (1953) concluded after the first series of surveys for schistosomiasis in Khuzestan that unless immediate

attention was paid to the disease it would become a major problem, " . . . on assistera dans les années futures à l'extension de la bilharzoise jusqu'à ce que cette maladie devienne un problème sanitaire majeur" (p. 526).

As a result of their surveys, and because of the proposed irrigation scheme in the Dez area of Khuzestan, the Ministry of Health, along with the Plan Organization of Iran, asked the Institute of Public Health Research (at the time, the Institute of Malaria and Parasitology) to organize a research and control station in Dezful with the assistance of the School of Public Health of the University of Teheran. The World Health Organization (WHO) designated the project as Iran-38, and contributed advisors who also reported on the project: Louis Olivier (Gaud and Olivier, 1959); Jean Gaud (Gaud et al, 1963); Z. J. Buzo (Olivier and Buzo, 1963); R.J. Pitchford (1962, 1965). K.Y. Chu was appointed Project Malacologist by WHO, which also provided laboratory and field equipment as well as Land Rovers. In 1961, the Near East Foundation was asked to assist with the administration of the project and to provide a sanitation advisor.

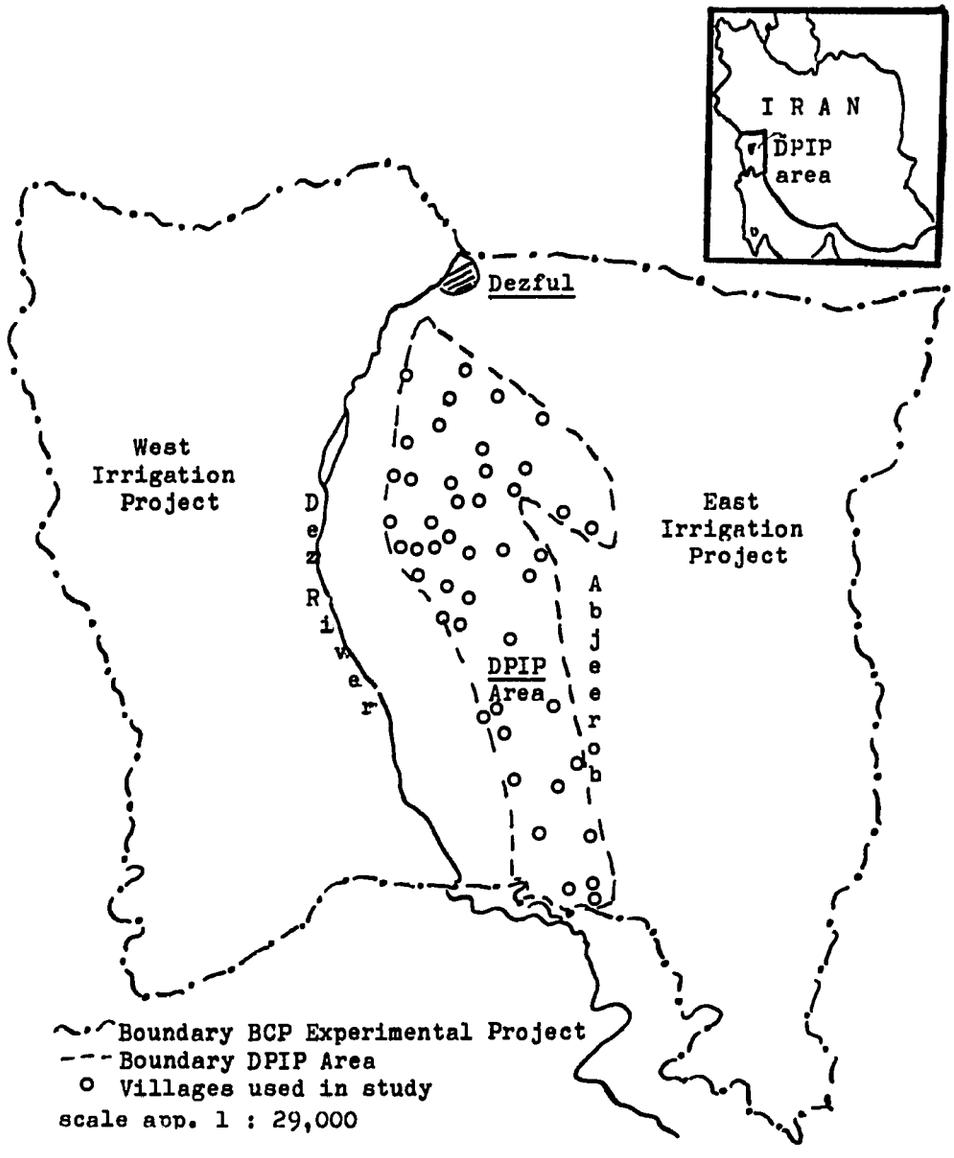
The initial objective of the project, in the beginning called Bilharziasis Pilot Control Project (the word pilot has now been removed), was to collect as much baseline information as possible on the status of schistosomiasis transmission in Khuzestan Province. This involved identifying the exact locations of the major

foci of schistosomiasis in Khuzestan, identifying snail vectors and their habitats, establishing rates of transmission, and mapping the villages.

The goal of the second stage was to identify the, "most effective and economical way to control schistosomiasis" (Arfaa, 1967, p. 358). To accomplish this objective, an area where transmission was most intensive was chosen and designated the Bilharziasis Experimental Control Project (Figure 12). The area of 1,646 square kilometers encompasses all 250 square kilometers of the DPIP. In addition to the high levels of disease present, this area was selected because a primary concern of the BCP has been the effect of irrigation of the spread of schistosomiasis.

The third objective was to implement control measures in an attempt to bring the disease to low levels of prevalence, hopefully even to eradicate it. Seven foci of the disease were established from the first set of surveys. These are shown on the map in Figure 13). The only species found in the area was *S. haematobium*, and the major focus, as shown on the map, was in the area south of Dezful and north of Ahwaz.

Because funds to BCP were allocated slowly, detailed epidemiological surveys of villages in the experimental area were not begun until 1963. (A few villages had been surveyed in 1961.) By 1964, the age-distribution of those infected with schistosomiasis had been established for 39 villages — twelve of them in



From BCP maps

Figure 12. Map of Bilharziasis Experimental Control Project

Construction of East and West Irrigation Projects started in 1968.

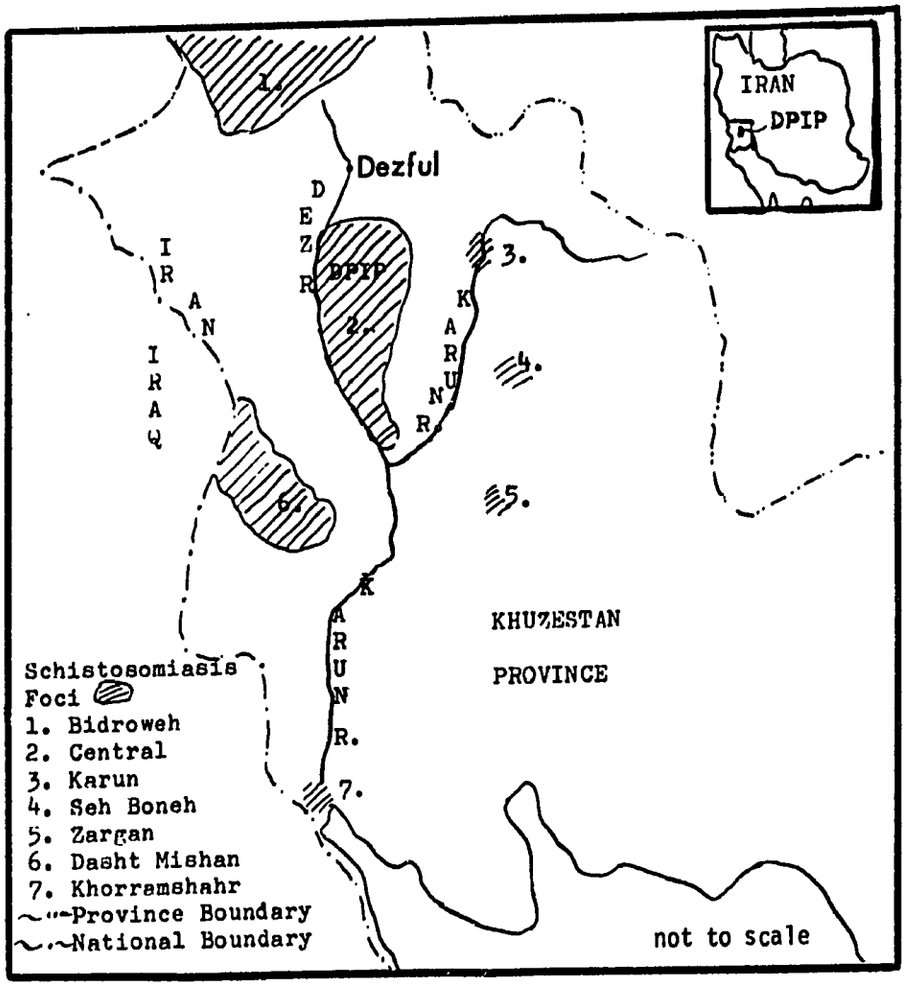


Figure 13. The seven foci of schistosomiasis in Iran
(Data collected by BCP)

the DPIP area. By 1965, all 188 villages in the experimental control area had been surveyed for over-all prevalence. One survey made in 1955 for intensity of infection, or obvious pathological effects, measured eight items; bloody urine, fever, anorexia, micturation pain, vesical region pain, headache, uticaria, and asthenia. Of the 930 infected persons examined in that study, one-third had one or more symptoms of disease (Arfaa, 1967, p. 363). Thus, despite high levels of prevalence, intensity was low. In a later survey, urine egg-counts showed that, "the association between prevalence and egg-counts is by no means clear-cut" (Arfaa, 1967, p. 364). The 1965 survey disclosed that prevalence rapidly approached a peak in 11-15 year olds then declined until a slight increase appeared in the 50-60 age group. Unusually high levels of prevalence (17 percent) were found in the 0-2 year olds because mothers washed them in snail-infested borrow-pits and ponds around the villages.

Bulinus truncatus (Photograph A) was found to be the only snail vector for *Schistosomiasis haematobium*. *B. truncatus* also carries *Schistosoma bovis* and *Paramphistomium microbothium* which infect animals in Khuzestan. Their relationship to humans is not well enough understood at this time to be of concern in this study. When Gaud, Arfaa, and Zeini surveyed the area from 1958 through 1961, the major breeding places were, "closely connected with human activities, essentially with irrigation" (1963, p. 26). Before

DPIP was constructed, these scientists had noted the following:

> Contrary to what may be noted in other countries, the irrigation canals themselves neither constitute the most numerous nor the most important breeding places.
>
> These canals occasionally harbour *bulini* and most probably contribute to their dissemination.
>
> *B. truncatus* breeding places primarily result from faulty drainage.
>
> Irrigation waters in excess or waters coming from leakages or overflowing of irrigation canals become breeding places when they are stagnant or cannot reach their natural drains.
>
> (1963, p. 26; French edition 1962, p. 272).

The effects of the DPIP noted in the previous sections helped to create the kinds of stagnant water favorable to the reproduction of *bulini*. In post-DPIP surveys, Chu established,

> From 1963 to 1965, the types of habitats seen were similar to those found by Gaud et al (1962). They include ponds, some old canals, drains ... swamps ... and springs.
>
> From 1965 onwards, an increased number of habitats was found in swamps and in sidepools along new canals and new highways ...
>
> The flow of water in the old canals was much slower than it had been previously; thus, more canals became infested with *B. truncatus* during 1966.
>
> ... towards the end of 1966, two new tertiary canals became infested with snails.
>
> (1968, p. 610)

Specific information about *B. truncatus* in the DPIP area that Gaud had observed and noted, and which Chu observed and experi-

mentally proved over several years (among many noted by both men) were:

- maximum density (as mentioned in Chapter II) is low
- maximum infectivity of the snails occurs in spring and autumn
- maximum transmission (cercarial shedding) occurs in spring and autumn, but some also occurs during summer
- *bulini* can survive dessication[5] up to six months and breeding intensity increases after a six month dessication compared to normal snails

An oddity of the *bulini* populations in this area, observed by both Chu and Gaud, is their discontinuity. While included in reports of both men, this observation probably refers to pre-DPIP conditions when a regular supply of water did not exist in the area. Habitats that existed in one season could be free of snails the next without control measures. Heavy winter rains, summer droughts, and possibly animals tended to disperse the snails. Thus, although the main transmission season was shown to be spring and autumn, it was also demonstrated that *bulini* were very hardy creatures who could survive long periods of heat and cold to become once again fast-breeding populations.

---

[5]Dessication occurs most often as a result of drought

Data Sources for Schistosomiasis Transmission Simulation Model

Since 1959, the BCP has issued Quarterly Reports. These include, for each quarter, prevalence in each village examined during the quarter, potential and actual snail habitats, results of special studies such as the study of incidence, and results of various control measures such as molluscicidng, chemotherapy, and engineering. In addition to these reports, data used here were obtained from published articles by the BCP staff and from the files of the Bilharziasis Research Station in Dezful. The author had the opportunity of accompanying staff members on their field operations and observed that data were carefully collected and conscientiously recorded. Thus, the data are considered highly reliable. Details about the methods of data collection can be obtained from Arfaa et al, 1972a, 1972b, 1970, and 1967; from Chu et al, 1968, 1967 and 1966; from Massoud et al, 1973 1972, and 1969; and from Farahmandian et al, 1973.

For prevalence determinations, a team composed of one physician and two technicians set the goal of examining 90 percent or more of the population in each village in the entire BCP area. Urine samples were taken between 10:00 a.m. and 2:00 p.m., by collecting 20 ml. of urine in a sterile bottle (Photograph 14). Each sample was identified by name, age, and sex. Samples were decanted into a test tube, refrigerated, and allowed to settle. Four hours later, sediment was removed by pipette and examined

for eggs on a watch-glass under a microscope. This procedure was followed before mass chemotherapy treatments were scheduled, and for incidence studies.

Data about snail populations include all areas with snail habitat potential noted for presence or absence of *B. truncatus*. This simplified habitat-notation is in contrast to surveys in some other control projects which have painstakingly attempted to sample by counting snail populations. Snail density measurements were made from 1962-1965, in limited areas, but these were not continued once the BCP put less emphasis on research and more on control measures. The BCP procedure is considered acceptable because of the small number of snails in any particular habitat and because of the low proportion of infected snails in any particular snail population. The information from the BCP procedure proved sufficient to establish the STS model and analysis.

Bilharziasis Control Project Control Programs

Mollusciciding experiments started with two habitats in 1964. During the following years various molluscicides such as copper sulphate, sodium pentachlorophenate, and Bayluscide were tried and compared. Since 1967 Bayluscide only has been used. Habitats are treated before maximum snail populations peak in the spring. After the initial treatment, the habitats are checked, "at least once every three months and (if re-populated), treated immediately -

except during winter seasons" (Arfaa, et al, 1970, p. 913) (Photograph 15). By 1968, all of the recorded habitats in the Dez area had been treated at least once.

Chu established the criteria for evaluating the effects of molluscicidings:

> "A presumptive 'complete kill' of *B. truncatus* in a habitat after molluscicidal treatments should be the result of negative finding in a monthly collection for a period of one year or longer, covering at least two potential snail population peaks. A 'failure' may be counted when one or more live snails is collected within one year of treatment."
> (1968, p. 634).

Chu's standards were first used in stagnant waters, but were later applied to drains and canals (discussed by Arfaa et al, 1970, p. 913-914).

In addition to molluscicidings as a means of snail control, engineering measures were applied on a small scale in the DPIP area. Major engineering efforts were concentrated in the Abjeerob area directly bordering the east of the DPIP. Engineering measures included drying up or filling borrow-pits, small ponds, and large swamp areas around villages. Occasionally swamps were plowed under for agricultural use. Banks of canals were, and continue to be, repaired and canals cleaned. Responsibility for land preparation and canal maintenance has been shared by the BCP with KWPA and the agri-businesses.

After experimenting with Miracil-D and Astiban, the drug chosen for treating people was Ambilhar. Side-effects, although present, are limited. Those observed during a few days after treatment include headache, abdominal pain, nausea, fever, vertigo, and vomiting, but, as noted before, they are not as serious as the side-effects from other drugs. However, Ambilhar is time-consuming to administer, requiring two oral doses daily for four days, which means that the treatment team must return to the village each of the four days (photograph 16). In addition, some villagers do not complete the series which then must be started over. Records are meticulously kept. The BCP is now experimenting with Hycanthone, a new drug, with good results. Hycanthone requiring only one injection, may be easier to administer, but the potential side-effects can be grave. Side-effects observed in the Khuzestan area resemble those from Ambilhar (Arfaa, 1972c). Elsewhere, however, Hycanthone has caused hallucination, cancer in laboratory animals and mutations in mice, among other effects. Many consider it too dangerous for mass treatment (Hulbert, 1974; Haese, 1973).

Although chemotherapy is only administered after transmission has been eliminated through snail control and where prevalence is greater than 10 percent, the combination of its dangerous and/or unpleasant side-effects and difficulties in administration suggest that chemotherapy is not worth the effort it involves.* To the

* It must be noted, however, that much of the success in controlling schistosomiasis in Iran has been due to the continued use of mass-chemotherapy.

arguments against it, Bueding (personal communication, 1974) adds that the de-infection rate, when worms die in the human host without any treatment, is high enough to make the potentially dangerous use of chemotherapy an unnecessary hazard.

Sanitary and health education measures are other tools for combatting the transmission of schistosomiasis which should have many positive possibilities. These measures should, for greatest effect, involve all the social agencies working together. Thus, the BCP, in one village, experimented with a variety of sanitation and health education measures — latrines in each house, one bathhouse for the village, one laundry, one well and pump with special faucets located in the village and a new school (Sahba and Arfaa, 1967). Despite four years of extensive effort, this village remains a paradigm of why the BCP does not stress sanitation and health measures in disease control programs. In 1974, the author on a visit to the village accompanied by BCP staff members, saw fly-encrusted faces of children, faucet handles broken by curious and playful youngsters attracted to their gleaming hardness, an unused bathhouse, drains in the middle of village streets filled with accumulations of dirt and waste matter, and manure piles alongside homes as they always have been, ready for use in the fields (Photographs 17 through 21).

The best intentions of the BCP were thwarted by a combination of events, the most important being the movement of villagers in

Shahabad's neighboring areas to shahraks. Because of the likelihood of moving, the inhabitants of Shahabad are unwilling to invest in repairs for the broken faucets, water system, and drains with the results described in the preceding paragraph (Iranshahi, personal communication, 1974). An additional contributing factor appears to be the inability of the health education program to change villagers' patterns of behavior. Campaigns to introduce desirable sanitary standards employed Western techniques and symbols that were assumed to be universally understood but were not. For instance, bright posters to discourage urinating in the canals depicted a man doing so, but with a huge super-imposed "X" over him. An anthropologist explained that the villagers were confused, an "X" has no meaning for them, they thought the posters pictured some new kind of windmill. (BCP Quarterly Report, January-March, 1964 indicated 3 percent of the population understood this poster, p. 16.)

The BCP has successfully controlled schistosomiasis in the newly irrigated areas of the Dez Pilot Irrigation Project. Various methods of control and combinations have been tried and the results recorded by the BCP. Control has required a long, expensive effort involving many manhours of dedicated work, over a period of 13 years, at a cost ranging from 8 million to 10 million rials each year. Contrasted with areas such as Egypt and the Sudan where controls have been attempted for many decades and the disease still

rages, the BCP's work in Iran is remarkable. However, as long as irrigation systems are expanded and armies, migrant workers, and others crisscross borders, schistosomiasis must continue to be considered a problem — even in the BCP area. In addition, it may well be that success in schistosomiasis control in new irrigation systems can be achieved at lower cost capitalizing on experience gained to date, and coupled with new evaluation techniques. This approach is considered in the following section.

CHAPTER FOUR

Utilizing data from the Dez Pilot Irrigation Project (DPIP) and from the Bilharziasis Control Project (BCP) the STS model is used to predict the impact of irrigation systems on schistosomiasis prevalence levels and to evaluate the cost-effectiveness of control measures. Because of its potential use to policy planners, major emphasis is placed upon the model as a tool for such evaluations in the planning process.

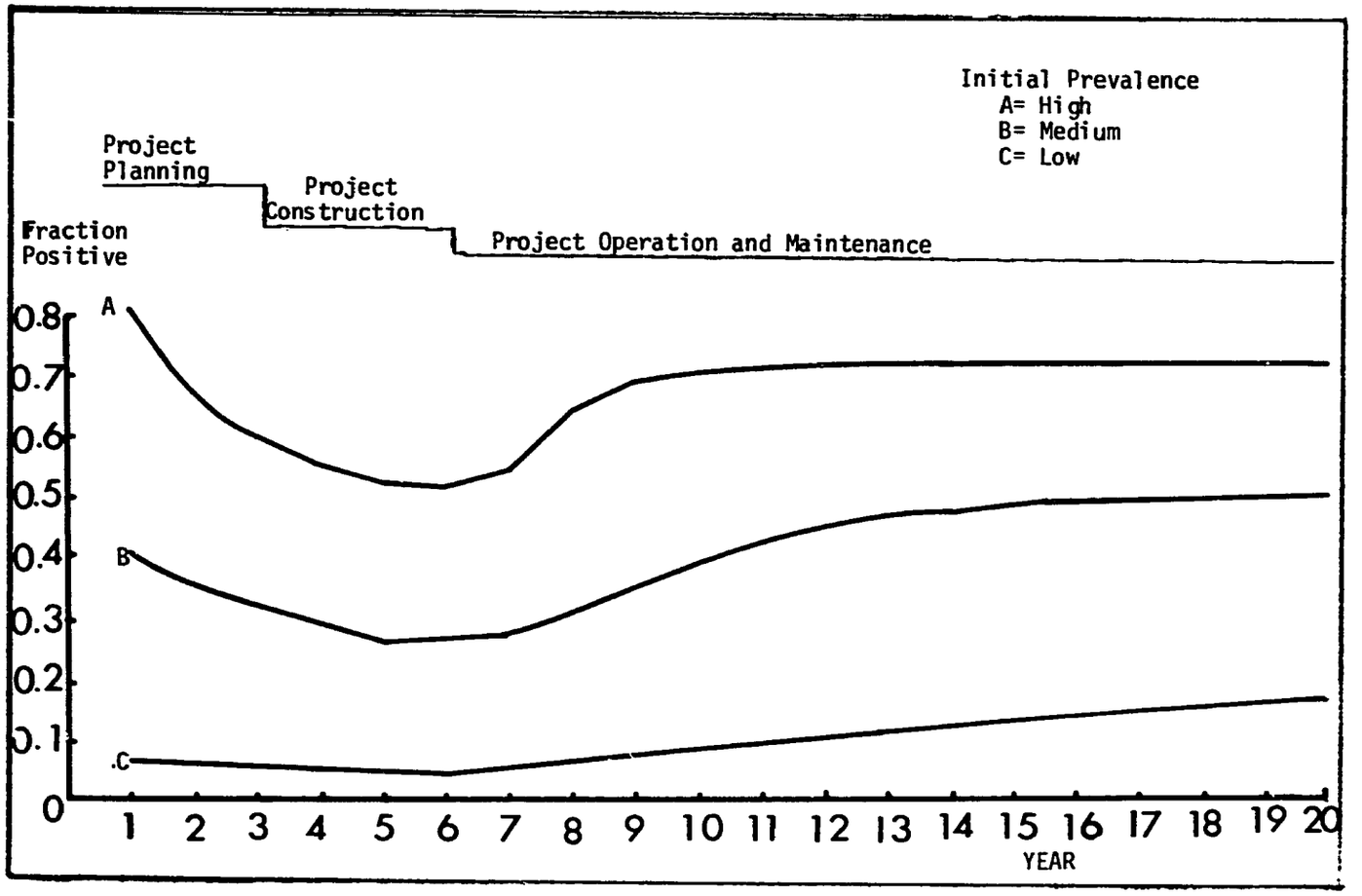
Impact of Irrigation Systems on Prevalence Levels

Predicting changes in prevalence in new or expanding irrigation systems where schistosomiasis is a recognized problem, may be done by appropriately increasing the value in Equation 3 of the STS model of the extent of accessible snail habitats (H) for the years of project construction and operation along with including baseline prevalence (Y_0) and total population values for each village in the area of expansion. The graph in Figure 14 shows the results of use of the model for three different levels of initial prevalence conditions, high, medium, and low. The analysis was based upon baseline conditions in the project area, with assumptions about increases in snail habitats in the absence of control measures (from BCP data for each year of DPIP available records, data given in Appendix I), and on total population

Figure 14. Projected Hypothetical Increases In Prevalence
(Under different initial conditions)

Results are shown for 3 year period of irrigation project construction.

Results are shown for 14 year period of irrigation project in operation.


Initial Prevalence
A= High
B= Medium
C= Low
Project Planning
Project Construction
Project Operation and Maintenance
Fraction Positive
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
A
B
C
1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 16 17 18 19 20
YEAR

increases due to the new project. After construction of the hypothetical irrigation project, the initial prevalence levels were surpassed except in the case where the original level was already high. The decline in prevalence during years of project construction may have resulted from land leveling and filling in of swampy areas for canal construction thus eliminating snail habitats (Booher, 1974, pp. 16-30).

Use of the model with refinements is possible in areas where there is no known schistosomiasis but where the introduction of irrigation systems increases the likelihood of transmission through settlements of infected migrants interacting with existing vector snails, and/or snails brought in by infected migrants or animals. This refinement requires the addition of a probability term to Equation 3 or Equation 4 to account for the likelihood of introduction of new infections where none had existed.

Evaluations of Control Measures By Use of the Model

Since 1967, Arfaa and co-workers have been evaluating the results of various schistosomiasis control methods and in 1972 preliminary estimates were made of the total costs of the BCP. The wealth of material which has been collected and analyzed provides an opportunity to evaluate the relative costs and effectiveness of the variety of eradication-control methods used on the project. Such an analysis may prove useful in planning future

schistosomiasis control programs in a cost-effective manner.

It should be noted that the cost-effectiveness analysis in this chapter is based on the premise that Iranian planners have decided that disease control programs are desirable. Thus, this is not a benefit-cost analysis of the project as a whole, and the benefits from disease control are not considered nor are the overall costs of the DPIP and of the BCP. Some perspective may be gained, however, by noting that the DPIP cost ∿ $25,000,000 (U.S.$) to construct and average annual operation and maintenance costs are estimated at $1,000,000 (McCulloch, personal communication, 1974). The average total annual costs of the BCP are $200,000, of which about two-thirds is spent on control operations.

The objectives of the BCP have been to break transmission of schistosomiasis and then to eradicate the disease. These are substantial objectives and the BCP has already achieved both within a limited area. An optimal control strategy could be arrived at if it were possible to determine the total costs of all different combinations of control measures that BCP could have used. However, because of limitations of data, only the combined control program used by BCP actually was analyzed. In addition, strategies of separate controls, mollusciciding, chemotherapy, and engineering were examined. In the first analysis, the effectiveness of separate controls on reducing prevalence was compared with the results of the BCP combined controls program

using the actual annual control budget of the BCP as a constraint on control expenditures. In the second analysis, constant level of control expenditures was assumed and the separate controls were again compared for their effectiveness. In the final analysis, the BCP control program was modified to demonstrate the effectiveness of a constant level of control expenditures on maintaining low levels of prevalence.

To determine cost-effective strategies, one may choose between examining varying costs with a given level of effectiveness or varying levels of effectiveness with constant costs or both. Varying levels of effectiveness with constant costs was the technique used in this study because there is uncertainty about the effectiveness of alternative control strategies in reducing prevalence. The analyses do not represent an exhaustive consideration of alternatives but indicate how the model may be used in such analyses, and permit some provisional conclusions about the different control strategies examined. Further work in this field is considered in Chapter V.

The proper selection of measures of effectiveness goals is of major importance. For example, if reducing prevalence, the number of people infected at any one point in time, is the objective chosen, then control by chemotherapy appears dramatically effective — prevalence of disease is reduced immediately. Over a period of time, however, examination of the records shows the

frequent recurrence of infection. On the other hand, reduction of the level of disease in the population by reduction of habitats may be delayed in time. Comparison of the two methods then must include a time component.

Frequency of Control Applications

Comparing the effectiveness of control measures requires a knowledge of how successful each round of treatment is, i.e., the number of times the same habitat must be molluscicided, the number of people who become re-infected after chemotherapy treatment, and the number of times engineering measures must be repeated on the same habitat.

Results from the BCP's mollusciciding efforts were analyzed to establish the likelihood of a need for mollusciciding any given habitat. Each habitat as reported in the BCP's Quarterly Reports was followed over time to determine the frequency of mollusciciding. Since the project coded and dated each habitat, each habitat could be followed throughout the eleven years of the project's treatments.

Habitats were separated into canals, drains, swamps, sidepools, and ponds. Each was noted for frequency of mollusciciding. Table 7 shows this frequency and the ranking of habitats according to the number of treatments each had required. For use in the STS model analysis of control-effectiveness, all habitats were grouped to determine the expected value of mollusciciding frequency. This

TABLE 7 — REQUIRED FREQUENCY OF MOLLUSCICIDING

Kind of Habitat	A* % Requiring One Application	B* % Requiring Two Applications	C* % Requiring Three to Ten Applications
Canals	37.9	29.3	32.8
Drains	36.6	14.6	48.8
Swamps	50.0	10.7	39.3
Sidepools	46.4	28.6	25.0
Ponds	70.0	20.0	10.0

* A + B + C = 100%

RANKING OF HABITATS BASED ON THE FREQUENCY ANALYSIS

Drains

Canals

Swamps

Sidepools

Ponds

Compiled from Bilharziasis Control Project
Quarterly Reports, 1966 - 1973

was done specifically for the years after irrigation waters were received by all villages in the area from 1966-1973. The expected value of the need for repetitive treatment of any habitat was estimated as 2.7 times over the life of the treatment program. Taking into account the time-horizon of the treatment program, 8 years, the need for mollusciciding the same habitat averaged once every three years (8 ÷ 2.7), and, the snail habitat reversion factor used in the cost-effectiveness analysis was 0.33 per year.

The correction factor for chemotherapy was based on both the success rate of treatment and the proportion of infected people actually treated. Success in treatment was measured from follow-up examinations done after each mass chemotherapy. The numbers of people who still passed eggs, an indication of ineffective treatment[6] were noted in the Quarterly Reports. From these data, the calculated rate of success was quite high, 95 percent. However, the project was not able to locate and treat every infected person in the villages. Therefore, the success rate was modified by the average fraction of infected people treated in the DPIP, 0.79. The chemotherapy factor used to determine the fraction of the population not cured was one minus the product of the average fraction treated (0.79) times the success rate (0.95), or, (1 - 0.79 (0.95)) = 0.25.

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[6]Re-infection might have occurred in some cases.

Engineering measures were not as widely applied in the DPIP area by the BCP as were mollusciciding and chemotherapy. Engineering measures were applied in only 84 or 26 percent of the 326 habitats reported for the eight years of control efforts. In addition, it was difficult to determine whether an engineering measure had been applied to a habitat more than once because the notations used in the Quarterly Reports were not as clear as those for mollusciciding. Arfaa et al, (1972) stated that engineering measures were permanent. Thus, despite the unavailability of specific information from which to calculate a success rate, it was decided to use 95 percent as a success rate to account for relapses that might have occurred but were not noted. The correction factor used in the cost-effectiveness analysis to indicate rate of reversion for engineering measures was 0.05. Reversion rates for mollusciciding and engineering and the failure rate for chemotherapy are given in Table 8 below.

TABLE 8 — CORRECTION FACTORS FOR DIFFERENT CONTROL MEASURES

Control Measure	Reversion Rate
Mollusciciding	0.33
Engineering	0.05
	Failure Rate
Chemotherapy	0.25

Costs of Control Applications

Costs for applications of each of the control measures were calculated from BCP data. However, because cost data were infrequently noted in the BCP Quarterly Reports, it was necessary to compute the separable costs of the various procedures required in each control measure. Engineers Mansoori and Hebert, Drs. Arfaa, Farahmandian, and Sahba (all associated with BCP) made this possible by supplying the necessary information about costs of labor per day, costs of different equipment and materials, and costs of transportation, such as cars and drivers needed for chemotherapy and mollusciciding. It was possible to estimate average unit costs for each treatment measure from this information and from BCP records and files. The estimates appear below in Table 9.

TABLE 9 — AVERAGE UNIT COSTS FOR DIFFERENT CONTROL MEASURES

Control Measure	Average Cost
Mollusciciding	5 rials/meter Includes: labor, equipment, car and driver, molluscicides
Chemotherapy	10,000 rials/treatment Includes: labor, materials, car and driver for treatment (4 days each) and follow-up studies, drugs
Engineering: All kinds of engineering measures averaged	17 rials/meter Includes: labor, equipment, car and driver, materials (including fill at 16 rials/cubic meter)

(Exchange rates for rials and U. S. dollars are given in Appendix II).

Methodology of Cost-Effectiveness Analysis

One of the villages, Deylam Sofla, was chosen to demonstrate the use of the STS in cost-effectiveness analysis. This village was typical of those in the BCP control program in that a variety of measures were used to control schistosomiasis, including extensive engineering control measures in the beginning of BCP's activities in the village. The effectiveness of different control measures used separately and in combination should be revealed because of the high levels of prevalence in the village before the BCP's work.

For the first analysis, the total annual BCP expenditures in the village of Deylam Sofla were calculated (Table 10). In order to compare strategies of separate controls to the BCP combined controls program, these annual expenditures were used as the constraint on total funds available for each year. This constraint was used because it enabled direct comparison of the effectiveness of the separate control strategies with the effectiveness of the BCP combination approach. With standardized costs the effectiveness of the different control programs may be compared within the same framework in order to examine the validity of the BCP program. If it had been possible to calculate a suitable discount rate for the year of BCP expenditures, it would have been more appropriate to use a discounted rate of expenditures that would have arrived at the actual BCP expenditures. Since this was not possible,

TABLE 10 — EXPENDITURES FOR CONTROL MEASURES IN DEYLAM SOFLA
Computed for 1967 - 1973

Year	Control Measure	Expenditure for Control (rials)
1967	Engineering	56,780
1968	Combination of Molluscicidng Chemotherapy	30,000
1969	Molluscicidng	12,500
1970	Chemotherapy	10,000
1971	Molluscicidng	15,000
1972	Molluscicidng	7,500
1973	Molluscicidng	7,500
		139,380 Total

Compiled from the Bilharziasis Control Project
Quarterly Reports, 1967 - 1974.

the annual expenditure constraint was used as a second best choice. For purpose of analysis all of the money available in each year was considered spent. This assumption enabled repeated use of a control measure if more money were available than actually could be used by a single application of the control. Repeated use of a control measure occurred frequently as part of the BCP program so there was some basis in reality for this assumption. For example, when mollusciciding was analyzed, the total expenditures for each year were divided by the cost-per-unit for mollusciciding to determine the meters of accessible snail habitats that could be treated. In 1967, the 56,780 rials of total expenditure for Deylam Sofla, were divided by 5 rials per meter permitting treatment of 11,356 meters of accessible snail habitat. Since this number of meters exceeded the meters of habitat actually infested with snails in that area, re-application could take place (a common control practice of the BCP). To examine prevalence after postulated completion of control project expenditures, the model was run for 10 years after the last year of available data from the BCP. By use of appropriate correction factors, each type of control measure was analyzed independently of the other control measures for its effect on reducing prevalence levels.

For the second analysis, the budget constraint was changed to one of constant annual expenditure. The annual budget was taken to be equal to the first year of BCP expenditures, 56,780

rials. This analysis was an attempt to examine the effectiveness of separate controls under constant expenditures. By keeping costs the same every year, the effectiveness of the separate measures on reducing prevalence were compared. Again the expenditures were ceased after 7 years of a control budget to determine the prolonged effectiveness of the separate control measures under a relatively high budget constraint. In this analysis, because of the change in the budget constraint, the BCP combined controls program could not be included for comparison.

For the third analysis, the results of continued low expenditures on reducing prevalence were examined for the BCP combined controls program. In this case, 7500 rials, the BCP expenditures in Deylam Sofla for the last two years of available data, 1972 and 1973, were used as the minimum budget constraint extended for 22 years past the earlier postulated cessation of controls; after 10 years, prevalence levels remained constant. Chemotherapy was the control measure chosen since it was hypothesized that small expenditures in this instance would be sufficient to maintain prevalence at low levels.

Three different comparisons were made as a result of these analyses, first, comparison of levels of prevalence resulting from the use of the different control strategies for 7 years of control expenditures, second, comparison of the percent changes in prevalence from the use of different control strategies over the 7 years

of control expenditures, and third, comparison of hypothetical levels of prevalence at the end of a projected 10 year period in the first and third analysis and 22 years in the second analysis. Other measures of effectiveness such as the discounted number of man-years sick or the mean fraction of prevalence could have been used. The first three were considered sufficient to demonstrate use of the model in analyzing the effectiveness of the different strategies.

Reversion rates for molluscicidng and engineering and failure rate for chemotherapy, as noted before, were incorporated into the analyses. Thus, for every accessible snail habitat treated by molluscicidng, the meters treated were multiplied by the molluscicide reversion rate, 0.33. The product was the number of meters that reverted to snail infested habitats in the year following treatment. For example, in Deylam Sofla in 1967, the total meters of accessible snail habitat that could be treated were divided by the meters of accessible snail habitat that actually existed during that year. The result, 3.4, was the power to which the reversion rate, 0.33, was raised, $0.33^{3.4} = .02$, in order to give a reversion rate based on treatment considerations. Correction factors for the reversion rate of engineering control measures and failure rate of chemotherapy were computed in the same way.

After the amount of treatment possible was calculated, and necessary corrections made in reversion rates, several accounting

steps were taken to insure accurate representation of the controls. These may be summarized in the following equation:

$$H_{t+1} = H_t - T_t + \alpha \sum_{j=0}^{t-1} T_{t-j} + H'_{t+1}$$

where H_{t+1}, the meters of accessible snail habitats, is the sum of H_t meters of accessible snail habitats from the year before minus the meters of habitat treated, T_t, plus the sum of reverted potential habitat from previous years of treatment and reverted treated habitat from year t,

$$\alpha \sum_{j=0}^{t-1} T_{t-j}$$

where α is the reversion rate for the treatment, and H'_{t+1} is new habitat in year t+1. These steps, are outlined below for the engineering control measures and for mollusciciding:

1) Calculate meters of accessible snail habitats that can be treated within annual expenditure constraint

2) If constraint is too small to accommodate actual meters of accessible snail habitats, carry over excess meters to following year's sum of meters of accessible snail habitats

3) Multiply treated habitats by reversion rate. Carry over this product to next year's sum of meters of accessible snail habitats

4) Subtract the product obtained in #3 from meters of treated accessible snail habitats to obtain potential habitats which have accumulated over the years of analysis. Potential habitats refer to treated accessible snail habitats that annually revert to infested at the appropriate reversion rate.

5) Multiply potential habitats that have accumulated to the year of analysis by the appropriate reversion rate. Carry over that product to next year's sum of meters of accessible snail habitats.

Thus, the STS model accommodates the following under the term H, meters of new accessible snail habitats arising in one year; meters of untreated accessible snail habitats carried over from the year before; and meters of reverted treated accessible snail habitats.

The procedure for examining the effectiveness of chemotherapy as a control measure for schistosomiasis involved the use of a failure of treatment rate. In the STS model, the failure rate for chemotherapy treatment corrects the value of P, the people infected in Equation 3. For the cost-effectiveness analysis, the failure rate was corrected by the number of treatments possible under the annual expenditure constraint. Thus, for Deylam Sofla in 1967, chemotherapy could have occurred 5.7 times. The reversion rate, 0.25, raised to the 5.7 power, gave a corrected reversion rate for 1967 of 0.0004 which was then used in the model to correct P, the number of people infected for the next year.

It is important to recall that for demonstration purposes when one control measure is chosen for the analysis, no other control measure can be used for that analysis. When either molluscicidng or engineering control measures is chosen for analysis, no resources are available for chemotherapy and vice versa.

Results of Cost-Effectiveness Analysis

For the first analysis consideration of the different criteria shown in Table 11 and Figure 15 suggest that the combined controls program of the BCP was more successful in reducing prevalence over the years of the project for which data are available than using a single control alone. However, in the analysis of the hypothetical cessation of expenditures after the last year of available BCP data, prevalence started rising for each control strategy considered alone in the first analysis. Chemotherapy appeared highly successful in reducing prevalence immediately after use. However, when expenditures were ceased in the model run, prevalence increased rapidly in 5 years to a high level which was maintained until the end of the hypothetical run. When chemotherapy was halted in the model, re-infection occurred causing the sharp rise in prevalence, because under the terms of the first analysis, only one control measure could be used in any run, so that no accessible snail habitats were molluscicided or controlled by engineering measures during the chemotherapy run. Both molluscicidng and engineering were under the same limitations, and neither alone succeeded in reducing prevalence below the level at the start of control measure application. When control expenditures were stopped in the model, mollusciciding reached the same high level as chemotherapy in 5 years. Engineering measures (Figure 15) caused a slight decline in prevalence after expendi-

TABLE 11 — RESULTS OF FIRST COST-EFFECTIVENESS ANALYSIS

Control Measure	Level of Prevalence at End of Treatment 1973	% Change in Prevalence Over All Yrs. of Controls 1967-1973	Projected Level of Prevalence 10 Yrs. After Cessation of Controls
Mollusciciding	0.73	10.6% increase	0.80
Engineering	.69	4.5% increase	.75
Chemotherapy	.60	9.1% decrease	.80
BCP Combined-Controls	.20	68.4 decrease	.78

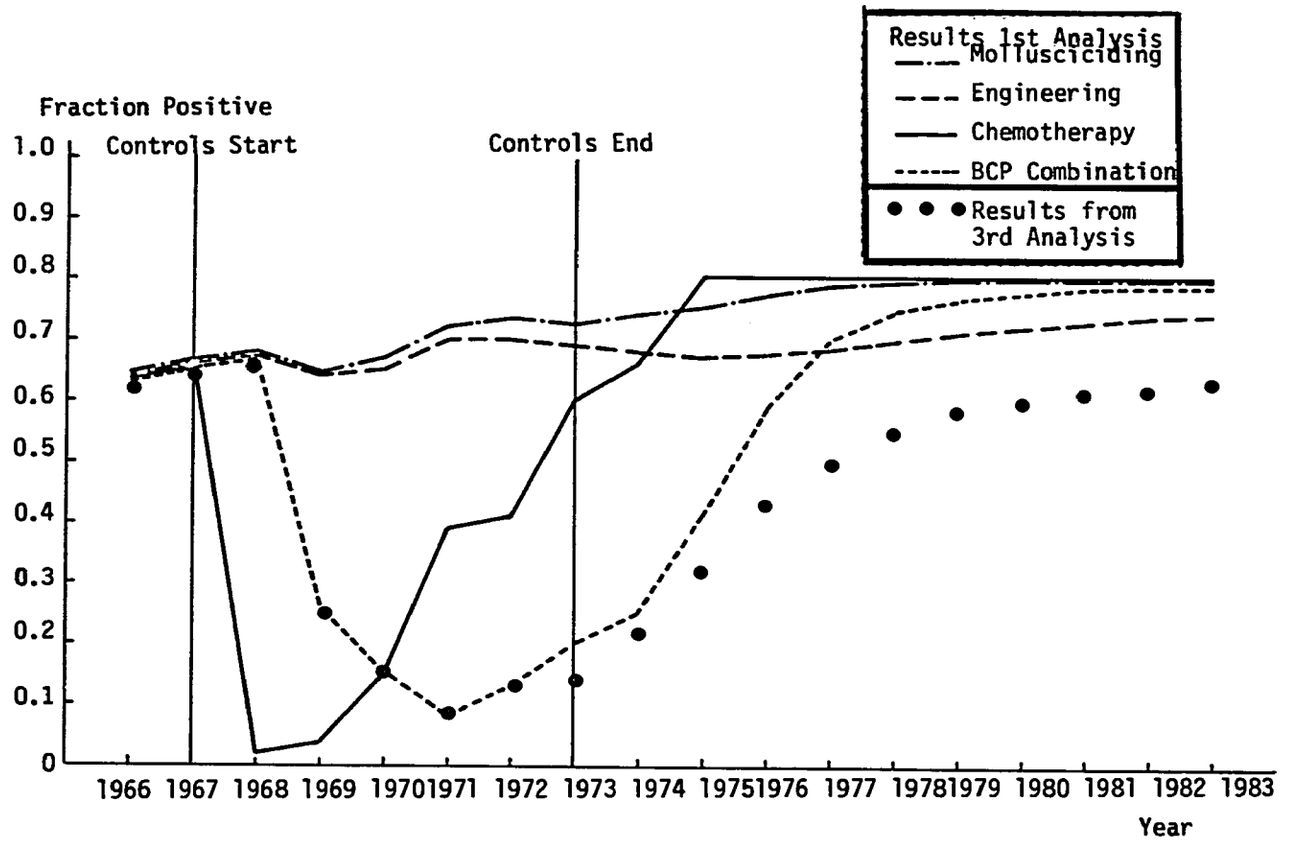
Initial Level of Prevalence for Percent Calculation:
0.63 in 1963.

Figure 15. Results of First and Third Cost-Effectiveness Analyses

Graph for First Analyses compares effects of mollusciciding, engineering, chemotherapy, and BCP combined controls program starting before any controls in 1966, continuing from when all controls began in 1967, and extending to end of available data in 1973. Model is used to project prevalence levels for ten years after (hypothetical) cessation of controls.

Graph for Third Analysis shows a hypothetical continuation of a BCP control program of chemotherapy with low level of expenditure for ten years following last year of available data.

(This analysis was run for twenty-two years but prevalence leveled after ten years.)


Results 1st Analysis
Molluscicidng
Engineering
Chemotherapy
BCP Combination
Results from 3rd Analysis
Fraction Positive
Controls Start
Controls End
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1966 1967 1968 1969 1970 1971 1972 1973 1974 1975 1976 1977 1978 1979 1980 1981 1982 1983
Year

tures were stopped in the model. After declining for 3 years, prevalence again began to rise but reached slightly lower final levels of prevalence than with cessation in the model of the other three control strategies.

For the second analysis, the results in Table 12 and Figure 16 suggest the same pattern as described above. It is interesting to note for a total expenditure in this second analysis of 397,460 rials compared to the actual BCP total of 139,380 rials that the resulting levels of prevalence projected for separate controls after cessation of controls in the model are the same. The model demonstrates, for the very much higher expenditure in the second analysis, a greater percent decrease in prevalence for each separate control measure at the end of the treatment expenditure. One possible conclusion from this analysis is that the combined control program of the BCP even with a low total budget is still the most effective strategy as long as expenditures are continued, and depending on the measure of effectiveness chosen.

The third analysis used a minimum level of expenditure which was less than half of the average rate of annual expenditure of the BCP to try to maintain the lowest level of prevalence arrived at by the BCP, 0.08 beyond the 7 year expenditure period. Since prevalence had begun to rise in the case of the BCP program when molluscicidng was used in 1972 and 1973 and since engineering measures require large amounts of money, it was decided to examine

TABLE 12 — RESULTS OF SECOND COST-EFFECTIVENESS ANALYSIS

Control Measures	Level of Prevalence at End of Treatment 1973	% Change in Prevalence Over all Yrs. of Controls 1967-1973	Projected Level of Prevalence 22 Yrs. After Cessation of Controls	Projected Level of Prevalence 10 Yrs. After Cessation of Controls
Molluscicidng	0.61	7.6% decrease	0.80	0.80
Engineering	0.42	36.4% decrease	0.77	0.66
Chemotherapy	0.005	99.2% decrease	0.80	0.80

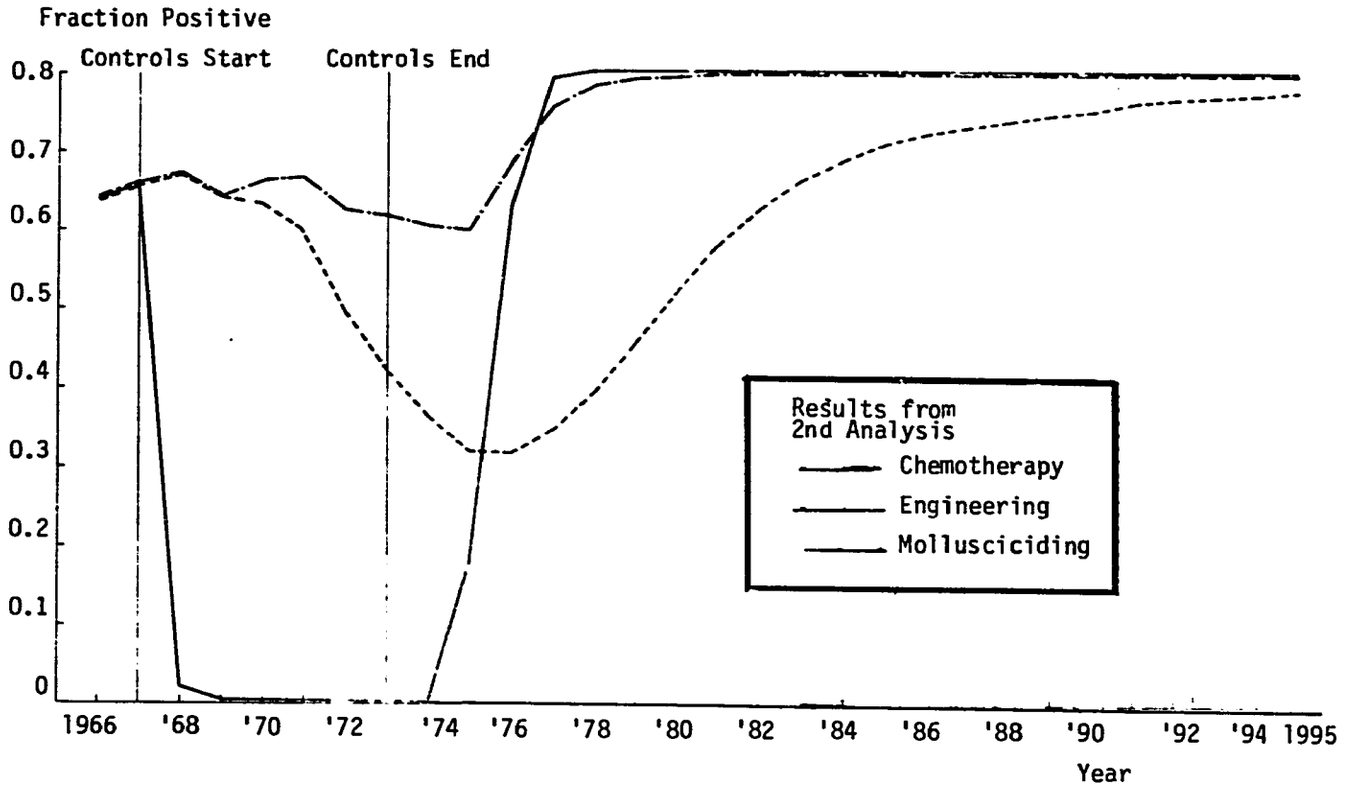
RESULTS OF THIRD COST-EFFECTIVENESS ANALYSIS

BCP Program with Prolonged Chemotherapy

	Projected Level of Prevalence 22 Yrs. After Cessation of Controls	Projected Level of Prevalence 10 Yrs. After Cessation of Controls
	0.63	0.68

Figure 16. Results of Second Cost-Effectiveness Analysis

Graph for Second Analysis shows effects of one high constant annual expenditure for each of the control measures on reducing prevalence levels over a seven year period. Model is used to project prevalence levels for twenty-two years after (hypothetical) cessation of controls.


Fraction Positive
Controls Start
Controls End
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1966
'68
'70
'72
'74
'76
'78
'80
'82
'84
'86
'88
'90
'92
'94
1995
Year
Results from
2nd Analysis
Chemotherapy
Engineering
Mollusciciding

the effectiveness of chemotherapy with a small constant expenditure. The results in Table 12 and Figure 15 demonstrate that this amount of chemotherapy was not effective in maintaining low levels of prevalence. In fact, with continuous expenditures, prevalence rose to high levels although at a slower rate than with the cessation in the model of the combined control program. In addition the final level was lower than levels reached with the cessation in the model of control expenditures.

These analyses point out possible uses of the STS model in analyzing the cost-effectiveness of different control strategies. The major conclusion resulting from the different tests is that the combined control program of the BCP is most effective as long as expenditures are made. In order to maintain low levels of prevalence expenditures need to be of a high enough level so that a combined program may continue. Maintaining low levels of prevalence with separate controls would require excessively high budgets continued over many years.

CHAPTER FIVE

Conclusions

The STS model developed and verified in this study can provide some useful approaches to immediate problems. Because one of the model parameters, accessible snail habitats, is directly altered by manmade manipulation of the landscape, i.e., changes producing increased water availability, the dynamics of schistosomiasis prevalence may be simulated.

A valuable feature of the STS model is that it can be used to consider a wide ranges of alternatives. In addition, the model can be usefully employed when data are limited. Thus, funds as well as manpower earmarked for planning and carrying out statistical surveys can be released permitting concentration of time and money on evaluating alternatives and carrying out control strategies.

The STS model, with limited data, provides a systematic technique for analyzing the costs and relative effectiveness of alternative disease control measures. Such analyses should in turn be helpful in making rational selections of control programs from the many alternatives available. Potential future work with cost-effectiveness analysis is described below.

Since the STS can be used to predict the impact of irrigation on schistosomiasis using measurable factors involved in the

spread of schistosomiasis, it is expected that the model can be extended beyond the data used in its verification in evaluating similar problems in other regions of the world were irrigation projects are planned. In areas as diverse as Iraq, Brazil, Nigeria, the People's Republic of China, and for new irrigation projects in Iran, use of the model could be attempted to predict the impact of new or expanding irrigation projects on the prevalence of schistosomiasis.

In applying the model to areas where schistosomiasis is a threat, a stochastic term may be added to the simulation equation by use of a random number generator. A stochastic model would permit detailed examination of different probabilities of success of various control methods in several different types of disease transmission situations by use of "Monte Carlo" simulation.

It may be possible to accommodate in the model other kinds of schistosomiasis, perhaps even other diseases which require intermediate hosts. The possibility exists because the concept underlying the model involves fundamentals of the transmission cycle of *S. haematobium* — ones common to other parasitic diseases — where infection of the disease is a function of the interaction of the intermediate source and the number of people already infected.

Suggestions for Future Research

Further experimentation is possible with the STS model on the basis of the data used in the cost-effectiveness analysis and additional data from the BCP. Within the framework of cost-effectiveness analysis, two extensions of research are being considered, one methodological, the other practical. Use of the model for cost-benefit analysis may also be possible if data on the economic effects of schistosomiasis on employment or on agricultural productivity are available for irrigation project areas.

The methodological considerations include changing the budget constraints and expanding the cost-effectiveness analysis to examine different combination of alternatives and different sequencing of control measure application. By changing the budget constraint from an annual one to a total budget within a definite time frame one can examine the effectiveness of a large initial expenditure for disease control with smaller maintenance expenditures within an established time frame. It is first necessary to determine the desirable length of time for the eradication of schistosomiasis or to keep the disease below a certain level, e.g., 1 percent of the population. In addition, it is necessary to determine the appropriate discount rate over the years of control expenditures to be able to compare the desirability of different time frames. A flexible budget within a time bracket differs from most of the schistosomiasis control programs which are based on

annual budgets and unstated time goals.

Considerations of different combinations of controls are possible under the different budgeting programs in order to determine optimal control strategies for different budget and disease conditions. In addition to examining different combinations of controls than those used by the BCP, controls such as alternative water supplies could be studied for their effectiveness in reducing prevalence.

Sequencing of controls within the cost-effectiveness analysis can also be examined as a result of a flexible budget. Sequencing is complicated because each year's combination of control measures is dependent on the effectiveness of the combination used in the year before (May and James, 1974, p. 226). In order to examine the effectiveness of the entire program over time, a sequential expenditure cost-effectiveness curve must be derived. Once this curve is defined, the most cost-effective sequencing of alternative strategies can be identified.

Finally, different choices of the measures of effectiveness can be examined. These measures of effectiveness can include those already examined in this study such as level of prevalence at a certain point in time or the percent change in prevalence before and after control programs. Additional effectiveness measures might include maintaining a desired low level of prevalence over the planning horizon or minimizing the discounted

number of man-years of infection. The choice of alternative control strategies is sensitive to the choice of the measure of effectiveness so that several measures should be examined.

The practical considerations for future research include application of alternative strategies. For example, with a budget that permits a large initial expenditure, the prolonged effectiveness of engineering demonstrated by the model in the first and third cost-effectiveness analyses could be utilized. Along with examining the feasibility of beginning the control program with engineering measures, two additional studies could be made. First is the appropriate timing of chemotherapy application. Usually chemotherapy is delayed until elimination of snail habitats is attempted; because of re-infestation of snail habitats resulting in the re-infection of people as demonstrated in the third analyses, concomitant use of chemotherapy and engineering measures might be more effective than delayed use of chemotherapy. Second, the degree of application of molluscicidng could be studied. Molluscicidng might be more effective as a maintenance measure following the use of engineering control measures rather than as the major control used. A regular program of spraying as maintenance for snail control might be more successful than saturation molluscicidng.

These suggestions for future research are being considered in order to assist combined- controls programs similar to that of

BCP. Extended examination of available methods may offer more efficient approaches for permanent control of schistosomiasis.

General Reflections

Reflecting on the manhours and energy of others involved in deriving the models which aided in the development of the STS model, and on the calculations, computer programming, and other work required to test the STS, one must conclude that even the most intense and careful mathematical calculations designed to judge ways of helping mankind must sooner or later confront the actual conditions of human existence. Every computation had to acknowledge the reality of certain unaccountable variables. The STS model, like every other useful model, works within narrowly circumscribed assumptions that cannot begin to encompass the behavior of men. Use of the STS model can help point to the selection of treatment programs for reducing certain types of disease, but the author believes successful programs for disease eradication must keep in mind the humanity behind their goals. The ideas which follow developed as data were collected for the model. They derive from the author's observations in one country she was privileged to visit. They are not intended as criticisms and they do not diminish her admiration for the strength and determination to improve living conditions seen there. Rather it was those qualities which prompted these reflections.

Schistosomiasis exists among people who are new to Western technology. They see the innovations, wonder about them, and are beginning to want them. In fact, many of the wonders, such as electricity in the shahraks, are being thrust upon them but without due consideration of the inadequacies of partial measures. For example, it is not sufficient to place a multi-million dollar dam among ancient fields and expect only good results. When a people's established patterns of behavior are disrupted, common sense dictates substitution of patterns of quality commensurate with those destroyed. The suggestion below might protect the cultural heritage, indeed might build upon it through the kinds of understanding outlined by Maslow (1943), White et al., (1972), and Wolman (1969), which use self-motivation as keystones. Two approaches which may assist in the development of new cultural patterns which improve the quality of living, and in which self-motivation plays an important role, are health education and sanitation. Due to the difficulty of quantifying their potential far reaching effects, health education and sanitation measures are not considered in this study to the degree warranted by their importance; yet, these two activities should be the basic components of any disease control program. If health education and sanitation programs were designed in keeping with the customs, past experiences, and present needs of a particular population, these programs would be more acceptable. In short, the people

would then use latrines and drinking water systems (Davies, 1966). Even without the availability of models, every disease control worker knows that sanitation provides the essential and fundamental break in the transmission of disease, particularly, schistosomiasis (Swisher, 1972, p. 615).

The snails that permit the spread of schistosomiasis are 600 million years old. They have been found in the Cambrian strata of the earth. They are not going to vanish like some endangered species for these vectors are small, without market value, of incredible toughness, and they can burrow into the earth to wait for rain or warmth or whatever conditions they lacked that made them retreat. Hoping to hunt out each and every snail is like hoping to count weeds in a marsh. It could be done, but is it worth the effort? Yet, unless new thinking about schistosomiasis control is started, stomping out the snails is the chosen means of most planners for breaking the transmission cycle. The obvious way is not difficult to broach. It is bringing technology into the homes, and thus the lives, of the developing country's population. Otherwise, building a dam, irrigating long dry fields, and changing the face of the land through science without adding similar dramatic changes to lives is like placing a shoe on one foot and leaving the other one bare.

APPENDIX I

Included in Appendix I are a printout of the computer program for the Schistosomiasis Transmission Simulation Model, the data used in verifying the model, a list of names of villages used in the study, and data used in cost-effectiveness and impact analyses. The notations used in the program statements are the same as given in Table 4 except that R in the computer program is the number of people infected and P is total population, C in the program is Incidence or I in the table of notation and M is the year of analyses. The data lines are arranged so that lines 185 through 189 give the baseline prevalence for each village in the same order as the following data lines. Lines 190 through 5402 are keyed to the list of villages in that line 190 is the first line for village number one Bande-bal; line 200 is the first line for village number two, Ghaleh Rob Bande-bal; line 300 is the first line for village number three, Ghaleh Now Shams Abad; up to line 5400 which is the first line for village number 54, Ameer Abad. Each village's data line gives the following information: H, P, Q for 1961 through 1973. Thus for each village there are 13 consecutive arrangements:

H, P, Q,	H, P, Q,	H, P, Q,...,	H, P, Q
1961	1962	1963	1973

Deylam Sofla is village number 29 and the data for that village used as the basis for the cost-effectiveness analyses are in lines

2900, 2901 and 2902. Data on the baseline prevalence were obtained from Gremliza (1962). Data for the remaining years were obtained from the Quarterly Reports and Files of the Bilharziasis Control Project, Dezful, Iran. Data for the impact analyses in Chapter IV (pp. 1-2) are based on the initial prevalence, total population, and meters of accessible snail habitats for three different villages with three different levels of prevalence: #29, Deylam Sofla, .806; #26, Sardar Abad, .411; #10, Ghaleh Ghazee, .169.

STS Program (Basic Language)

```
1       THIS PROGRAMPREDICTS SCHISTOSOMIASIS PREVALENCE (Y(I,J)
2      FOR 2 YEARS BEFORE AND 11 YEARS AFTER CONSTRUCTION OF
3      DEZ IRRIGATION,PROJECT,DEZFUL,KHUZESTAN PROVINCE ,IRAN(1961-
4      1973). PREVALENCE IS COMPUTED FROM INPUT DATA OF BASELINE
5      PREVALENCE FOR 1961 AND NUMBER OF PEOPLESICK (CORRECTED
6      FORCHEMOTHERAPY) AND EFFECTIVE HABITAT EACH YEAR.THE
7      MODEL RUNS FROM JAN.1 TODEC.31 FOR EACH YEAR.PRINT OUT IS
8      FOR EACH VILLAGE AND EACH YEAR:NUMBER OF PEOPLE SICK
9      (UNCORRECTED BY CHEMOTHERAPY),TOT.POP.AND PREVALENCE.
10  DIM Y(14,54)
15  FOR J=1 TO 54
20  READ Y(1,J)
25  NEXT J
30  FOR J=1 TO 54
33  PRINT "VILLAGE NUMBER ";J
35  FOR I=1 TO 13
40  READ H,P,Q
45  LET M=1960+I
55  LET R=P*Y(I,J)
60  PRINT M,R,P,Y(I,J)
65  LET R=R-(R*Q)
70  LET Y(I,J)=R/P
80  LET A=(5.675E-06)*H↑1.109*R↑.455
85  LET B=.2
90  LET C=A/(A+B)*(1-EXP(-(A+B)))
95  LET Y(I+1,J)=C*(1-Y(I,J))-B*Y(I,J)+Y(I,J)
100  NEXT I
110  NEXT J
185  DATA .012,.157,.018,.063,.06,.111,.033,.017,.06,.169
186  DATA .029,.028,.071,.011,.015,.036,.049,.031,.011,.32
187  DATA .453,.306,.222,.34,.369,.411,.484,.708,.806,.7
188  DATA .535,.758,0,.769,.616,0,0,0,.037,0,.032,0,.015
189  DATA .018,0,0,0,.016,.059,.024,.044,.009,0,.017
190  DATA 0,264,0,0,260,0,0,256,0,0,250,0,0,244,0,0,237,0
191  DATA 68,259,0,3000,269,0,3200,278,0,3200,288,0
192  DATA 0,298,0,0,308,0,0,313,0
200  DATA 175,126,0,0,120,0,0,113,0,0,112,0,0,110,0,0,131,0,0
201  DATA 126,0,2900,127,0,3050,134,0,0,137,0,0,140,0
203  DATA 0,156,0,0,172,0
300  DATA 300,118,0,300,130,0,300,143,0,300,142,0,300,142,0
301  DATA 300,110,0,2500,139,0,2500,139,.92,0,154,0
302  DATA 0,172,0,0,191,0,0,230,0,35,250,0
400  DATA 275,134,0,160,131,0,160,127,0,160,127,0,2660,127,0
401  DATA 0,134,0,0,141,0,0,146,0,3500,168,0,0,168,.8
402  DATA 0,169,0,0,170,0,0,170,0
500  DATA 400,201,0,9,225,0,9,249,0,9,242,0,9,232,0,0,250,0
501  DATA 0,254,0,0,264,0,0,285,0,1500,306,0,0,327,0,0,350,0
502  DATA 0,370,0
600  DATA 300,154,0,0,206,0,0,259,0,0,259,0,0,259,0,0,260
601  DATA 0,0,301,0,0,258,.89,56,332,0,0,297,0,0
602  DATA 369,0,0,441,0,62,514,0
700  DATA 0,693,0,0,732,0,0,772,0,0,783,0,0,794,0,0,833,0
701  DATA 0,925,0,0,957,0,0,1001,0,3400,1074,0,0,1147,.52
702  DATA 0,1220,.36,0,1293,0
800  DATA 0,186,0,0,190,0,0,194,0,0,198,0,0,204,0,0,184,0
801  DATA 0,222,0,0,223,0,0,216,0,0,225,0,0,234,0,0,243,0
802  DATA 0,253,0
900  DATA 0,175,0,0,204,0,0,236,0,0,233,0,0,233,0,0,243
901  DATA 0,718,257,0,0,264,0,0,276,0,0,286,0,0,296,0,0,306,0,0
902  DATA 316,0
```

STS Program (continued)

```
1000  DATA 325,251,0,0,256,0,0,250,0,0,262,0,0,264,0,0,254,0
1001  DATA 0,279,0,0,286,0,0,288,0,0,270,0,0,251,0
1002  DATA 0,400,0,0,330,0
1100  DATA 350,148,0,0,163,0,0,178,0,0,193,0,0,208,0,0,182,0
1101  DATA 0,192,0,0,209,0,0,228,0,0,219,0,0,210,0,0,238,0
1102  DATA 0,264,0
1200  DATA 0,595,0,0,595,0,0,595,0,0,595,0,200,595,0
1201  DATA 0,708,0,0,758,0,0,812,0,200,842,0,0,606,0,0,750
1202  DATA 0,0,750,0,0,750,0
1300  DATA 0,145,0,220,158,0,220,171,0,220,184,0,220,197,0
1301  DATA 220,188,0,220,192,0,220,195,0,220,202,0
1302  DATA 220,113,1,0,116,0,0,120,0,1120,123,0
1400  DATA 0,462,0,160,487,0,160,512,0,160,537,0,700,564,0
1401  DATA 0,696,0,0,634,0,3500,658,0,3000,688,.94,700,688
1402  DATA 0,0,688,0,0,688,0,0,688,0
1500  DATA 0,136,0,0,136,0,0,136,0,0,137,0,0,137,0,0,154,0,0,156
1501  DATA 0,0,169,0,0,176,0,0,154,0,0,177,1,0,200,0,0,211,0
1600  DATA 0,114,0,0,120,0,0,126,0,0,132,0,0,140,0,0,134,0,0,140
1601  DATA 0,0,145,0,4400,153,0,700,171,0,0,187,0,0,200,0,0,173,0
1700  DATA 350,191,0,0,195,0,0,199,0,0,203,0,0,209,0,0,246,0
1701  DATA 0,252,0,0,259,0,0,260,0,0,260,0,0,260,0,0,260
1702  DATA 0,0,260,0
1800  DATA 275,165,0,200,168,0,200,171,0,200,174,0,200,177,0
1801  DATA 720,182,0,1520,181,0,520,199,0,0,198,0,576,198,0,520
1803  DATA 198,0,0,198,0,0,197,0
1900  DATA 325,193,0,0,200,0,0,207,0,0,214,0,0,220,0,0,222,0
1901  DATA 290,212,0,290,234,0,440,229,0,290,239,0,0,249,0
1902  DATA 2000,259,0,0,269,0
2000  DATA 0,381,0,0,422,0,0,463,0,0,504,0,0,547,0,0,472,0,0,537
2001  DATA 0,0,557,.86,0,631,0,2000,624,0,0,615,0,0,700,0
2002  DATA 0,750,0
2100  DATA 450,259,0,0,281,0,0,303,0,0,325,0,0,346,0,0,356,0
2101  DATA 1300,354,0,1300,340,.83,0,386,0,0,390,0,0,394,0
2102  DATA 0,398,0,0,401,0
2200  DATA 550,351,0,410,373,0,410,393,0,410,414,0,410,433,0
2201  DATA 2538,520,0,5000,439,0,3000,493,.77,5604,502,.65
2202  DATA 3000,512,.64,228,522,.83,2506,532,0,2506,542,0
2300  DATA 550,259,0,410,269,0,410,279,0,410,289,0,410,298
2301  DATA 0,2538,325,0,5000,270,0,3000,293,.82,5604,317,.92
2302  DATA 3000,340,.88,228,363,.57,2506,386,0,2506,411,1
2400  DATA 400,690,0,652,691,0,652,692,0,652,693,0,3012,695,0
2401  DATA 1200,774,0,500,774,.84,1230,774,.86,75,774,.18,3400
2402  DATA 874,0,0,888,0,0,902,0,0,918,0
2500  DATA 850,221,0,0,218,0,0,215,0,0,212,0,0,209,0,4707,209
2501  DATA 0,6851,228,.83,5507,226,.93,1507,228,.9,2307,228
2502  DATA .93,707,248,0,707,268,.78,707,288,0
2600  DATA 600,290,0,0,293,0,0,296,0,0,299,0,2000,303,0
2601  DATA 2000,320,0,2000,275,.93,2500,312,0,2500,353,1
2602  DATA 2500,363,.82,0,356,0,0,359,0,0,362,0
2700  DATA 175,323,0,175,322,0,175,321,0,175,320,0,2000
2701  DATA 320,0,1000,346,0,3000,360,0,500,325,.83,678,310
2702  DATA .52,178,298,.8,178,270,0,178,338,0,178,347,.5
2800  DATA 1075,387,0,1075,409,0,1075,431,0,1075,453,0,0,477
2801  DATA 0,0,508,0,0,534,.87,1000,512,1,0,568,.6,0,509,.61
2802  DATA 1000,450,0,0,391,0,0,332,0
2900  DATA 1300,431,0,2079,434,0,2079,437,0,2079,440,0,3340,444
2901  DATA 0,3340,444,0,3340,465,0,2000,564,.77,2500,433,.79
2902  DATA 1500,480,.81,1500,431,0,1500,431,0,1500,431,0
3000  DATA 475,60,0,475,62,0,475,64,0,626,66,0,3000,68,0
3001  DATA 0,72,0,0,82,0,0,71,.83,0,83,0,0,55,0,0,53,0,0,51
3002  DATA 0,0,49,0
3100  DATA 450,92,0,147,92,0,147,93,0,147,94,0,2000,94,0
```

STS Program (continued)

```
3101  DATA 2000,93,0,2026,96,0,1526,95,.77,0,185,0,2000,141
3102  DATA 0,0,96,.75,0,106,0,0,116,0
3200  DATA 984,33,0,984,41,0,984,49,0,984,57,0,984,65,0,984
3201  DATA 64,0,2984,108,0,2000,119,.95,0,116,0,0,104,.46
3202  DATA 0,92,.83,0,72,0,26,51,0
3300  DATA 0,34,0,0,44,0,0,54,0,0,64,0,0,74,0,0,74,0
3301  DATA 2000,76,.76,0,79,0,0,84,0,0,84,.89,0,85,0,0,86
3302  DATA 0,0,87,0
3400  DATA 1325,184,0,290,211,0,290,234,0,290,257,0,400,277,0
3401  DATA 400,240,0,2200,240,.78,0,245,0,0,250,.82,1500,240
3402  DATA 0,0,483,.86,0,440,0,1900,401,0
3500  DATA 575,467,0,44,469,0,44,471,0,44,473,0,44,476,0,2200
3501  DATA 486,0,2200,525,.89,2200,520,.87,3094,538,.99
3502  DATA 3094,538,.83,94,450,0,0,450,0,0,450,.61
3600  DATA 0,94,0,0,99,0,0,104,0,0,109,0,0,114,0,2031,119,0
3601  DATA 203[illegible],109,0,2031,132,.77,2031,140,.64,3000,116,0,0
3602  DATA 94,[illegible],0,100,0,[illegible],108,0
3700  DATA 0,79,0,0,185,0,0,89,0,0,94,0,0,99,0,0,104,0,0,124,0
3701  DATA 0,115,0,2000,114,0,0,113,.8,0,111,0,0,110,0,0,109,0
3800  DATA 0,104,0,0,110,0,0,116,0,0,122,0,0,127,0,0,98,0,0,114
3801  DATA 0,0,115,0,0,127,0,0,127,0,0,127,0,0,127,0,0,127,0
3900  DATA 0,110,0,0,113,0,0,116,0,0,119,0,0,123,0,0,84
3901  DATA 0,0,94,0,0,101,0,0,105,0,0,122,0,0,139,0,0,157
3902  DATA 0,0,172,0
4000  DATA 0,143,0,0,148,0,0,154,0,0,160,0,0,165,0,0,150,0,0,174
4001  DATA 0,0,172,0,0,184,0,0,173,0,0,161,0,0,173,0
4002  DATA 0,198,0
4100  DATA 0,196,0,0,205,0,0,214,0,0,223,0,0,233,0,0,178,0,0,234
4101  DATA 0,0,249,0,0,268,0,0,229,0,0,189,0,0,350,0,0,337,0
4200  DATA 0,126,0,0,135,0,0,144,0,0,153,0,0,161,0,0,151,0
4201  DATA 0,163,0,0,178,0,0,178,0,0,163,0,0,148,0,0,133
4202  DATA 0,0,240,0
4300  DATA 525,136,0,220,140,0,220,144,0,220,148,0,220,153
4301  DATA 0,0,153,0,0,160,0,0,164,0,0,155,0,0,162,0,0,169
4302  DATA 0,0,176,0,0,183,0
4400  DATA 0,402,0,0,390,0,0,378,0,0,362,0,0,352,0,0,401,0
4401  DATA 0,417,0,0,427,0,0,462,0,0,438,0,0,414,0,0,360
4402  DATA 0,0,366,0
4500  DATA 0,237,0,0,237,0,0,236,0,0,235,0,0,234,0,0,246,0
4501  DATA 0,277,0,0,284,0,0,305,0,650,287,0,0,269
4502  DATA 0,0,260,0,0,286,0
4600  DATA 0,125,0,0,132,0,0,139,0,0,146,0,0,154,0,0,140,0
4601  DATA 500,166,0,0,176,0,0,182,0,0,122,0,0,155,0,0,188
4602  DATA 0,0,222,0
4700  DATA 0,108,0,0,111,0,0,114,0,0,117,0,0,122,0,0,130,0
4701  DATA 0,110,0,0,116,0,0,126,0,0,79,0,0,79,0,0,79,0,0,79,0
4800  DATA 0,63,0,0,64,0,0,65,0,0,66,0,0,67,0,0,67,0,0,75
4801  DATA 0,0,79,0,0,77,0,0,232,0,0,245,0,0,256,0,0,320,0
4900  DATA 375,243,0,0,246,0,0,249,0,0,252,0,0,257,0,0,252
4901  DATA 0,0,253,0,0,281,0,0,281,0,0,282,0,0,283,0,0,284,0,0
4902  DATA 284,0
5000  DATA 525,171,0,0,173,0,0,175,0,0,177,0,0,179,0,0,173
5001  DATA 0,1000,178,0,0,178,0,0,184,0,0,189,0,0,194,0,0,199
5002  DATA 0,0,204,0
5100  DATA 0,71,0,0,75,0,0,79,0,0,83,0,0,91,0,0,86,0,0,92
5101  DATA 0,0,95,0,0,102,0,0,108,0,0,116
5102  DATA 0,0,126,0,0,136,0
5200  DATA 0,112,0,0,113,0,0,114,0,0,115,0,0,116,0,0,118,0,0,118
5201  DATA 0,0,123,0,0,136,0,0,111,0,0,86,0,0,100,0,0,134,0
5300  DATA 0,83,0,0,91,0,0,99,0,0,107,0,0,114,0,0,101,0,0,119
5301  DATA 0,0,127,0,0,140,0,0,103,0,0,65,0,0,50,0,0,50,0
5400  DATA 0,123,0,0,128,0,0,133,0,0,138,0,0,145
5401  DATA 0,0,134,0,0,159,0,0,165,0,302,167,0,0,161
5402  DATA 0,0,154,0,0,133,0,0,111,0
9999  END
```

List of Villages in Study Area*

1. Bande-bal
2. Ghaleh Rob Bandebal
3. Ghaleh Now Shams Abad
4. Boneh Abdol Mohammad
5. Chagha Sorkh
6. Ghaleh Say-yed
7. Shams Abad
8. Anjeerak
9. Khalteh
10. Ghaleh Ghazee
11. Alee Kowlee
12. Koo-tee-yan
13. Khayr Abad
14. Najaf Abad
15. Ghaleh Now Askar
16. Boneh Cheetee
17. Farrash
18. Balangoon
19. Hossay-nee-yeh Balangoon
20. Khosrow Abad
21. Boneh Raheemeh
22. Baya-tee-yoon Arshad
23. Baya-tee-yoon Rafat
24. Ghaleh Abdol Shah
25. Ghaleh Now Sardar Abad
26. Sardar Abad
27. Deylam Olya
28. Sham-oon
29. Deylam Sofla
30. Boneh Say-yed Taher
31. Boneh Nebhan
32. Boneh Khepel
33. Boneh Yoones
34. Boneh Alvan
35. Salar Abad
36. Boneh Charee
37. Azeez Abad
38. Kermalak Tahmasebee
39. Kermalak Alee Abad
40. Ghaleh Shaykh
41. Dehbar
42. Ghaleh Now Beesheh Neyl
43. Ghalvand
44. Sharaf Abads (three villages close together)

* keyed to data lines of computer print-out

List of Villages in Study Area (continued)*

45. Abbas Abads (two villages close together)
46. Ghaleh Rob Koway-yekh
47. Hajee Abad
48. Ghaleh Rob Jaybar
49. Koway-yekh
50. Ghaleh Abbas
51. Ghaleh Agha Hassanee
52. Jaybar
53. Boneh Teeleh
54. Ameer Abad

* keyed to data lines of computer print-out

APPENDIX II

Information about the Dez Pilot Irrigation Project is presented as background for the discussion in Chapter III.

Exchange Rates

Year	Rials equal to 1 U.S.$
pre-1960	76
1960-1971	75
1971-1973 (May)	68
1973 (June) - (February) 1975	67.5*

* Author's experience in Iran

Dez Pilot Irrigation Project Budget Requirements
(DPIP, 1964, App.1)

Capital Investment	Estimated Costs*
Roads	1,237,000
Canals	7,500,000
Drains	593,000
Land Preparation	1,000,000
Crop Damage	501,000
Government Facilities	395,000
Plans,Engineering,Surveys	2,777,000
sub-total	14,003,000
Operations and Maintenance	
Headquarters - Housing	375,300
Irrigation Works -maintenance	230,000
Roads - maintenance	336,000
Water Distribution Service	374,000
Field Trial Farm - Research Center	596,500
Village Production Service	1,200,000
Credit Management	105,000
Laboratory Service	111,500
Technical Studies	997,000
Health,Sanitation,Education	506,000
Agricultural Subsidy	310,000
General Administration	1,726,540
Training	190,000
sub-total	7,058,000
Indirect and General Development Costs	2,636,000
Credit Revolving Funds	1,600,000
GRAND TOTAL	25,297,000

*US$

Dez Pilot Irrigation Project Timetable, as of 1964
(DPIP, 1964, App.7)

Project Landowner Discussions	
Begin	Aug. 1960
Complete	Apr. 1961
Main Canals, Drains, Roads	
Surveys	1959-62
Design	1960-63
Start Construction	Mar. 1962
Complete Construction	1965*for canals, continuing construction drains
Private Land Preparation Construction	
Preliminary Surveys	1960-61
Preliminary Designs	1960-61
Detailed Surveys	1961-65
Detailed Designs	1961-65
Start Construction	Fall 1962
End Construction	continuing land preparation*
Government Facilities	
Safi Abad Field Trial Farm	
Surveys and Design	Dec. 1963
Land Acquisition	Mar. 1963
Construction	Sept. 1964
Training Center	Oct. 1962 - July 1963
Water Distribution Service Organization	Aug. 1962
Credit Services	Oct. 1962 (ended 1969)
Agricultural Equipment Service Organized	Oct.1962
Health, Sanitation, Education Organized	Oct.1960

* indicates change in schedule based on later data

Canal Capacities
(DPIP, 1964, App. 8)

Canal No.	Flow Capacities(m^3/sec)	km.
Pilot Diversion Canals	67	0.0-1.7
Pilot East Canal	53	1.7-3.6
Pilot East (concrete)	48	3.6-8.9
Pilot East	45	8.9-13.2
Pilot East	18	13.2-21.4
Pilot East	10	21.4-28.4
E-1	4.2	0-1.4
E-2	3.2.	0-1.0
E-3	1.6	0-1.4
E-4	1.3	0-1.4
E-5	7.8	0-1.8
E-6	1.3	0-0.5
E-7	1.7	0-2.8
E-8	0.5	0-1.0
E-9	0.8	0-1.3
E-10	0.5	0.0.9
E-11	0.5	0-1.3
E-12	0.7	0-0.7
E-13	0.5	0-0.5
E-14	2.0	0-0.9
E-15	1.1.	0-1.3
Pilot West (concrete)	13.5	0-4.1
Pilot West (concrete)	8.2	4.1-8.5
Pilot West	5.7	8.5-9.7
W-1	1.6	0-1.6
W-2	2.4	0-0.5
W-3 (concrete)	0.5	0-1.2
W-4	0.8	0-1.8
W-5	3.7	0-1.9

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