Irrigation and Vector-Borne Diseases: A Case Study in Sri Lanka

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Introduction

During eight months of field work in the Mahaweli Program, System C, Zone 2 during Maha season 1984/85, technical irrigation features associated with vector habitat creation were studied. These include: 1) Irrigation water supply design criteria for rice cultivation; 2) problems of excess water when constructing, operating, and maintaining the irrigation/drainage canal network; 3) methods of identifying potential vector breeding habitats in the project area; and 4) environmental management measures.

The Study Area

System C is located on the right bank of the Mahaweli River. It comprises 63,000 hectares (Fig. 1).

The area's topography is sloping and irregular, which, combined with soils and other factors, limits the area of land that is suitable for irrigation.

Suitable areas for irrigation are the valley bottoms or small catchments, whose soils are Low Humic Gleys (LHG). These gradually change uphill, at slopes up to 3%, to imperfectly drained Red Brown Earth (RBE) soils, which are also suitable for irrigation? The ridges and steepest slopes (4-6%) consist of well-drained RBE soils or granite rock knobs, which are not suitable for irrigation. This means that only about 26,000 hectares (42%) of System C is suitable for irrigation. Table 1 shows the land use.

Table 1. Land use in Mahaweli, System C.

Category	Hectares	%
Turnout - paddies & residual land	28,102	45
(Irrigable)	26,041	42
Settlement townships & hamlets	11,113	17
Forest	7,711	12
Grazing	4,816	8
Other (rocks, etc.)	2,536	4
Total	28,102	100

For administrative purposes, System C has been divided into zones, of which Zone 2 was the first to be developed. During the wet season of 1984/85, the full extent of Zone 2's irrigable land (4,000 hectares) was under irrigation for the first time. The crop was rice.

Zone 2 is situated in the intermediate climatic zone, which forms the transition between the Wet and Dry Zones. The mean yearly rainfall is 21 centimeters, most of which falls in the wet season (or Maha) during the Northeast Monsoon from October to April. The dry season (or Yala) coincides with the Southeast Monsoon from May to September.

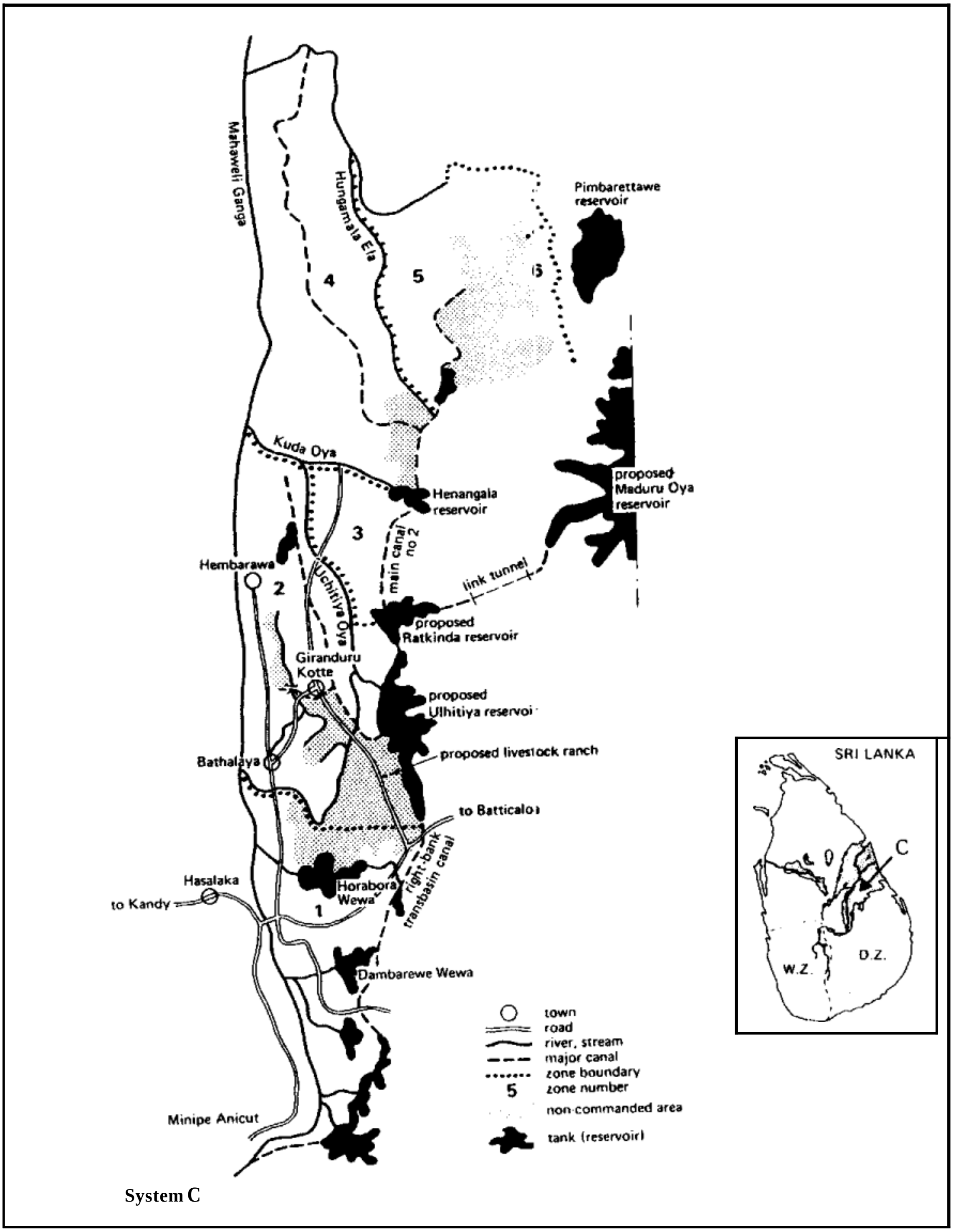
The headworks in the Mahaweli River provide the necessary water storage and flow regulation to safeguard the water supply to System C's main reservoir, the Ulhitya, throughout the year.

System C's irrigation system consists of a main canal taking off from Ulhitya, branch canals discharging into various buffer reservoirs, and distribu-

[1]With assistance from Ir. J. de Wolf and Dr. J.M.V. Oomen, International Institute for Land Reclamation and Improvement (ILRI), Wageningen. Netherlands, and Ir. K. Roscher, University of Agriculture. Wageningen.

'Hunting Technical Services. 1980. *Feasibility Study, System C, Mahaweli Project.* Borehamwood, United Kingdom.

Figure 1. The **Accelerated Mahaweli Development Project, System C, 1983.**



utary channels taking off from these reservoirs and conveying water to the minor irrigation units, or turnouts. Every turnout has one field channel running downslope and serving between 5 and 20 farmers, each owning one hectare allotments of paddy lowland. In addition, each settler family gets a **0.5** hectare homestead on which to cultivate other food crops.

Public Health and Vector-Borne Diseases in System C

The major public health problems being combatted by the Sri Lankan authorities are malaria, gastro-enteritis, accidents, dysentery, and anemia.[3] In System C, the most prevalent ailments are those related to poor hygiene and sub-standard living conditions: malnutrition, water-washed disease!, respiratory diseases, and vector-borne diseases (Table 2).

Table 2. Some data on public health in System C, 1983-84.

Diseases treated	1983 (%)	1984(%)
Respiratory infections	20.6	21.3
Warm infestations	16.8	16.3
Skin infections	13.6	12.7
Malnutrition	12.2	11.5
Bowel infections	11.5	14.5
Genito-urinary infections	9.0	6.1
Accidents	6.9	5.4
Clinically detected malaria	4.4	8.3
Cardiovascular conditions	0.5	0.4
Filarial infections	0.3	0.4
Other illnesses	4.2	2.9
Total cases treated	**37,551**	**46,531**

The most serious vector-borne diseases are malaria, filariasis, dengue, and Japanese B-encephalitis.

Malaria. Countrywide figures show an average of 7% of the examined blood films to contain malaria parasites, with incidences of 12% in 1983 and 17% in 1984. In Sri Lanka, the sole proven vector of malaria is *Anopheles culcifacies.* Mosquitoes of this species prefer a breeding place in full sunlight, clear water, and on a sandy or rocky bed. Six other *Anopheles* species present in Sri Lanka are confirmed malaria vectors in neighboring countries. Research data point to potential danger from these -and five other anopheline species.[4]

Filariasis. Bancroftian filariasis is endemic in the denselv populated southwestern coastal strip. Recent independent research[5] revealed incidences of 5% transmission of this disease in the endemic belt, as well as recorded incidences outside the belt. The vector is *Culex quinquefasciatus,* which prefers a shady and organically polluted breeding place. Brugian filariasis is thought to have been eradicated from the island during the first intensive Anti-Filariasis Campaigns, when the removal of water plants associated with the breeding place of its vectors, *Mansonia spp.,* proved to be a successful measure.

Dengue and Japanese B-encephalitis (JE). Records of the prevalence of these diseases are not available, but serological evidence suggests that dengue fever is associated with densely populated human habitation. Its main vector, *Aedes aegypti,* prefers a breeding habitat in man-made containers: old tires, tin cans, etc.

The main vector for JE is *Culex tritaeniorhyncus,* which breeds in rice fields. Pigs apparently play a role in the epidemiology of the disease!

Health Care

Three independently operating organizations provide health care in System C: the Mahaweli Authority, the Ministry of Health, and the Anti-Malaria Campaign. Each contributes to community health services, hygiene education, and sanitary provisions around settler's homes.

[3] Ministry of Health. 1983. *Annual Health Bulletin.* Colombo.

[4] Anti-malaria Campaign. *Second Independent Assessment of the Intensive Malaria Control Programme.* Colombo: Ministry of Health.

[5] Jayasekera, N. and K.S.P. Kalpage. 1986. *Entomological and Parasitological Field Study on the Transmission of Bancroftian Filariasis in Sri Lanka.* Colombo Medical Research Institute (in preparation).

Measures included in the present program of controlling vector-borne diseases are: indoor insecticide spraying and medical treatment of recognized cases, particularly of malaria. In the endemic belt, the Anti-Filariasis Campaign regularly sprays larvicides on the potential breeding places of the filariasis vector. For the following reasons, however, there is an urgent need for **a** more diversified, and therefore less vulnerable, long-term control of vector-borne diseases:

1. The increased human mobility in and out of the Project area is promoting the transmission of vector-borne diseases.[7] The intensity of transmission is likely to change with the changing micro-climate, vegetation, animal population, number of waterways, and other environmental changes now being introduced by development activities.[8]

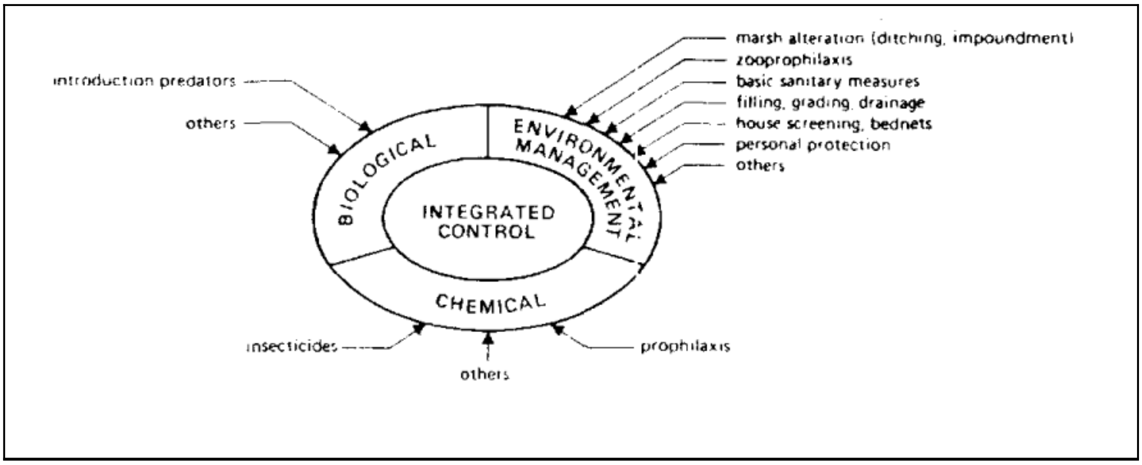
2. Neither the Anti-Malaria nor the Anti-Filariasis Campaigns have sufficient funds or manpower to intensify their activities in the Mahaweli Project areas.[9]

3. The present vector control by spraying is not entirely effective because: **a)** An estimated 40%[10] of the System C population are displaying an increasing unwillingness to have their houses sprayed because of the unpleasant smell and the fear that it has an adverse effect on health; and b) pools **used** by humans and animals must be excluded from spraying because of the risk of the pools becoming poisoned.

4. The heavy reliance on chemicals to control vector-borne diseases makes the Campaigns vulnerable because of the pace at which vector mosquitoes develop resistance to the chemicals.[11]

Figure 2 shows the concept on an integrated control that has been developed to meet the need for more diversified approaches to vector control. This

***Figure* 2.** Diagram of the components to be considered in an "Integrated Control" approach to mosquito control[a/]



[a/] Axtell, R. C. 1979. Principles of Integrated Pest Management (IPM) in relation to mosquito control. ***Mosquito News*** 39:709-718.

[7] Fernando, M. **(ed.).** 1984. *Human* Population Movements and *their* Impact on Tropical Disease, *Transmission* and *Control in Sri* Lanka. Proceedings of a Workshop. University of Peradeniya, Faculty of Medicine; the World Bank; and the World Health Organization (WHO).

[8] TAMS (Tippets, Abbett, McCarthy, and Stratton). 1980. *Environmental* Assessment *Accelerated* Mahaweli *Development* Programme (for Ministry of Mahaweli Development). New York.

[9] Anti-Malaria Campaign. 1978-83. Administration Reports. Colombo: Ministry of Health and Anti-Filariasis Campaign. 1978-78. *Administration* Reports. Mount Lavinia: Ministry of Health.

[10] Based on an Anti-malaria Campaign field staff report.

[11] Several of the suspected new malaria **vectors** have already developed multiple resistance to the insecticides now available (see ref. footnote 4).

concept combines chemical. biological, and environmental management methods that suit the local requirements and possibilities. In Zone 2, where the irrigation systems determines the environment in a large part of the area, the analysis and possible improvement of present water-management practicies form an essential element in environmental management for vector control.

Identifying Vector Habitats in Zone 2

Whether water forms a suitable breeding place for vectors depends on a variety of factors. In irrigated agriculture, a relationship has to be established between observed water bodies, the practices that led to their creation, and whether they will cause the proliferation of specific vectors. To establish this relationship in Zone 2, three matrices were developed

Matrix I. Potential mosquito breeding places were classified by adapting the system described in the WHO Manual on Environmental Management for Vector Control to the local situation. The stagnant bodies of water cncountercd in Zone **2** were placed in one of seven categories (Table 3). according to criteria such as organic pollution, exposure to sunlight, vegetation, freshness of the water, and the size of the pool.

***Table* 3.** Classification of the most common potential breeding places in System ***C*,** Zone 2

A. Large bodies of fresh water in full or partial sunlight (floating or emergent vegetation occurs especially near the edges):

1. Ulhitya/Ratkinda reservoir, irrigation tanks, level crossings; large borrow pits, waterlogged pools behind filled D-channel bunds, large natural surface depressions.

2. Marshes.

B. Small water collections, stagnant and often muddy, but not polluted; full to partial sunlight:

1. Vegetation present (scattered or fringed): Marginal pockets along irrigation canals, semi permanent rain pools in natural or man-made surface depressions (e.g., in between road and canal bund), seepage pools behind tank or canal bund, old borrow pits, clogged drainage ditches.

2. Vegetation absent: Recent borrow pits, rock pools on excavation sites, new road ditches, wheel ruts, foot- or hoof-prints, rain water ground pools.

C. Marshy patches, often polluted with organic matter; abundant vegetation (oily mono-layen, iron-colored water, smell of decomposition):

1. Margins of level crossings, seepage ponds/depressions along irrigation canals constructed in fill, poorly drained, shallow but extensive surface depressions.

2. Roads saturated with water overflowing from field channes

3. Muddy broad sections of natural drains where the water flow stagnates (mainly in upper parts of intermediate drains)

D. Paddy fields.

1. Swampy, poorly drained fallow lowland paddy fields before land preparation

2. Recently tilled fields.

3. Fields during seeding (levelled fields, no water layer, but small shallow pools)

4. Fields during transplanting (levelled fields, shallow water).

Continued

5. Fields during crop growth.

6. Washing pits.

E. Partially or heavily shaded water under abundant vegetation:

1. Sluggish irrigation-drainage streams (slow water flow from one pool to another), pools at the interception of drains in D-channels, ponds.

2. Stagnant pools in spillway drainage beds.

F. Running watercourses, clear fresh water, direct sunlight.

1. Pools in drying stream beds (natural streams or irrigation canals), seepage pools from irrigation structures in canal beds, pools in streameroded canal depressions directly behind drop structures, turnout structures and cross regulators.

2. Irrigation ditches and lowland grass/weedy field drainage ditches.

3. Small side-pockets along shoreline of irrigation canals (erosion gullies, bund breaches, etc.).

G. Man-made containers

1. Stilling basins of irrigation structures (turnouts, cross-regulators), silt catcher of reservoir spill.

2. Wells, cisterns discarded receptacles, discarded tires, gutters, etc.

Matrix I is used with the classification list, and relates the observed breeding places to the confirmed or potential vectors responsible for transmitting diseases in Zone 2 (Fig. 3). Because data relating the mosquito species to the potential breeding places is unavailable, only the form of the matrix is shown.

Figure 3. Matrix I: Identification/relation to mosquito species.

Disease	Mosquito species	Potential breeding place						
		A	B	C	D	E	F	G
MALARIA								
	An. culicifacies							
	An. subpictus							
	An. vagus							
	An. varuna							
	An. annularis							
	An. nigerrimus							
	An. pallidus							
	An. barbirostris							
	An. aconitus							
	An. jamesi							
	An. tesselatus							
	An. maculatus							
	An. karwari							
FILARIASIS								
	Cx. quinquefasciatus							
	Mansonia sp.							
DENGUE								
	Ae. aegypti							
	Ae. albopictus							
JAP. B. ENCEPHALITIS								
	Cx. tritaeniorhynchus							
	Cx. gelidus							

Matrix II. From direct observation of the irrigation system and of agricultural practices, and from other information, we identified (Fig. 4) the point in the irrigation system (e.g., reservoir, main canal, etc.) and in the irrigation cycle (e.g., pre-irrigation, land-preparation, etc.) where the various breeding places become an important hazard to health.

Matrix III thus completes the stepwise cause-and-effect analysis, which starts with identifying the vector and ends with identifying the irrigation feature that influences vector habitat. Although the matrices still need more data from both irrigation and entomology, they provide a framework for further study of the linkage between irrigation and vector ecology under the specific environmental conditions of Zone 2.

Figure 4. Matrix II: Location of potential breeding places.

	Pre-Irrigation	Land-Preparation	Crop Establishment	Vegetative Growth	Harvest	Post-Irrigation
Reservoir	A1, G1	A1, G1	A1, G1	A1, G1	A1, G1	A1, G1
Main/Branch Canal	F1	F3	F3	F3	F3	F1
Buffer Reservoirs	A2	A1;B1;C1	A1;B1;C1	A1;B1;C1	A1;B1,C1	A2
Distributary	A1;C1;G1	A1;B1,2	A1;B1,2	A1;B1,2	A1;G1;C1	A1;G1,C1
Channel	F1	F3;E1	F3;E1	F3;E1	F1	F1
Field Channel	C1;F1	B1;C1,2	B1;C1,2	B1;C1,2	C1;F1	C1;F1
Field Ditch		F2	F2	F2		
Field	D1	D2,6	D3,4,6	D5,6	Dh	D1
Field Drainage		F2	B1;F2	B1;F2	B1;F2	
Natural stream	E1;F1	C3;E2	C3;E2	C3;E2	C3;E2	E1
Domestic Environ.	G2	G2	G2	G2	G2	G2
Natural Environ.	A1;B1,2 C1	AA1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1	A1;B1,2 C1

Matrix II thus indicates the relative importance of the irrigation system as a whole for potential vector breeding in the area, and singles out those elements of the irrigation system that contribute most to the breeding risk.

Matrix III. Matrix III establishes the relationship between the location of the breeding places and those features of water management and irrigation engineering that cause their existence: hydrology, design, construction, etc. (Fig. 5).

Irrigation Features Related to Vector Habitat Creation

Matrix III directs attention to that feature of the irrigation system, which, by an analysis of its details, will prove to be the cause of a particular type of breeding place. Even so, a general rule

Figure 5. Matrix III: Relationship between breeding place and irrigation feature.

	Hydrology	Farm-Water Management	Design	Construction	Operation	Maintenance
Reservoir	A1		Gt		A1	A1
Main/Branch Canal				F3		F1,3
Buffer Reservoirs	A2;C1			B1	A1	A1
Distributary	A1;B1		A1;E1	A1;B1,2;C1	C1	B1;C1;F1
Channel			G1	E1;F1,3		F3
Field Channel	A1;B1		F1	B1;C1,2;F1	B1;C1,2;F1	B1;C1
Field Ditch		F2		F2		F2
Field		D1.6				
Field Drainage	Bt	F2				B1;F2
Natural stream	A1;C3;E1 E2;F1			C3;E1,2		C3;E1,2
Domestic Environ.				G2		G2
Natural Environ.	A1;B1;C1		B1	B2		B2

seems to apply: the more carefully and minutely irrigation development is planned and executed, the less likely it is to encourage mosquito propagation. Some examples of the principles under-lying this rule were observed in Zone 2.[12] **Hydrology.** The sloping and irregular topography of System *C* has imposed two major constraints on the drainage of the area. First, drainage of the large area of land excluded from the irrigation scheme would have required a large number of culverts and other devices because, in many cases, the newly constructed roads and canal bunds have cut off stretches of this land from the natural drains.

Second, numerous small unirrigable patches are scattered within the irrigation system's boundaries. These contain natural and man-made surface depressions that do not drain to the drainage network laid out as part of the irrigation system. These depressions collect water from blocked natural drainage, rainfall, surface runoff, and seepage, to create large and small, often brightly sunlit, bodies of stagnant water that retain an overall breeding potential for the area throughout all phases of the irrigation cycle.

Design. **A** complex network of reservoirs and major and minor canals resulted from the policy of creating the largest possible command area in the undulating topography and varying soil conditions of System *C*. The control of water flows in all parts of this network is, in itself, a complex matter, which places heavy demands **on** the **staff** operating the system. The situation is further complicated by the decision to leave canals unlined, with all the attendant problems of erosion and seepage.

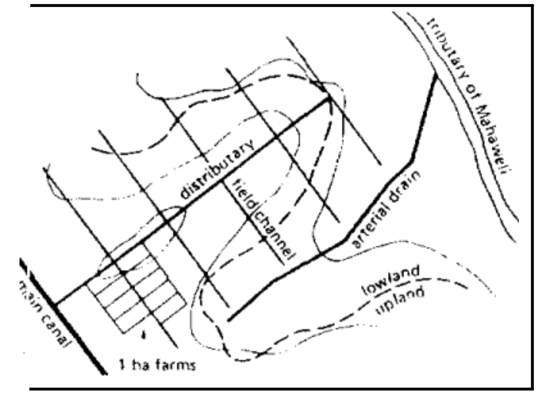
The design of separate parts of the system may create public health hazards. Figure *6* gives an example of how the canal layout has been adapted to the topography.

Distributary canals are aligned along the lateral spurs of the main ridges, which means that a major part of every distributary **runs** through the imperfectly to well-drained **RBE** soils. Where these canals have been excavated in erodible RBE soils, serious bund erosion **has** been observed. One effect of this erosion is the deposition of silt, which, in the pre- and post-irrigation periods, leads to uneven canal beds with many shallow sunlit pools of stagnant water. In consequence, conditions in the distributaries and branches are particularly conducive to the development of mosquito larvae until the first issue of water, after which a constant **flow is** maintained in the canals. Potential breeding areas remain, however, where erosion gullies in bunds form pockets of standing water.

Especially in the minor canals, there are two other effects of bund erosion: First, over the full length of the field channels and at the tail end of distributaries, the deposition of silt causes capacity problems. The subsequent overtopping of canal embankments leads to pool formation in adjoining surface depressions. Second, accelerated water flow and whirlpool action occurring downs-tream of culverts, bridges, drop and check structures, and bends, cause bank erosion. This widens the canal cross-section, retards water flow, and creates breeding places in the side pockets along the embankment. **In** contrast, the large Ulhitya Reservoir **cannot** be reckoned as a dangerous breeding place. The reservoir bund closest to the nearest settler hamlet exceeds the average flight range of most mosquito vectors: 1-3 kilometers.

Unlike Ulhitya, the score of smaller irrigation reservoirs incorporated in the system (and in proximity to human habitation) may contribute considerably to vector breeding. Often the embankments

***Figure* 6.** Example of canal layout in System *C*.



[12]We should emphasize that development in the project area is Still in a transitional phase. The changing environmental and other conditions may, in the long run, influence the relative importance of the observed causes of vector habitat creation.

[13]World Health Organization. 1982. *Manual on Environmental Management for Mosquito Control.* Geneva, Switzerland: WHO pub. 66. pp281.

of small irrigation reservoirs (or tanks) are infested with emergent or floating vegetation, of which *Salvinia natans* is a suspected breeding requisite for *Mansonia spp.,* thevector of Brugian filariasis.

These small reservoirs serve the purpose of buffering the effects of disproportion between frequency of adjustments in major and minor canals. Water levels, therefore, are subject to irregular fluctuations throughout the year, causing an exposed drawback zone suitable for mosquito breeding each time the water recedes. If the drawback zone does not consist of isolated small depressions, however, the shallows will empty when the water recedes, leaving the eggs, larvae, and pupae stranded.

Construction. Since 1977, the Mahaweli Development Programme has been "accelerated," which means that the tempo was increased in constructirg headworks and opening new lands to irrigation. This increased tempo also meant that shortages were encountered, including: 1) Accurate topographical maps of the new lands to be developed, 2) expertise and management for planning and monitoring construction, **3)** well-equipped and experienced local contractors for executing the work, and **4)** supplies of high-quality construction materials.

The effects of these shortages are now appearing in the irrigation infrastructure. Examples include the following:

1. Not all the canal beds and structures have been constructed at the proper elevations. The result is incorrect water flows, stagnation of water in canal sections, and overtopping of bunds, with the consequent formation of poo s in adjoining depressions.

2. Some canal sections have been constructed to **fill,** without being compacted, which is necessary to avoid seepage and leakage. This has led to the continuous presence of adjacent waterlogged surface depressions.

3. Complicated construction works such as large culverts, water-level regulating structures, aqueducts, and inverted syphons have not all been made with the highquality materials they require, nor have they all been accurately installed. This is necessary not only to prevent the creation of breeding places, but also *to* safeguard the delivery of design water flows throughout the system.

Operation. The quality of the design and construction determines the boundary conditions within which operational procedures are laid down that supposedly guarantee a uniform and reliable supply of sufficient irrigation water. In System **C,** the accelerated implementation of a complex design under difficult topographical conditions has resulted in complicated operational procedures that have not been able to prevent shortages or excesses of water.

According to Moore,[14] the cause of many of the problems in large-scale irrigation schemes in **Sri** Lanka lies in the operational procedures applied, which rank low in formality, information, and control. His contention also holds for Zone **2.**

Formality. The formality of operation in Zone *2* is characterized by: a) **An** almost total lack of written technical procedures for the adjustment of control gates downstream of the main canal; b) the absence of explicit job descriptions for water management staff; and c) poor coordination **of** policies and activities, leading to haphazard implementation of rainfall corrections, rotation schedules, cropping calendars, etc.

In circumstances like this, an alert and effective water management **for** the equitable distribution of irrigation water is impossible. The result is that farmers and water management staff are becoming alienated. Poaching water and damaging irrigation structures are common actions when farmers feel that their complaints about water shortages are not heard.

Information Flow measurements are imperative if one is to verify channel flow and locate faulty design **or** construction **in** the canal system. Flows in the main and branch canals or Zone *2* are measured with Parshall flumes, and in the distributaries with short-crested (hump) weirs. Only a minimum number of measurement devices, however, have

[14] Moore, M.P. 1980. ***Approaches to Improving Water Management on Large-scale Irrigation in Sri Lanka.*** **Colombo: Agrarian Research and Training Institute (ARTI) Occasional Pub. 20.** pp47

been incorporated in the canal network, and many of them cannot he used for accurate readings because of improper elevation or the absence of a reading gauge. At present, the only records that are kept are those of the main sluice. Further down the system, unrecorded "guesstimates" from improvised methods are used for adjusting minor irrigation structures.

Control. Discrepancies between water requirements and actual amounts issued are inherent in irrigation. Some soils are more porous than others, while differences in canal topography. length, and maintenance may mean that two adjacent canals require very different - but hard to assess - amounts of water at their head ends to ensure supplies to their tail ends.

Another factor is the degree of control it is possible to exercise over the water flows. In Zone **2,** from distributary level down to the fields, the vertical sluice-gate inlet structures are adjustable, but they cannot he sufficiently fine-tuned to guarantee the required flow (see footnote **2).** During rainfall of more than 8 centimeters, for example, the main flow can he accurately cut hack for one week to ***50%.*** From the distributaries downward, however, the adjustments can only he approximated, which is likely to starve tail-end distributaries of water. Furthermore, rain-fall is unevenly distributed over Zone **2.** Because data from only one rain gauge are used, canals at the tail ends of the system sometimes dry up.

At turnout level, farmers have difficulty controlling the water issues. During land preparation, the system operates at full capacity, delivering a continuous flow of roughly **30** liters per second to every turnout gate. But the number of farmers under one turnout varies widely, leading to over-irrigation at the smaller turnouts. This, in combination with local drainage problems, causes land to he inundated for several weeks at a time.

Along the field channels, three farmers must share the design flow by using two-outlet boxes, one of which remains half-closed. Such a discrepancy between design and rotational procedure cripples any endeavor to achieve an equitable distribution of water within the turn-out.

Too much water was issued as a palliative for these shortcomings during the wet season 1984-85, and this disguised the need for urgently required construction, reorganization, and maintenance within the system. Other risks attendant on an overgenerous supply of water arc that farmers become wedded to lavish water use and lose their ability to handle water as a scarce commodity or to manage rotational water deliveries. both undoubtedly leading to the creation of vector breeding places.

Once a vector habitat has been identified somewhere in the system, it is difficult to determine whether its occurrence is related to one specific operational feature. Operational short-comings tend to have a cumulative effect. This, however, does not derogate from the general rule that the more carefully the minutely irrigation development is planned and executed, the less likely it is to cause mosquito propagation.

Maintenance. Wherever maintenance of an irrigation system is neglected, water flows will he retarded, areas will he inundated, and other processes favorable to the formation of pools of standing water are likely to take place. Maintenance work in Zone ***2*** is not well-organized, mainly because of the lack of consensus on responsibilities at the institutional and turnout levels.

At the institutional level, the construction of the system by one agency and the subsequent transfer of project management to another has not resulted in effective maintenance. For the first two years after construction, maintenance is the responsibility of the construction agency, hut with construction still in progress in other parts of the System C, and in System B as well, this agency is having difficulty in releasing the manpower and machinery needed for maintenance in Zone ***2.***

At turnout level, the operation, and maintenance of the infrastructure **is** left to the farmers. They elect a farmer-leader to represent them and to see that works are executed according to agreed-upon procedures. The farmer-leader, however, lacks the authority to enforce the rule that every farmer must clean the canal section adjoining his or her paddy plot, so not all farmers do their share of the work. The result is excessive plant growth in the canals, damaged canal bonds, and silted canal beds.

Another factor complicating cooperation at the turnout is hidden tenancy, which makes the ownership of some plots unclear.[15]

On-farm Water Management and ***Crop Husbandry.*** Two methods of rice cultivation are practiced in Zone **2.** One is the "transplanting" method, which uses plant material from a nursery; the other is "direct seeding," by which seeds is broadcast directly on the fields and no transplanting is done.

Farmer's activities in irrigated rice cultivation and the implication of these activities on vector breeding have been extensively studied by the Food and Agriculture Organization (FAO).[16] One important feature appears to be underestimated, however, namely that a farmer's decisions on the sequence of his activities and the techniques he applies to his cultivation and irrigation practices are not taken autonomously. To a large extent, these decisions are constrained by the timely and adequate availability of the necessary inputs: water, labor, traction power, seed, and fertilizer. Thus, basic input provisions must be safeguarded before the farmers can employ cultivation techniques that will minimize the creation of vector breeding places.

Broadcasted paddy fields appear to provide more breeding grounds than transplanted fields because of the absence of a uniform water layer in the first two weeks after seeding and a relatively slow closing of the crop canopy. Nevertheless, a potentially dangerous situation occurs with a transplanted rite crop when a second nursery proves necessary because the first did not provide enough plant material for the full one hectare plot. This leads to an extra three weeks of fallow for the still unplanted but tilled fields.

During our field observations, we found that each cultivation stage maintained its typical breeding habitats. In the pre-cultivation period, often waterlogged, poorly drained, lowland fallow fields arc favorable for mosquito breeding. In the land preparation period, the recently plowed fields form a vast inundated area in which the chances for breeding depend (among other things) on the interval between successive activities. A rule of thumb is that a plowed basin left untouched for ten days or longer (in the climatic circumstances of Zone 2) allows a high percentage of the larvae enough time to develop into adult mosquitoes.

During crop and canopy establishment, the breeding danger is thought to lessen because the vegetative cover hinders the oviposition of female anopheline mosquitoes (see footnote 16). But other water bodies remain: borrow pits, undrained depressions along irrigation canals, seepage ponds, blocked drains. In the wet season of 1984/85, this situation was aggravated by the continuous oversupplies of irrigation water.

After the harvest, when the sluice gates have been closed, the enormous lengths of drying-up canals are particularly attractive for the proliferation of mosquitoes, and the marshy fallow fields constitute a favorable breeding habitat for ***Culex tritaeniorhynchus,*** especially after the first rains have fallen on the decomposing stubble (see footnote 13).

Conclusion

Despite the complexity of relationships between irrigation engineering and the creation of vector breeding places, efficient water management can impede the creation of the latter. It remains to be seen, however, whether a reduction in the breeding potential in Zone **2** will find expression in an actual reduced density of the vector populations. The large area that could not be incorporated into the irrigation system offers alternative breeding grounds that will certainly diminish the effectiveness of any environmental management measures incorporated into the engineering works.

Still, an overall improvement in water management should be an important component in any irrigation project - serving, as'it does, the dual purpose of better control over vector breeding and an increased agricultural productivity. Once water management has been improved, thought can be

[15] Gunawardena, L. 1983. Analysis of Zone 2, System C. Colombo: Mahaweli Economic Agency.

[16] Mather, T H. and Trink Than That. 1984. *Environmental* Management *for Vector* Control *in* Rice Fields. Rome, Italy: FAO Irrigation and Drainage Paper 41

given to more complex environmental management measures for vector control. Given the present technical and organizational level of water management in Zone 2, however, such measures are not yet relevant.

In Sri Lanka, it is now *increasingly being recognized* that the medical profession cannot be held solely responsible for remedial action against the health risks introduced by engineers. What is needed for the long-term control of vector-borne diseases is inter-sectoral collaboration between the engineering and the medical professions - at ministerial level and at project level. This is a prerequisite to the incorporation of preventive measures in the design and management of irrigation projects.

In the process of establishing integrated control of disease vectors in Zone 2 - and in other parts of the Mahaweli Project - irrigation water management would be a good place to start.