Health and Irrigation

Proceedings of the Copenhagen Workshop on Health and Irrigation
held in Eigtved's Pakhus, Ministry of Foreign Affairs,
Asiatisk Plads 2, DK, 1448 Copenhagen, Denmark, 18–20 August 1997

Health and Irrigation

Proceedings of the Copenhagen Workshop
on Health and Irrigation
held in Eigtved's Pakhus, Ministry of Foreign Affairs,
Asiatisk Plads 2, DK, 1448 Copenhagen,
Denmark, 18–20 August 1997

Flemming Konradsen and Wim van der Hoek, Editors

IIMI
INTERNATIONAL IRRIGATION MANAGEMENT INSTITUTE
DANISH BILHARZIASIS LABORATORY

Konradsen, F. and W. van der Hoek (Eds.) 1998. Health and irrigation: Proceedings of the Copenhagen workshop on health and irrigation, held in Eigtved's Pakhus, Ministry of Foreign Affairs, Asiatisk Plads 2, DK, 1448 Copenhagen, Denmark, 18–20 August 1997. Colombo, Sri Lanka: International Irrigation Management Institute.

/ health / water resources development / environmental effects / social change / irrigation systems / disease vectors / waterborne diseases / domestic water / water use / malaria / schistosomiasis / ecology / rice / water management / case studies / Africa / Sri Lanka / Senegal / West Africa / Kirindi Oya /

ISBN: 92-9090-355-4

Please direct inquiries and comments to:

International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Responsibility for the contents of this publication rests with the individual authors.

Cover photo, by Dr. Henry Madsen, shows washing place in a large canal in the Niono area of the "Office du Niger," Mali.

Contents

Acronyms

AWDI	alternate wetting and drying irrigation systems
CGIAR	Consultative Group on International Agricultural Research
DANIDA	Danish International Development Agency
DBL	Danish Bilharziasis Laboratory
GIS	geographical information system
IIMI	International Irrigation Management Institute
JE	Japanese encephalitis
KOISP	Kirindi Oya Irrigation and Settlement Project
OMVS	Senegal River Authority
SWIM	System-Wide Initiative on Water Management
WARDA	West Africa Rice Development Association

Foreword

The human health impacts of water resources development activities have been debated for the past several decades. However, relatively little action is taken to reduce the negative impacts of such activities and possible health benefits are not thoroughly explored. This is likely to be a reflection of the complex interactions between the changes brought about by development activities, including environmental and social changes, and their combined impact on human health and natural resources. To work out these linkages, substantial knowledge needs to be generated. Also, the capacity and objectives of the institutions involved in implementing water resources development projects, including irrigation systems, are very rarely related to health. Therefore, a close involvement of health departments and environmental protection agencies is needed at all stages of the project. This is unlikely to take place. However, part of the responsibility for the limited integration of health concerns into the irrigation sector is with the health research institutions who have not been efficient enough at getting their message and priorities across in a way that could be understood by other professions. More importantly, very few operational disease control measures have been developed in a collaborative effort between health and irrigation specialists. To encourage a closer collaborative effort between these groups, the Danish Bilharziasis Laboratory (DBL) and the International Irrigation Management Institute (IIMI), through its Health and Environment Program, decided to arrange an international workshop focused on the linkages between irrigation and human health. The workshop was sponsored by the Danish International Development Agency (DANIDA) and was held in Copenhagen for three days in August 1997. In addition to the financial support for the workshop, the research section of DANIDA provided valuable support in the planning and implementation.

The main objectives of the workshop were to provide an update on recent research findings and ongoing programs pertaining to irrigation and health, identify research priorities and develop new research projects, and to foster collaboration between participating institutions. The workshop brought together a multidisciplinary group of 28 people from 13 countries. The main topics of the workshop related to the opportunities for disease vector control through appropriate irrigation management practices and the health aspects of domestic use of irrigation water. As a result of the workshop, a number of research proposals have been finalized and will form the basis for future collaboration between a number of the institutions involved in field-based activities in irrigated areas.

Niels Ø. Christensen
Director,
Danish Bilharziasis Laboratory

David Seckler
Director General,
International Irrigation
Management Institute

An Overview
of
Vector-Borne Diseases Associated with Irrigation

M.W. Service
Liverpool School of Tropical Medicine, Liverpool L3 5QA, United Kingdom

Introduction

The world population is predicted to grow from 5.8 billion to an estimated 10 billion by the year 2050, with 90 percent of this increase occurring in the developing countries. This expanding population will require more food, which needs to be grown in the developing countries and not imported from the richer countries.

About 30 percent of the earth's land is classified as arid or semiarid, yet some 600 million people struggle to survive in such inhospitable areas. Irrigation should enable more food to be grown in these areas to feed the people. An example of successful irrigation in arid areas is Israel, which grows food for home consumption as well as for export.

Health Problems

Of all irrigated crops, rice provides the worst disease scenario because large areas of rice cultivation are flooded for long periods. Presently there are about 290 million hectares of irrigated land of which rice fields comprise about 145 million hectares. Nevertheless an estimated 3 percent annual increase in rice yields is needed to meet the increasing demand. However, in many countries, rice production has remained much the same over the last 10 years, and in Malaysia production has actually slumped and consequently imports have increased. Bangladesh is cultivating almost all the available land but its increasing population requires more rice; so output must be increased through better yields. This usually requires more fertilizers and insecticides, which increases costs and may produce environmental damage as well as promote the development of insecticide resistance not only in rice pests but in mosquitoes as well.

Irrigation often causes widespread ecological and environmental changes, such as an increase in the bird population, especially aquatic ones, and a decrease in livestock and wild animals. Mechanization is often associated with a reduction in water buffaloes and other draught animals. For example, in Bangladesh and Pakistan one tractor displaces two to two-and-a-half bullocks. These changes can favor a great increase in the biting of people by mosquitoes, which can lead to increased disease transmission. For example, in South Africa, droughts in 1971 and 1977 resulted in the sale of cattle and this was followed by malaria outbreaks. Similarly, a severe drought in Indonesia in 1977 caused farmers to sell their cattle and this was followed by a five-fold increase in malaria. Sometimes, the reverse, an increase in animals, occurs. For example, on the Mahaweli rice irrigation scheme in Sri Lanka, pig production was officially promoted and the first ever outbreak of Japanese encephalitis occurred in 1985. This is a disease transmitted by mosquitoes (*Culex tritaeniorhynchus*) that breed in rice fields. The virus responsible multiplies in pigs, which become a rich source of the virus for human infection.

The most important vector-borne diseases resulting from rice cultivation are malaria, Japanese encephalitis and schistosomiasis.

Malaria

Flooded rice fields provide ideal habitats for many species of malaria vectors and it has been estimated that about one-fourth of all malaria vectors sometimes breed in rice fields or their irrigation channels. Furthermore, when irrigation allows double cropping of rice, the result is additional malaria transmission peaks, or even year-round transmission in areas that formerly experienced malaria outbreaks only in the rainy season(s). In the Kisumu area of Kenya, the number of malaria vectors (*Anopheles arabiensis*) biting people living on or near the Ahero rice irrigation scheme is about 70 times the number biting villagers living a few kilometers away.

Japanese Encephalitis

More than 40 arboviral diseases are associated with rice growing but, despite being restricted to Asia, by far the most important disease among them is Japanese encephalitis.

Schistosomiasis

Schistosomiasis is widespread in Africa (*Schistosoma haematobium, Schistosoma mansoni*) and also occurs in parts of Asia (*Schistosoma japonicum*), Latin America (*Schistosoma mansoni*), the Near East and the Middle East (*Schistosoma mansoni*). Transmission can be prevented by people not urinating or defecating in water or on land next to it, and by not swimming, or playing, or working with bare feet in snail-infested waters. But changing people's behavior is extremely difficult.

Other Diseases

In addition to the above diseases, the proliferation of water storage pots and colonization of them by mosquitoes (*Aedes aegypti, Aedes albopictus*) can result in dengue outbreaks, while the creation of spillways can provide breeding places for simuliid vectors of river blindness (onchocerciasis). Slum conditions amongst tenant farmers may provide opportunities for increased rat populations, rat fleas (*Xenopsylla* species), and plague. Flooded pit latrines, organically polluted drains, and other waters provide ideal breeding grounds for the mosquito vector (*Culex quinquefasciatus*) of bancroftian filariasis, a disease that can cause elephantiasis.

It should be appreciated that malaria and some other diseases are also transmitted by mosquitoes breeding in rice fields in non-tropical areas; for example, West Nile fever in the Mediterranean and Western Equine Encephalomyelitis in California.

Resettlement

Resettlement policies and migrant seasonal labor can introduce new diseases into communities. Conversely, new settlers may be non-immune and have little protection against diseases and consequently become very ill when diseases like malaria are rife on an irrigation scheme.

Possible Solutions

Larviciding aquatic breeding places of malaria vectors with insecticides, and mollusciciding waters to control the snail intermediate hosts of schistosomiasis have long been practiced on irrigation schemes, but usually with only limited success in reducing illness. Problems include insecticide resistance, the organization and sustainability of control measures that have to be repeated every two weeks or so, and the high costs involved. There can be other problems. For example, in Kenya in the 1970s, when agriculturists sprayed insecticides on rice plants growing on the Ahero irrigation scheme to combat rice pests, most aquatic invertebrates, including mosquito predators, were killed. The sudden elimination of predators allowed the malaria vector, *Anopheles arabiensis*, to increase explosively. Similar upsurges in vector populations following insecticide applications have been documented in Japan.

Also, insecticide spraying can promote the development of insecticide resistance, and there may be environmental consequences of the widespread and repeated use of chemicals for vector control.

Insecticide-impregnated bed nets (*e.g.*, with permethrin or deltamethrin) can afford protection against night-biting malaria and bancroftian filariasis vectors but not against day-biting mosquitoes such as those transmitting Japanese encephalitis. Nets have to be re-impregnated every six months. Procuring funds to buy the nets and cover costs of re-impregnation, and the organization and supervision of treatment and the correct usage of nets may be difficult.

Another problem is that the intensity of disease transmission varies considerably between, and sometimes within, countries so that control measures that might significantly reduce disease transmission or illness in one situation may be insufficient in others. For instance, it is easier for insecticide-treated bed nets to reduce malaria in China, where transmission levels are relatively low, than in most African countries where transmission can be intense. Similarly, a twenty-fold population reduction of adult malaria vectors in Sri Lanka can greatly reduce, or even eliminate, malaria, but in Africa this level of control has little impact on transmission.

However, fashionable biological control methods such as employing "mosquito-fish" have not usually proved very effective in reducing disease transmission.

Considerable attention is being focused on "alternate wet and dry cultivation of rice" (intermittent irrigation) to reduce mosquito breeding. Undoubtedly, in some situations, this procedure can reduce mosquito breeding and disease transmission. Examples of this are the control of malaria and Japanese encephalitis in parts of China and Japanese encephalitis in Japan, the only two countries that are extensively employing this strategy. There are many problems with this method and recent trials in India have not been very successful. To succeed, the practice must be acceptable to farmers and be perceived as giving economic benefits, the soil type must allow rapid drainage and reflooding, and the technique must be applied simultaneously to all fields and often over a large area. Also, drying out fields may kill fish and other mosquito predators and there may be problems enforcing control on individual tenants.

Conclusions

Although environmental and health factors may be considered at the planning or assessment stage, all such considerations are often abandoned during final design and implementation, usually for economic reasons. The problem is that environmental, health, and social considerations are not easily quantified in terms of tangible benefits or economic values, and are readily forgotten.

It should be the responsibility of agriculturists, engineers, and economists to ensure that health implications are appreciated and minimized in project construction. Particular measures to minimize vector-borne disease threats should be integrated into projects from their conception. But the irrigation sector often lacks knowledge and expertise in health disciplines, and sound advice on environmental or health hazards is often not always available locally.

[For a list of recommended literature see Appendix C.]

Abstracts of Research Papers Presented

Vector Control Linked to Small-Scale Irrigation in Sri Lanka

F. KONRADSEN,[1] F.P. AMERASINGHE,[2] P.H. AMERASINGHE,[2] Y. MATSUNO,[1] AND W. VAN DER HOEK[1]
[1]International Irrigation Management Institute and the [2]Department of Zoology, University of Peradeniya, Sri Lanka

---

On behalf of the researchers from the International Irrigation Management Institute and the Department of Zoology at the University of Peradeniya, Mr. Flemming Konradsen of IIMI gave a brief background introduction to a project implemented in Sri Lanka.

THE PROJECT DEALT with a range of issues related to malaria transmission in an area dominated by smal-scale, tank-based irrigation systems. Results from the project have shown that the economic and social impacts of malaria at the household level vary greatly from year to year due to the large fluctuation in the transmission levels. However, in a year with an average transmission, malaria infection resulted in an economic loss of 6 percent of net household income due to labor days lost and an average of US$3.00 was spent per malaria episode as direct expenditure. Entomological studies in the project area identified stream bed pools as the most important breeding site for the principal vector of malaria, *Anopheles culicifacies*. The homesteads, forest areas, irrigated fields, irrigation canals, and seepage areas below the tanks were only of limited importance. Initial epidemiological studies concluded that immediately before the main transmission season, living close to the stream was a risk factor for malaria.

The project looks at options to control breeding in the stream. This is not a new concept. In the 1930s and 1940s, flushing of streams for mosquito control was tested in Sri Lanka and in other Asian countries. However, these traditional structures had serious limitations. The need to find new ways to control malaria was the reason for looking at possibilities to incorporate health objectives into the normal irrigation water management routine. In areas of the dry zone of Sri Lanka where the natural streams are used as conveyance canals between irrigation reservoirs, water flow and levels can be manipulated.

The association between water level in the stream and breeding of *Anopheles culicifacies* was investigated and the feasibility of using existing irrigation infrastructure to reduce the breeding potential assessed. It was found that the most feasible option would be to implement a management routine where water is released periodically from an upstream reservoir to reduce the number of breeding sites downstream. This study indicated that by regulating the water level above 20 cm in the stream throughout the dry season, the breeding of *Anopheles culicifacies* could be significantly reduced. A water release would have to be issued every tenth day for approximately 48 hours to ensure that water reaches the end of the stream. The intervention would have only limited impact on the water lost for agriculture since the water released would be captured by the downstream tank and the management input would be minimal. However, for the intervention to work, a high degree of support from the local community is essential and coordination between government departments is needed.

Measuring device in Yan Oya stream.

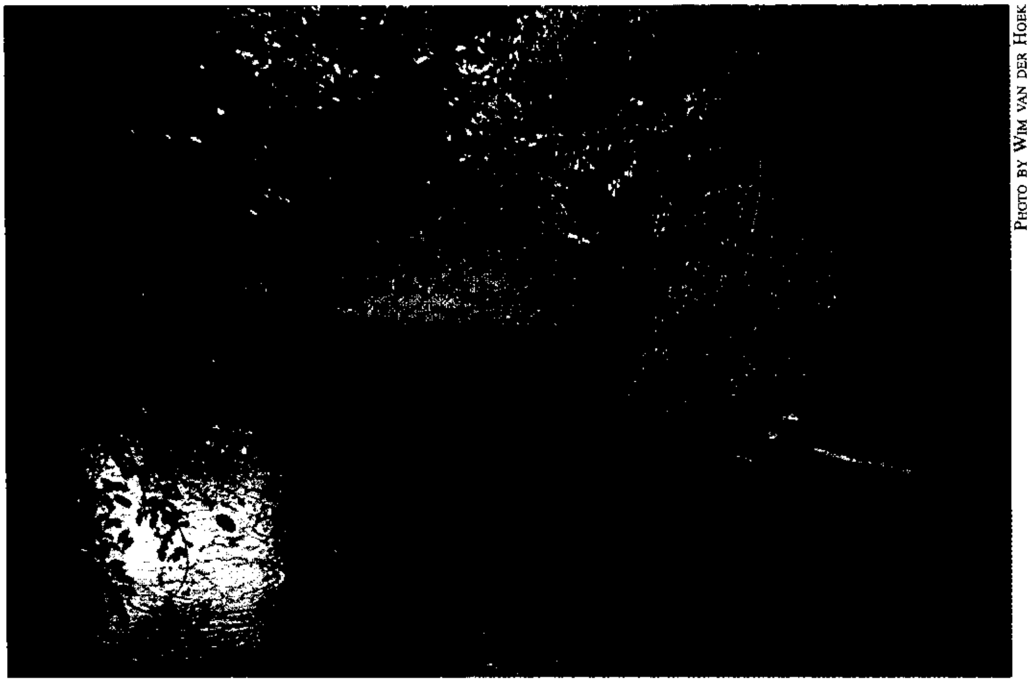
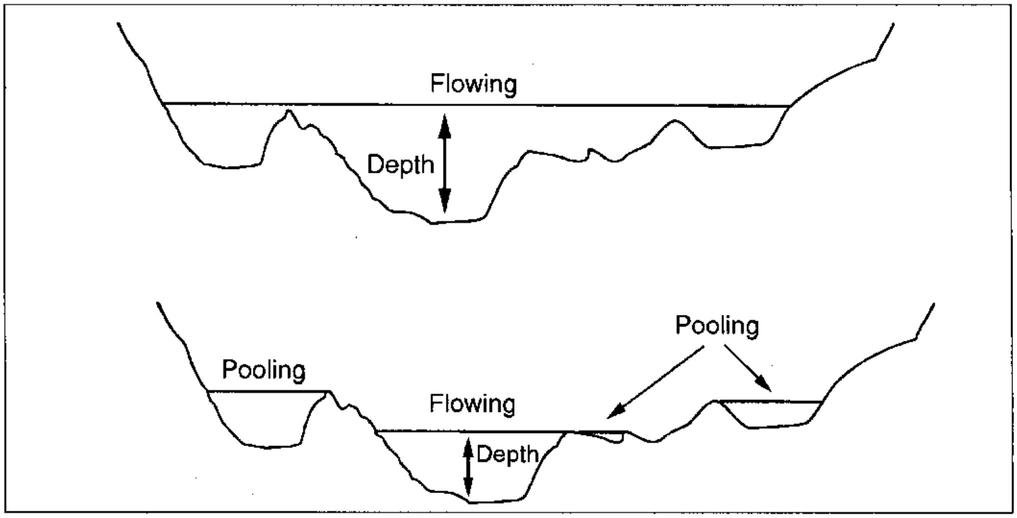


Photo by Wim van der Hoek

Development of pools in the Yan Oya stream as water levels decrease.



Irrigation and Schistosomiasis in Africa—Ecological Aspects

HENRY MADSEN
Danish Bilharziasis Laboratory

Dr. Madsen made a brief presentation on the background of the transmission ecology of schistosomiasis (Bilharzia), focusing on the importance of morbidity control through an integrated approach including chemotherapy, snail control, health education, sanitation and a good, safe water supply. He stated that, to be effective, control programs aimed at the intermediate host snail need to be based upon a thorough knowledge of their distribution patterns and their population dynamics. He further added that it was important that this should not be generalized since each endemic area may have its own characteristic transmission patterns and efficient snail control measures effective in one place may not necessarily be effective elsewhere.

NUMEROUS EXAMPLES DEMONSTRATE that the establishment of irrigation projects and water resources development activities in general have resulted in an increased transmission of schistosomiasis. It is therefore necessary to take steps to minimize the impact of irrigation activities on the spread of the disease. It is important to realize that a great variety of irrigation systems exist in Africa and they all may have specific problems related to the establishment of the schistosome intermediate host. Therefore, any environmental management based control effort would depend upon system-specific conditions such as canal structure, canal water management practices, presence of water storage ponds within the system, and composition and density of aquatic macrophytes in the canals and reservoirs. Any control intervention in an irrigation system would depend upon human water contact behavior and the ecology of the intermediate host, the snail, present in the area. Within irrigation systems, transmission is highly focal. Snails are often found in large numbers at points in the system where humans bathe, fetch water, wash, etc. It is also important to note that people often use the sides of canals for sanitary purposes and this could only be changed by building latrines and by health educational campaigns.

The large variation in snail densities and intensity of human schistosome infection within irrigated areas is exemplified through the findings from studies undertaken in both North Africa and West Africa. In the "Office du Niger" irrigation scheme in Mali, surveys showed that the intermediate-host snails of both urinary and intestinal schistosomiasis were very common in the large distributors but were found very rarely in the field canals. The snails were generally found within the bottom vegetation, which means that considerable water level fluctuations are needed before any effects on snails could be anticipated. Since snails thrive in the submerged vegetation, they are not vulnerable to increased water velocity. In the Gezira-Managil scheme in Sudan, the minor canals were found to be the most important transmission sites as snail densities are generally high and most of the human water contact takes place in these canals. In the Tessaout-Amont irrigated area of Morocco, the most important habitat for the snails was in the siphon boxes created at diversion points or offtakes. Stagnant water always remains in these boxes as against the tertiary canals that run dry between irrigation water releases. The siphon boxes are also preferred points for children's recreational activities, making it an important transmission site. In the Lagdo area of Northern Cameroon, a dam for the generation of hydropower and an irrigation project were launched in 1987. Schistosomiasis was present in the area before the water resources development activities took place but it increased even further following implementation of the project. The disease is a major public health problem today. Snail populations are now abundant in most parts of the scheme, especially in poorly maintained canals and drains with high densities of aquatic macrophytes.

At present, focal molluscicide application implemented seasonally according to the transmission pattern is the most realistic approach to snail control. However, the high cost of the chemicals and the impact, especially on fish, makes it necessary to look for alternative control options such as biological or environmental/engineering measures. The most promising biological approach is the introduction of nonsusceptible snail species that may act as competitors of the intermediate host. A number of environmental/engineering measures can be used to control snails in irrigation systems. They include increasing the water velocity in canals, fluctuating water levels in canals and reservoirs, periodic drying out of canals, redesigning canals to reduce standing water, and removing aquatic vegetation. However, it is unlikely that any single method will provide an effective means of controlling snails. Also, the success will depend upon collaboration between farmers, irrigation operators, and disease control agencies.

(The full paper presented by Dr. Henry Madsen
will be published as an IIMI Discussion Paper.)

Principal canal in the Lagdo area, Northern Cameroon.

PHOTO BY HENRY MADSEN

refuses to act because of their narrow concept of river basin management. Their intransigence is supported by the World Bank; in fact an OMVS restructuring forced by the World Bank now makes integrated river management almost impossible. If the $1million for health in the loan were spread over the 40-year life of the loan, it means that the OMVS and the World Bank value the lives to be lost at only $12 each. That is the tragedy.

Abstracts of Research Proposals

Alternate Wetting and Drying Irrigation Systems for Vector Control

M. H. BIRLEY
Liverpool School of Tropical Medicine

Introduction

ENTOMOLOGISTS HAVE PROPOSED for many years that alternate wetting and drying irrigation systems (AWDI) would control mosquitoes breeding in rice fields and irrigation channels. Until recently the idea of AWDI was not widely accepted by the irrigation community. The objections did not relate to agricultural yield as it is known that yields can be increased, but to the complexity of management. IIMI staff have now observed that AWDI has become a standard management procedure in at least two systems in India to conserve water. The stage is set to determine the effect of this environmental management on the ecology of local mosquito species and disease transmission.

Irrigated rice ecosystems in many parts of Asia are associated with two important mosquito-borne diseases: malaria and Japanese encephalitis (JE). In India, malaria transmission occurs mainly in the north and JE in the south. The transmission cycle for JE depends on the presence of wading birds and domestic pigs.

Experiments in Tamil Nadu have demonstrated a significant reduction in JE vectors by a combination of early season insecticide and AWDI. This body of work provides the basis for the current project proposal. The proposal will extend this work from a small to a large-scale experiment.

Irrigation Practices

According to IIMI, AWDI may become popular in Asia as a result of water scarcity. There is a clear need to map the extent of this practice and to relate it to other agricultural factors such as crop type, soil type, and management structure. The objective would be to determine the percentage of irrigated area that is, or could be, converted to AWDI.

Research Plan

The research plan will depend on obtaining the support, permission, and involvement of local collaborators.

It will then include the following steps.

1. Workshop to discuss research objectives and establish a plan of action (the Copenhagen workshop)
2. Steering committee meeting to establish areas of responsibility
3. Field site visit to determine logistics
4. Recruitment of fieldwork leader
5. Recruitment of staff, including Ph.D. students
6. Pilot field sampling protocol and analysis
7. Establishing a full field sampling program
8. Progress meeting to include quality control for field sampling and data entry, and presentation of initial results

A series of field studies will be required to sample mosquito populations, check the seroconversion rates of sentinel pigs for JE, and measure the prevalence rate of malaria parasites in human blood.

Research Methods

Adult mosquito sampling

An entomological sampling protocol will be established. Sampling should cover at least one and preferably two whole growing seasons. All mosquito species should be recorded, including nuisance biting ones. The primary collection should be of adult biting populations. Flooding and draining schedules should be agreed with irrigation workers with a target of one dry day every two weeks.

Sampling should consider spatial as well as temporal variation and be supported by a geographical information system (GIS).

Several different levels of detail for the adult mosquito faunal survey can be listed:

1. Genera
2. Species
3. Parity
4. Species complexes

It is proposed to concentrate resources on the first two levels. Sub-samples of parity for a limited number of important species will help to explain and predict the variation in density over time and space. Sub-samples should be preserved for future species complex analysis. Such analysis is expensive and can only be justified if the main results suggest that there is a significant effect. For example, there may be a need to determine whether the ratio of A and B members of the *Anopheles culicifacies* complex is changed by irrigation practices.

Adult mosquitoes will be sampled by indoor and outdoor landing catch and light trap, supplemented by indoor resting catch and outdoor animal baited traps. Important diurnal variations can be expected throughout the 24-hour cycle.

Larval mosquito sampling

Field surveys of larval habitats and densities should be more limited but conducted as appropriate. Larval mosquitoes should be sampled using dippers. Larval predators should also be sampled, including dragon fly larvae. Reuben and her colleagues in Madurai have demonstrated that predation is an important component of control when larvae are confined to small pools following incomplete drying.

Epidemiology

Sentinel pigs will be required for JE studies together with the appropriate tools for measuring serum conversion.

Special surveys of human communities will be required for active case detection of malaria parasites in human blood.

Modeling

To understand the relationship between AWDI and mosquito densities, operating computer models will be used. Hydraulic models will predict the fluctuations in dry areas at different points in an irrigation scheme as a result of AWDI. Considerable data will be required regarding water depths and flows throughout the system.

Vector population models will predict the mosquito population density at different points in the system as a function of the percentage of breeding sites that were dried.

As a first step, the simplest general equation to describe the mosquito population dynamics is as follows.

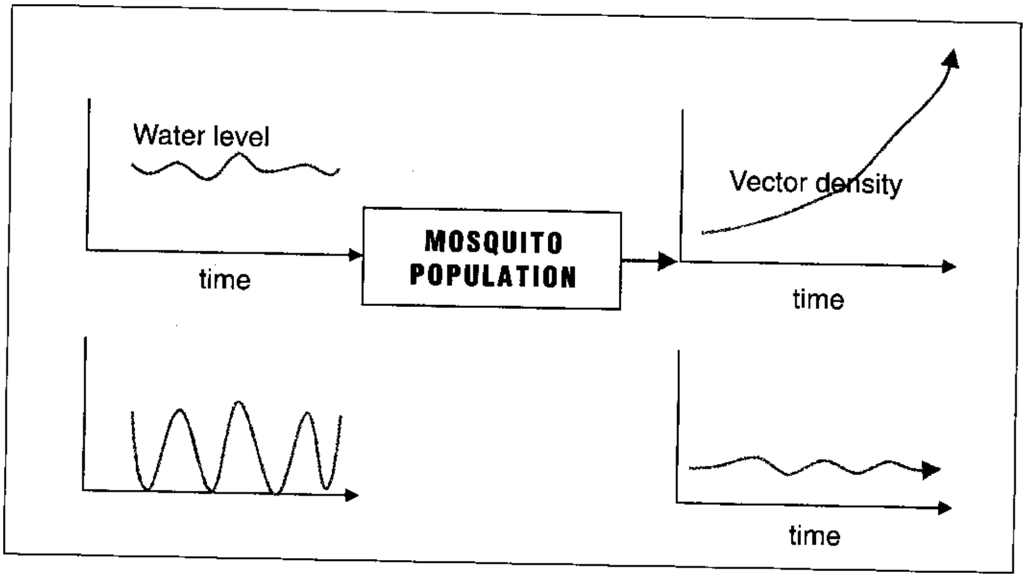
$$T_t = P.T_{t-u} + Q.T_{t-g} + R_t$$

where t = time in days, u=gonotrophic period (2-4 days), g=generation time (10-20 days), R is immigration, T_t is total biting density on day t, P is adult survival, and Q is a product of fecundity and larval survival.

This equation can be implemented on a computer and used to determine the effect of incomplete larviciding for a range of different conditions. Additional components will be required to predict predator-prey dynamics and the effect of rice plant growth.

Typical outputs of the model are illustrated in the following figure.

Model of link between water level management and mosquito density.



Brief summary of the participants' comments to the proposal on alternate wet and dry irrigation [AWDI]:

Robert Bos presented the main points that had been raised by the participants in the working group, which was followed by a general discussion among all participants.

A number of participants would like to see clearer emphasis on the infrastructural, managerial, and agricultural aspects of implementing a program of AWDI. During the early phases of the project, it would be important to define the agricultural constraints of AWDI to assess its wider feasibility across different geographical regions. To implement an effective AWDI program, adequate staff and proper infrastructure will need to be in place to handle the revised schedules. For proper assessment of the feasibility of AWDI, the farmer's perceptions would have to be included. Paddy farmers often store water in their fields as a back-up safety measure against unreliability in water supply and may therefore resist an AWDI approach unless they are very confident that water will reach their fields as scheduled. It also has to be realized that implementing AWDI in a system with a diverse cropping pattern will be more difficult. An assessment of the economic feasibility and cost-effectiveness of AWDI will have to be included in the proposed activity. Increased agricultural productivity and positive economic impacts at the individual household level would be important bottom line indices.

There was a feeling among some of the participants that the proposal should encompass the larger aspects of water management of irrigation water and not necessarily limit it to AWDI technologies. It was also suggested that the project should include sites in a number of additional countries to be able to generate findings of more general interest. The group emphasized that AWDI interventions should never be seen as a stand-alone intervention.

The planned study should be clear about whether the objective is to reduce disease or disease transmission. Risk management and disease reduction need to be clearly quantified, which will be very difficult in large parts of Africa but may be easier in Asia.

Water Management Interventions for the Control of Schistosomiasis in Irrigated Areas

ANDERS MALMGREEN-HANSEN
Danish Hydraulic Institute

THE MAIN AIM of the proposed project is to assess the feasibility of water management interventions for the control of the intermediate-host snails of human schistosomiasis in irrigated areas. The interventions will be identified through an extensive literature review and all control interventions will, as far as possible, be described from the point of view of snail ecology, irrigation management practices, and hydrological considerations. A limited number of interventions, which, on the basis of the literature, are seen as having the best potential for snail control, will be selected for further feasibility assessment. The focus of the feasibility assessment will be on the agricultural, economic, and irrigation aspects. However, the likely impact of the different control interventions on snail populations and transmission of the disease will be discussed on the basis of the best available information. The project will assist in prioritizing future research by selecting the control interventions most likely to be successful from irrigation, agricultural, and cost points of view. It is the objective of the project to identify the most feasible snail control options to replace or supplement the use of expensive chemical-based molluscicides.

Following the identification of a limited number of control interventions, a further assessment will be undertaken making use of the advances made in hydraulic and agro-hydrological modeling. The approach is to use already existing simulation models and apply them to three broad types of irrigation systems typical of Africa. Each of the proposed interventions, or a combination of them, will be tested using the models. The models will provide information on design requirements, impact on water consumption, management inputs needed, regulation requirements, and impacts on yields. The functioning of each model will be calibrated and tested against one basic set of data. Model simulations will also be compared with actual experiences of irrigation system operators. Although hydraulic simulations may be able to answer many questions, irrigation engineers would have to advise on the feasibility of the proposed recommendations. Such questions may be focused on the likelihood that local staff will have the skills and political power to operate the systems in the proposed way, farmer acceptance of the new operating regime, cost implications, etc.

Some of the interventions that are likely to be assessed as part of the project include:

- The operation of frequent water level fluctuation in small dams and reservoirs for the desiccation of snails and their eggs

- Dislodging and immobilizing snails through the maintenance of high flow velocities in major irrigation canals
- Design and construction of free draining structures within the systems to reduce the snail habitats and human water contact points
- Operation of water rotational schedules and improvement of maintenance practices to allow for periodic drying out of segments of the canal system to kill snails and snail eggs through desiccation
- Changing water management and maintenance practices to reduce the growth of aquatic vegetation in canals and drains, and thereby to reduce food availability, surfaces for oviposition, and protected areas available for the snails

The project includes aspects of relevance to the control of the intermediate host of *Schistosoma haematobium* and *mansoni* in the African continent. It is realized that the presence and density of snails differ greatly among different irrigation systems and that some of this variability is related to canal type, design of offtake structures, water management practices, extent of aquatic macrophytes, and a range of other site-specific conditions. This makes it very difficult to set general rules for the distribution of snails within the system and to estimate the impact of irrigation development of the transmission of the disease. In addition, the transmission sites within the system are likely to be very focal and the control of the snail population will have to be focused on the human water contact points. It is also realized that even if a feasible snail control intervention is identified for implementation in irrigated areas, it will always be one component of a greater control strategy that would also include treatment of patients, improved water supply and sanitation, and health education.

Brief summary of the participants comments to the proposal on water management interventions for the control of schistosomiasis in irrigated areas:

Ian Makin presented the findings of the working group dealing with this proposal and allowed for a general discussion among all participants.

The opinion was that the proposal should emphasize that the hydraulic models to be used in the project have been developed and only need to be applied to the study objectives. There was no clear agreement among the participants whether or not vector population and disease transmission models should be linked to the hydraulic models. A number of participants suggested that this approach may be too ambitious and the first phase of the study should focus on assessing the feasibility of a series of water management measures proposed for the reduction of vector populations with an emphasis on the agricultural and irrigation aspects. The feasibility of the water management measures should be tested with reference to a number of typical irrigation systems. One of the main objectives should be the provision of feedback by the irrigation professionals to the public health and biomedical researchers about the priorities in future research on water management for vector control.

The group had some discussion about the field testing of proposed interventions. The project was initially planned with emphasis on the use of hydraulic models to test proposed interventions against typical irrigation systems but primarily as a desk exsercise. It was felt that this desk approach would save time and resources when compared with an emphasis on early field trails.

The participants felt that social science researchers should be included in the study to give a more relevant feasibility assessment of the selected water management measures for vector control. Likewise, a number of developing countries' institutions should be actively involved in the project to give a better applicability assessment of the tested interventions.

Health Aspects of Nonagricultural Use of Irrigation Water

WIM VAN DER HOEK

International Irrigation Management Institute

Multiple Uses of Water

SCARCITY OF FRESH water resources and pollution of water are increasingly seen as global problems that limit economic and agricultural development, cause harm to the environment, and create public health problems. There is growing competition for water between agriculture, urban areas, and industries. In developing countries, typically, 90 percent of water is consumed by irrigation and there is therefore much pressure on the irrigation sector to transfer water to the other sectors and to make more efficient use of water.

Growing awareness of the need to increase the productivity of water in this environment of growing scarcity and competition has led to an inter-center initiative of the CGIAR[1] system, the so-called SWIM[2] initiative.

One of the research projects under SWIM is dealing with the multiple uses of irrigation water. While irrigation projects are designed to provide water for crop production, the water is used for many other purposes. It might be the only drinking water source for cattle, it might be used for fishing, and people might use water in canals or reservoirs for washing clothes, bathing or even as the source of drinking water. If there is a change in availability of water for irrigation, it will also affect these unofficial uses. Ignoring this could cause important losses to rural communities. The problem is that there is much anecdotal information about these nonagricultural uses but very little systematic documentation. One of the reasons is that every use is the responsibility of a different sector with its own objectives. Irrigation systems are designed to provide water for agriculture and rarely take domestic use into account. Domestic water providers see surface water as hazardous and emphasize separate domestic water supplies.

To get a better idea about these multiple uses, IIMI has started case studies in Sri Lanka and Pakistan, with a third one planned in Burkina Faso.

---

[1] Consultative Group on International Agricultural Research

[2] System-Wide Initiative on Water Management

Kirindi Oya Case Study

The importance of taking all uses and users of a single water supply into account is very well illustrated in the Kirindi Oya Irrigation and Settlement Project (KOISP) in the south of Sri Lanka. This is an area where there is, at the local level, competition for the available water resources. There was serious conflict in 1992, and again in 1997, when the Irrigation Department reserved water in the main reservoir for domestic uses during a serious drought. Farmers became very angry and demanded water releases for irrigation. Conflicts also exist in the area between herdsmen of cattle and buffaloes and farmers because of destruction of crops, between farmers and the Irrigation Department because of damage to irrigation structures, and between farmers and wildlife officials because of unauthorized use of water reservoirs in the nearby Yala National Park area. In a series of brackish water lagoons of very high environmental value in the Bundala National Park, too much drainage water from the KOISP has disturbed the salt balance needed for shrimp culture. There are plans for more tourist hotels and an oil refinery in the area. It has been stated by the Irrigation Department and the Water Supply and Drainage Board that there is no water available but other government departments have approved the constructions.

Health Aspects

With regard to the health aspects of multiple uses of irrigation water, the domestic uses are of importance. There are many basic questions for which we have no answers at the moment, at least no answers supported by scientific evidence. This is true even for the first and most simple question: To what extent *is* irrigation water used for domestic purposes? Related questions are: By whom is it used? Why is it used? What is the variation within an irrigation system over the year?

Second, *if* irrigation water is used for domestic purposes, what are the health impacts (both negative and positive)? If we would like to promote domestic use of irrigation water, what would be the conditions under which this would be acceptable and what would be the treatment needed? Finally, a very important question, what will happen when irrigation is made more efficient? For example, in the Gal Oya irrigation scheme in Sri Lanka, some canals were concrete lined to reduce seepage losses. It made irrigation more efficient, but it also lowered the water table and as a result wells used for drinking water dried up.

Water-Related Diseases

There are many diseases associated with water but of these the number one public health priority in developing countries is the diarrheal diseases. Children in developing countries typically have several episodes of diarrhea each year. It can cause death through dehydration or contribute to malnutrition.

There was a time when we had the very straightforward explanation that diarrhea was caused by drinking contaminated water and that changing to cleaner water would reduce diarrheal incidence. It has proved more complicated than that and we are now at the stage that nobody would like to talk about water quality in relation to diarrheal disease without taking the quantity of water, sanitation, and hygienic behavior into account.

It has been argued by people such as David Bradley that there is in fact too much emphasis on water quality issues. An exclusive focus on water quality issues is appropriate for western countries where problems over availability of water for domestic use were solved in the last century. In many developing countries, it is water availability that is still priority number one. Also, hygienic behavior ranks below water quantity. We know that, for example, hand washing is very effective in preventing dysentery and other diarrheal diseases. But in many areas of Africa, India, and China, hand washing after defecation or before preparing food seems like a luxury when the water has to be fetched at a water point two hours away.

Sanitation is a different story: improving the water supply without improving sanitation will not have much effect. They have to be improved together. There are good methods of improving sanitation that need no water but here the problem is that communities often are not very motivated to work on these improvements. When you ask communities about their priorities and their main problems, water always ranks very high and is often the number one community concern. Health often ranks quite low, and comes after concerns about food, schooling for children, housing, and transport.

Compared with diarrheal diseases, chemical pollution of water is not a very high priority for the public health agenda of developing countries. It does not cause the amount of disease and death that diarrhea is causing. However, the study of chemical pollution of water is more relevant in irrigated areas than elsewhere, because of the very high use of pesticides and fertilizer in irrigated agriculture. Pesticide poisoning *is* a very important public health problem in countries such as Sri Lanka, Pakistan, China, and the Philippines, but then we are talking about acute poisoning not the long-term health effects resulting from exposure through drinking water. Fortunately, reduction of acute pesticide poisoning, long-term exposure, and environmental effects can be achieved with the same interventions, which is a shift in agriculture to integrated pest management (IPM) and enforcement of legislation. IPM, which tries to reduce pesticide use, is now generally accepted as a key element in sustainable agricultural development.

Proposed Research Topics

Research on the health aspects of domestic use of irrigation water would come down to the point: Is irrigation water simply too polluted to be used for domestic purposes or does it enhance health by making more water available than what would otherwise be possible?

Depending on this the next issues could be: How will changes in irrigation management, "better" management, or "more efficient" management affect the domestic uses? And: How could irrigation water be made more suitable for domestic use?

Research on multiple uses of irrigation water is difficult because it needs people with different professional backgrounds: engineers, social scientists, public health experts, and biologists who all speak their own language. Experts in one field should be able to appreciate that the solutions they offer to a problem could easily have negative side effects elsewhere. IIMI wants to create a scientific basis for the discussion of the health impacts of nonagricultural uses of irrigation water and propose practical solutions to improve the water supply and well-being of poor communities in developing countries.

Brief summary of the participants' comments to the proposal on non-agricultural use of irrigation water:

Steven Ault reported from the working group and chaired the discussion among all participants.

The group recommended expanding the focus of the study objectives to include domestic water use in its wider sense, for example, water for homesteads. A number of small-scale surveys would be needed to document the actual importance of irrigation water as a source of water for domestic uses. To implement these recommendations, standard formats should be developed and adapted by collaborators in a number of developing countries. Following this survey approach, a limited number of detailed studies should be implemented to assess the health impacts.

Although the quantities of irrigation water used for domestic purposes may be very small, it will require significant changes in the water management approach by the irrigation departments to ensure water availability between cultivation seasons. Therefore, it may be more cost effective to design a dual-purpose irrigation/domestic water supply system.

The supply of domestic water to irrigation communities should be linked to the possible problems of schistosomiasis transmission in canals in African systems.

Appendices

APPENDIX A

Copenhagen Workshop on Health and Irrigation, 18–20 August 1997, Denmark

AGENDA

Monday August 18—First Day

Time	*Speaker*	*Subject—Title*
08.30–09.00	Dr. David Seckler Dr. Niels Christensen	Opening Remarks
09.00–09.15	Dr. Wim van der Hoek	Introduction to Agenda and Objectives
09.15–10.15		Presentation of Individuals and Institutions
10.15–10.45		*Coffee/tea break*
10.45–11.15	Prof. Michael Service	Keynote Address
11.15–12.00	Mr. Flemming Konradsen	Presentation of First Paper
12.00–13.15		*Lunch - DANIDA Buffet at Eigtved*
13.15–14.00	Dr. Christian Tjell	Presentation of Second Abstract
14.00–14.45	Dr. Henry Madsen	Presentation of Third Paper
14.45–15.15		*Coffee/tea*
15.15–16.00	Dr. Thomas Teuscher	Presentation of Fourth Paper
16.00		Close of First Day

Tuesday August 19—Second Day

08.30–09.15	Dr. William Jobin	Presentation of Fifth Paper
09.15–09.45	Dr. David Seckler	Presentation of Global Water Atlas
09.45–10.15		*Coffee/tea break*
10.15–10.45	Dr. Martin Birley	Presentation of First Project Paper
10.45–11.15	Mr. A. Malmgren-Hansen	Presentation of Second Project Paper
11.15–11.45	Dr. Wim van der Hoek	Presentation of Third Project Paper
11.45–12.00		Introduction to Afternoon Session
12.00–13.15		*Lunch in the Ministry of Foreign Affairs*
13.15–14.45		Group Discussions
14.45–15.15		*Coffee/tea break*
15.15–16.45		Group Discussions
17.00		Departure for DBL by Taxi
17.30–19.30		Reception at DBL, Charlottenlund
19.30		Departure by Taxi to Hotel Komfort

Wednesday August 20—Third Day

08.30–09.30	Group 1	Presentation and Discussion
09.30–10.00		*Coffee/tea break*
10.00–11.00	Group 2	Presentation and Discussion
11.00–12.00	Group 3	Presentation and Discussion
12.00–12.30		Closing Remarks

Appendix B

List Of Participants

Dr. Priyanie Amerasinghe
Department of Zoology
University of Peradeniya
Peradeniya
Sri Lanka

Phone : (+94) 8 388693
Fax : (+94) 8 388018
E-mail : pry@sci.pdn.ac.lk

Ms. Lena Christensen
Technical University of Denmark
Department of Environmental Science and Engineering
Bygning 115
2800 Lyngby
Denmark

Phone : (+45) 45 25 16 00
Fax : (+45) 45 93 28 50
E-mail : lc@imt.dtu.dk

Dr. Steven Ault
Advisor in Environmental Health
PAHO/WHO Representation in Guatemala
7a. Avenida 12-23 ZONA 9
Edificio Etisa 3er. Nivel
Guatemala C.A. 01009

Phone : (+502) 33222032
Fax : (+502) 3343804
E-mail : sault@ops.org.gt

Dr. Niels Ø. Christensen
Danish Bilharziasis Laboratory
Jægersborg Allé 1D
2920 Charlottenlund
Denmark

Phone : (+45) 39 62 61 68
Fax : (+45) 39 62 61 21
E-mail : noc@bilharziasis.dk

Dr. Martin Birley
Liverpool School of Tropical Medicine
Health Impact Programme
Pembroke Place
Liverpool L3 5QA
United Kingdom

Phone : (+44) 151 708 9393
Fax : (+44) 151 708 8733
E-mail : mhb@liverpool.ac.uk

Mr. Peter Furu
Danish Bilharziasis Laboratory
Jægersborg Allé 1D
2920 Charlottenlund
Denmark

Phone : (+45) 39 62 61 68
Fax : (+45) 39 62 61 21
E-mail : pf@bilharziasis.dk

Mr. Robert Bos
Division of Environmental Health
Panel of Experts on Environmental
Management for Vector Control
World Health Organization
1211 Geneva 27, Switzerland

Phone : (+41) 22 791 3555
Fax : (+41) 22 791 5149
E-mail : bos@who.ch

Mr. Jasper Ijumba
Tropical Pesticides Research Institute
P.O. Box 3024
Arusha
Tanzania

Phone : (+255) 57 8813/8815
Fax : (+255) 57 8217
E-mail : tpri@marie.gn.apc.org

Dr. Moses Chimbari
Blair Research Laboratory
Josiah Tongogara Avenue/Mazowe Street
P.O. Box CY 573
Causeway, Harare
Zimbabwe

Phone : (+263) 4 792747/9
Fax : (+263) 4 792480
E-mail : Blair@healthnet.zw

Mr. Peter Jensen
International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Phone : (+94) 1 867404
Fax : (+94) 1 866854
E-mail : p.jensen@cgnet.com

Dr. William Jobin
Blue Nile Associates
P.O. Box 720
Dolores
Colorado 81323
USA

Phone : (+1) 970 882 7778
Fax : (+1) 970 882 7779
E-mail : bluenile@mcimail.com

Mr. Anders Malmgren-Hansen
Danish Hydraulic Institute
Agern Allé 5
2970 Hørsholm
Denmark

Phone : (+45) 45 76 95 55
Fax : (+45) 45 76 25 67
E-mail : amh@dhi.dk

Mr. Flemming Konradsen
International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Phone : (+94) 1 867404
Fax : (+94) 1 866854
E-mail : f.konradsen@cgnet.com

Dr. Clifford Mutero
International Centre of Insect Physiology and Ecology
P.O. Box 30772
Nairobi
Kenya

Phone : (+254) 2 802501/3/9
Fax : (+254) 2 860110
E-mail : icipe@cgnet.com

Dr. James Lenahan
International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Phone : (+94) 1 1867404
Fax : (+94) 1 866854
E-mail : j.lenahan@cgnet.com

Dr. Rachel Reuben
WHO/TDR Project on Rural Filariasis
Centre for Research in Medical Entomology
Post Box No.11, 4 Sarojini Street
Chinna Chokkikulam, Madurai
India

Phone : (+91) 452 530746
Fax : (+91) 452 530660
E-mail : icmr%bicmku@dbt.ernet.in

Dr. Henry Madsen
Danish Bilharziasis Laboratory
Jægersborg Allé 1D
2920 Charlottenlund
Denmark

Phone : (+45) 39 62 61 68
Fax : (+45) 39 62 61 21
E-mail : hm@bilharziasis.dk

Consultant Ebbe Schiøler
StS.4, Ministry of Foreign Affairs
Asiatisk Plads 2
1448 Copenhagen K
Denmark

Phone : (+45) 33 92 10 73
Fax : (+45) 33 92 04 93
E-mail : um@um.dk

Mr. Ian Makin
International Irrigation Management Institute
P.O. Box 2075, Colombo
Sri Lanka

Phone : (+94) 1 1867404
Fax : (+94) 1 866854
E-mail : i.makin@cgnet.com

Dr. David W. Seckler
International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Phone : (+94) 1 1867404
Fax : (+94) 1 866854
E-mail : d.seckler@cgnet.com

Professor Michael Service
Division of Parasite and Vector Biology
Liverpool School of Tropical Medicine
Pembroke Place
Liverpool L3 5QA
United Kingdom

Phone : (+44) 151 708 9393
Fax : (+44) 151 708 8733
E-mail : mservice@liverpool.ac.uk

Dr. Chris Thomas
Environmental Research Centre
Department of Biological Sciences
Durham University, South Road
Durham DH1 3LE
United Kingdom

Phone : (+44) 191 374 7406
Fax : (+44) 191 374 2417
E-mail : C.J.Thomas@durham.ac.uk

Mr. Bart Snellen
International Institute for Land Reclamation and Improvement
Postbus 45
6700 AA Wageningen
The Netherlands

Phone : (+31) 317 490968
Fax : (+31) 317 417187
E-mail : ilri@ilri.nl

Dr. Christian Tjell
Technical University of Denmark
Department of Environmental Science and Engineering
Bygning 115
2800 Lyngby
Denmark

Phone : (+45) 45 25 16 00
Fax : (+45) 45 93 28 50
E-mail : jct@imt.dtu.dk

Mr. Børge Storm
Danish Hydraulic Institute
Agern Allé 5
2970 Hørsholm
Denmark

Phone : (+45) 45 76 95 55
Fax : (+45) 45 76 25 67
E-mail : dhi@dhi.dk

Dr. Wim van der Hoek
International Irrigation Management Institute
P.O. Box 2075
Colombo
Sri Lanka

Phone : (+94) 1 867404
Fax : (+94) 1 866854
E-mail : w.van-der-hoek@cgnet.com

Dr. Thomas Teuscher
WARDA ADRAO
Bouake Headquarters
01 BP 2551 Bouake, Ivory Coast
West Africa

Phone : (+225) 63 45 14
Fax : (+225) 63 47 17
E-mail : T.Teuscher@cgnet.com

Mr. Jacob Williams
Joint WHO/FAO/UNEO/UNCHS Panel of Experts on Environmental Management for Vector Control
World Health Organization
1211 Geneva 27
Switzerland

Phone : (+41) 22 791 4227
Fax : (+41) 22 791 5149
E-mail : williamsj@who.ch

Useful References on Vectors

American Mosquito Control Association. 1995. Vector control without chemicals: Has it a future? A symposium. Presented at the Sixtieth Annual Meeting of the American Mosquito Control Association, San Diego California on April 11, 1994. *Journal of the American Mosquito Control Association*, 11: 247–293.

American Society of Tropical Medicine and Hygiene. 1994. Special symposium on vector control. *American Journal of Tropical Medicine and Hygiene*, 50 (supplement); 159 pp.

IIMI. 1986. *Irrigation and vector-borne diseases transmission.* Proceedings of the Workshop. Colombo, Sri Lanka: International Irrigation Management Institute; 66 pp.

IIMI. 1987. *A Selected Bibliography on Irrigation Management.* Colombo, Sri Lanka: International Irrigation Management Institute; 91 pp + 35 pp index.

Boudin, C., Lyannaz, J., Bosseno, M.F., Carnevale, P., and Ambroise-Thoma, P. 1991. Epidemiology of *Plasmodium falciparum* in a rice field and a savanna area in Burkina Faso: Seasonal fluctuations of gametocytaemia and malarial infectivity. *Annals of Tropical Medicine and Parasitology*, 85: 377–385.

Coosemans, M.H. 1985. Comparison de l'endemie malarienne dans une zone de riziculture et dans une zone de culture de coton dans la plaine de la Rusizi, Burundi. *Annales de la Societé Belge de Médecine Tropical*, 65 (supplement): 187–200.

Fenwick, A. 1989. Irrigation in the Sudan and schsitosomiasis. In *Demography and vector-borne diseases*, ed. M.W. Service. Boca Raton, Florida, USA: CRC Press.

Herrin, A.N. and Rosenfield, P.L. 1988. *Economics, health and tropical diseases.* University of the Philippines; 470 pp.

Hill, R.B. and Cambournac, F.J.C. 1941. Intermittent irrigation in rice cultivation and its effects on yield, water consumption and *Anopheles* production. *American Journal of Tropical Medicine*, 21: 123–144.

Lacey, L.A. and Lacey, C.M. 1990. The medical importance of riceland mosquitoes and their control using alternatives to chemical insecticides. *Journal of the American Mosquito Control Association*, 6 (supplement); 93 pp.

Mather, T.H. (ed.) 1984. *Environmental Management for Vector Control in Rice Fields.* FAO Irrigation and Drainage Paper, 41; 152 pp.

Mogi, M. 1984. Mosquito problems and their solution in relation to paddy rice production. *Protection and Ecology*, 7: 219–240.

Oomen, J.M.V., de Wolf, J. and Jobin, W.R. 1988. *Health and irrigation. incorporation of disease control measures in irrigation, a multi-faceted task in design, construction, operation.* International Institute for Land Reclamation and Improvement Publication, 45, vol. 2; 119 pp.

Oomen, J.M.V., de Wolf, J. and Jobin, W.R. 1990. *Ibid.* vol. 1; 304 pp.

Prescott, N. 1989. Economic analysis of schistosomiasis control. In *Demography and vector-borne diseases*, ed. M.W. Service. Boca Raton, Florida, USA: CRC Press.

Rajendran, R., Reuben, R., Purushothaman, S., and Veerapatran, R. 1995. Prospects and problems of intermittent irrigation for control of vector breeding in rice fields in southern India. *Annals of Tropical Medicine and Parasitology*, 89: 541–549.

Reuben, R. and Jayaraj, S. 1991. The role of design of South Indian irrigation systems in the ecology of Japanese encephalitis vectors. In *Case studies on vector borne disease problems associated with rural and urban water management*. Eleventh Annual Meeting, Joint WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control, Kuala Lumpur, 21–25 October 1991.

Robert, V., van den Broek, A., Stevens, P., Slootweg, R., Petrarca, V., Coluzzi, M., Le Goff, G., di Dico, M.A., and Carnevale, P. 1992. Mosquitoes and malaria transmission in irrigated rice fields in the Benue valley of northern Cameroun. *Acta Tropica*, 52: 201–204.

Robert, V., Gazin, P., and Carnevale, P. 1987. Malaria transmission in three sites surrounding the area of Bobo-Dioulasso (Burkina Faso): the savanna, a rice field and the city. *Bulletin of the Society of Vector Ecology*, 12: 541–543.

Robert, V., Chippaux, J.-Ph., and Diomande, L. 1991. Le paludism en Afrique de l'Ouest. Etudes entomologiques en zone rizicole et en milieu urbain. *Editions de l'ORSTOM*, Paris, 105 pp.

Russell, P.F., Knipe, F.W., and Rao, W.R. 1942. On the intermittent irrigation of rice fields to control malaria in south India. *Journal of the Malaria Institute of India*, 4: 321.

Seif, L.S. and De Datta, S.K. 1988. The impact of water management practices in rice on mosquito vector propagation. In *Vector borne disease control in humans through rice agroecosystem management*, pp. 67–83. Manila, Philippines: International Rice Research Institute.

Service, M.W. 1977. Mortalities of the immature stages of species B of the *Anopheles gambiae* complex in Kenya: Comparison between rice fields and temporary pools, identification of predators and effects of insecticidal spraying. *Journal of Medical Entomology*, 13: 535–545.

Service, M.W. 1984. Problems of vector borne diseases and irrigation projects. *Insect Science and its Application*, 5: 227–231.

Service, M.W. 1987. The linkage between mechanization of agricultural practices for rice cultivation and vector borne disease transmission. *In Effects of agricultural development on vector borne diseases*, pp. 125-129. Working papers of 7th Annual Meeting, Joint WHO/FAO/UNEP/UNCHS Panel of Experts on Environmental Management for Vector Control, 7–11 September 1987. FAO, Rome, AGL/MISC/12/87.

Service, M.W. 1989. Boon or bane? In *Demography and vector-borne diseases*, ed. M.W. Service, pp. 237–254. Boca Raton, Florida, USA: CRC Press.

Service, M.W. 1989. Rice, a challenge to health. *Parasitology Today*, 5: 162–165.

Speelman, J. J. and van den Top, G.M. 1986. Irrigation and vector borne diseases: a case study in Sri Lanka. In *Proceedings of the workshop on irrigation and vector-borne disease transmission,* pp. 44–55. Colombo, Sri Lanka: International Irrigation Management Institute.

Wada, Y. 1988. Strategies for control of Japanese encephalitis in rice production systems in developing countries. In *Vector-borne disease control in humans through rice agroecosystem management*, pp. 153–160. Manila, Philippines: International Rice Research Institute.

World Health Organization. 1988. *Vector-borne disease control in humans through rice agroecosystem management.* Proceedings of the Workshop on Research and Training Needs in the Field of Integrated Vector-Borne Disease Control in Riceland Agroecosystems of Developing Countries, 9–14 March 1987. Manila, Philippines: International Rice Research Institute; 237 pp.

World Health Organization. 1995. *Vector control for malaria and other mosquito-borne diseases.* WHO Technical Report Series, 857; 91 pp.