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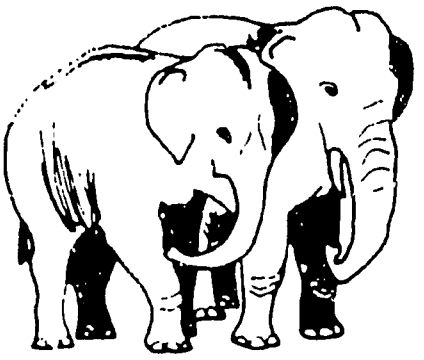


ENVIRONMENTAL ASSESSMENT

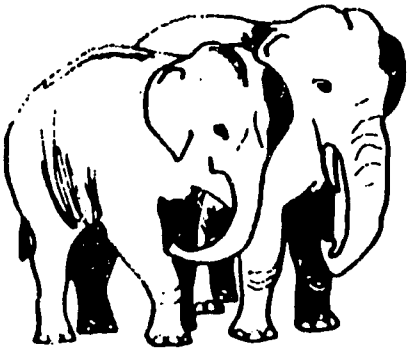
ACCELERATED MAHAWELI DEVELOPMENT PROGRAM

Funded by United States Agency for International Development

OCTOBER 1980

VOLUME III
AQUATIC ENVIRONMENT

Democratic Socialist Republic of Sri Lanka
Ministry of Mahaweli Development



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VOLUME III
AQUATIC ENVIRONMENT

TAMS TIPPETTS-ABBETT-McCARTHY-STRATTON
NEW YORK, NEW YORK

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F. WATER QUALITY

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EXISTING CONDITIONS

GENERAL

The available water quality data for the project area are compiled in Table F-1 for rivers and streams, Table F-2 for tanks, villus and lagoons and Table F-3 for groundwater. These data were obtained from a number of sources which are coded on Tables F-1, F-2 and F-3 as follows:

Code		Source
1	-	U. S. Operations Mission (1961)
2	-	Amarasiri (1965)
3	-	Amarasiri (1972)
4	-	Pattiaratchi and de Silva (1972)
5	-	Water Resources Bureau (1979)
6	-	Ceylon Association of Science, Presidential Address
7	-	Government Analyst's Department (records)
8	-	Irrigation Department (records)
9	-	National Water Supply and Drainage Board (records)
10	-	Dr. G. Shut (field notes)
11	-	TAMS (samples collected by TAMS in November 1979 and analysed by Occupational Hygiene Division of the Labor Department and by the Irrigation Department)
12	-	Schiemer (1979)

Localities of the surface water collections, according to the above listed sources, are graphically depicted on Figure F-1. Groundwater sampling stations are not included on Figure F-1, because the well and bore-hole locations have not been clearly defined. (Figures and Tables are located at the back of this TOPIC REPORT.)

There have been very few comprehensive, sustained water quality studies conducted for surface waters or groundwater in the Mahaweli Accelerated Development area. The most detailed studies involving seasonal analyses for selected water quality parameters were completed by the U. S. Operations Mission (1961) for single stations on the Upper Mahaweli Ganga, the Amban Ganga (at Elahera) and a few of the large irrigation tanks; by Amarasiri (1972) for some major irrigation tanks; and by the Government Analyst's Department at the Kotmale Dam Site. The data provided by Schiemer (1979) are the result of analyses conducted during the initial phase of a detailed limnological survey of Parakrama Samudra sponsored by UNESCO through the Limnological Institute of the Austrian Academy of Science. Consequently, the data presented here from this project are preliminary in nature. The survey has recently concluded, and the complete seasonal results should become available late this year. The remainder of the water quality data are derived from occasional isolated samples collected for analysis from various locations in the project area (Figure F-1).

IRRIGATION USE

Criteria have been recommended for the classification of the quality of water for irrigation use by the U.S. Department of Agriculture or USDA (1954) and the FAO (Ayers and Westcot 1976). These criteria are summarized in Tables F-4, F-5 and F-6.

Generally, the more commonly occurring problems with the quality of irrigation supplies are associated with high levels of salinity (as measured by electrical conductivity) and/or a high proportion of sodium in comparison with other inorganic constituents - chiefly, calcium, magnesium and bicarbonate.

Salinity

Salinity problems arise if salts from the applied irrigation water accumulate in the crop root zone, resulting in a reduction in yields. With shallow water tables, salinity problems may also occur due to upward movement of water and salts from the groundwater as the water evaporates from the soil or is used by the crop.

For most crops, salinity problems, due to the quality of the irrigation water, do not occur at electrical conductivity levels of less than 750 micromhos/cm. Detailed conductivity criteria are presented in Tables F-4, F-5 and F-6.

Sodium Problem Evaluation

In irrigation supplies, a high level of sodium in relation to other ions can result in the formation of alkali soils with very low permeability. The most common method of evaluating the relative amount of sodium in the water has been with the calculation of the Sodium Adsorption Ratio (SAR), described by USDA (1954) as the following:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where Na = Sodium in meg/l and Ca + Mg = Calcium plus Magnesium in meg/l. Problems do not usually occur with waters having SAR values up to about 10.

Permeability problems are also related to the carbonate (CO_3) and bicarbonate (HCO_3) content in the irrigation water. In waters containing high concentrations of bicarbonate there is a tendency for calcium and magnesium to precipitate as carbonates and, as their levels are reduced, the relative proportion of sodium is increased. This effect has usually been evaluated by the determination of the Residual Sodium Carbonate (RSC) method which involves the use of following formula:

$$RSC = (CO_3 + HCO_3) - (Ca + Mg)$$

Water with an RSC value of more than 2.5 is usually considered unsuitable for irrigation purposes.

Bicarbonate levels of as low as 1.5 can also cause problems when fruit crops are sprinkle irrigated during periods of very low humidity and high evaporation (Ayers and Westcot 1976). Under these conditions, white deposits are formed on the fruit or leaves which reduces the marketability of the produce.

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Table F - 1

Water Quality from the Project Area

Rivers and Streams

Sample Location	Date	Source	Temp. °C	D.O. mg/l	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l As	B	Fe	meq/l Ca	Mg	Na	K	CO_3	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	PO_4	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Mahaweli Ganga at Ginigathena	None	6			6.8	10	15	10.5*	14.5*											0.17								C1	
Mahaweli Ganga at Ginigathena	10/79	11	24.5	7.8	7.6		32																					C1	
Mahaweli Ganga at Ulapane	10/79	11	23.5	7.0	7.1		30																					C1	
Mahaweli Ganga at Peradeniya	5/78	9			7.0	15	35	24		25.5			5.0					0.22*		0.23	T	0.08						C1	High Fe
Mahaweli Ganga at Peradeniya	4/79	9			7.6	33	78	53		18			0.6					0.80*		0.23	T	-						C1	
Mahaweli Ganga at Getambe	None	6			6.8	15	20	14*	26*											0.11								C1	
Mahaweli Ganga at Primrose Hills	11/60	1			7.6		35							0.15+		0.14	0.13									0.51		C1-S1	
Mahaweli Ganga at Primrose Hills	12/60	1			7.7		50																					C1	
Mahaweli Ganga at Primrose Hills	1/61	1			7.5		60																					C1	
Mahaweli Ganga at Primrose Hills	3/61	1			7.4		55																					C1	
Mahaweli Ganga at Primrose Hills	4/61	1			6.9		35																					C1	
Mahaweli Ganga at Primrose Hills	5/61	1			7.6		35																					C1	
Mahaweli Ganga at Primrose Hills	6/61	1			7.3		30							0.34+		0.08	0.03									0.19		C1-S1	
Mahaweli Ganga at Primrose Hills	7/61	1			7.0		40							0.25+		0.11	0.02									0.31		C1-S1	
Mahaweli Ganga at Polgolla	5/79	9			6.2	25	115	74		64			1.6					0.72*		0.39	T	0.13						C1	Low pH, High Fe
Mahaweli Ganga at Polgolla	6/79	9			7.2		45	30		20			0.4					0.40*		0.28	T	-						C1	
Mahaweli Ganga at Polgolla	7/79	9			7.4	12	52	34		15			1.2					0.40*		0.23	T	0.55						C1	High NH_3
Mahaweli Ganga at Ukuwela Power Outlet	5/79	9			7.0	20	45	30		8			0.7					0.16*		0.34	T	-						C1	
Mahaweli Ganga at Victoria Dam Site	11/79	11	24.5	8.0	6.8		60							0.35	0.13	0.12		0.61							0.13	0.24	0.10	C1-S1	

(continued)

Table F - 1
(Continued)

Sample Location	Date	Source	Temp. °C	D.C. mg/l	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l As	B	Fe	meq/l Ca	Mg	Na	K	CO_3	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	PO_4	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Hulu Ganga at Teldeniya	None	6			7.0	25	40	28*	20*											0.20								C1	
Ma Oya at Hunasgiriya	None	6			7.0	10	27	18.9*	13.1*											0.23								C1	
Kurudu Oya at Watumulla	6/79	9			7.0	20	35	24		6			0.50						0.26*	0.17		T	0.04					C1	
Ulhitiya Oya near Beligalla	11/79	11	27	7.4	7.2		158							0.84	0.31	0.46		-	1.73						0.58	0.61	0.79	C1-S1	High HCO_3
Amban Ganga at Elahera	11/60	1			7.4		75	60						0.21+		0.17	0.09									0.52		C1-S1	
Amban Ganga at Elahera	12/60	1			7.7		175	110																				C1	
Amban Ganga at Elahera	1/61	1			7.7		170	105																				C1	
Amban Ganga at Elahera	2/61	1			7.6		110	70						0.02+		0.17	0.05									1.08		C1-S1	
Amban Ganga at Elahera	3/61	1			5.0		200	125																				C1	Low pH
Amban Ganga at Elahera	4/61	1			8.1		225	146																				C1	
Amban Ganga at Elahera	5/61	1			8.0		200	125																				C1	
Amban Ganga at Elahera	6/61	1			7.7		180	115						1.92+		0.31	0.04									0.32		C1-S1	
Amban Ganga at Elahera	7/61	1			8.0		170	105						1.75+		0.20	0.03									0.21		C1-S1	
Amban Ganga at Elahera	4/79	10	29		7.3		270																					C2	
Amban Ganga at Elahera	11/79	11	26	7.8	7.0		82							0.52	0.24	0.14		-	0.98						0.22	0.23	0.21	C1-S1	
Amban Ganga at Rattota	None	6			7.0	15	40	28*	24*											0.14								C1	
Amban Ganga at Rattota	1972	4					100																			1.00		C1-S1	
Amban Ganga at Rattota	4/79	10	26		6.3		108																					C1	
Trib. to Amban Ganga at Naula	4/79	10	30.5		7.3		370																					C2	

(continued)

Best Available Document

Table F - 1
(Continued)

Sample Location	Date	Source	Temp. °C	D.O. mg/l	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l As	B	Fe	meq/l Ca	Mg	Na	K	CO_3	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	PO_4	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Mahaweli Ganga at Mahiyangana	11/79	11	26	7.7	7.0		95							0.53	0.22	0.15		-	1.15						0.40	0.24	0.24	C1-S1	
Mahaweli Ganga at Manampitiya	4/79	7			8.0	50	181*	127*	110		<0.02	0.20	12	0.85	0.16	0.65+		-	1.29	0.28	4			0.04	0.28	0.91	1.00	C1-S1	High Fe
Mahaweli Ganga at Manampitiya	11/79	11	28	7.2	6.8		90							0.53	0.22	0.21		-	0.94						0.19	0.34	0.27	C1-S1	
Mahaweli Ganga near Chundankadu	11/79	11	30	5.4	7.0		132							0.66	0.34	0.22		-	1.35						0.35	0.31	0.34	C1-S1	
Mahaweli Ganga at Mutur	11/79	11	29.5	5.4	7.0		2120							1.23		13.2		-	1.81									C3	High HCO_3, salinity
Mahaweli Ganga-East Fork at Verugal	11/79	11	29	5.7	6.9		107							0.50	0.20	0.18		-	1.15						0.45	0.30	0.27	C1-S1	
Kotmale Oya at Dam site	3/63	7			7.2	14	40	35	35	45									0.24	0.17		T	0.02					C1	
Kotmale Oya at Dam site	6/63	7			7.2	10	35	25	20	10									0.20	0.17		T	0.01					C1	
Kotmale Oya at Dam site	6/63	7			6.4	10	50	40	90	140									0.20	0.28		T	0.04					C1	Low pH
Kotmale Oya at Dam site	3/70	7			7.2		50	22	20	8			1.2						0.16	0.17		T	0.26					C1	High NH_3
Kotmale Oya at Dam site	9/77	7			7.2	9	18	17					-	0.10	0.08	0.23+			0.16	0.20	3				-	0.77	-	C1-S1	
Kotmale Oya at Dam site	12/77	7			6.7	10	19	13					0.3	0.46	0.04	0.25+			0.18	0.23	3				-	0.50	-	C1-S1	
Kotmale Oya at Dam site	10/78	7			6.7	10	27	24					<.05	0.12	0.07	0.33+			0.30	0.17	3				0.11	1.07	-	C1-S1	
Kotmale Oya at Dam site	10/79	11	22.5	8.2	7.0		32.5																					C1	
Kotmale Oya at Talawakelle	None	6			7.1	10	15	10.5*	9.5*											0.14								C1	
Kotmale Oya at Talawakelle	10/79	11	21	8.6	7.1		30																					C1	
Trib. to Kotmale Oya at Ramboda	None	6			7.0	10	12	8.4*	11.6*											0.14								C1	
Trib. to Kotmale Oya at Ramboda	10/79	11	20	8.2	7.0		16																					C1	
Trib. to Mahaweli Ganga at Mt. Pleasant	None	6			7.0	10	40	28*	18*											0.17								C1	
Hulu Ganga at Haduliele	4/79	10	24.5		7.2		49																					C1	

(continued)

Table F - 1
(Continued)

Sample Location	Date	Source	Temp. °C	D.O. mg/l	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l As	B	Fe	meq/l Ca	Mg	Na	K	CO_3	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	PO_4	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Maduru Oya near Wagawatta	11/79	11	27	7.5	7.2		82							0.40	0.19	0.34			- 1.03						0.44	0.63	0.57	C1-S1	
Maduru Oya at Dam site	4/79	7			7.8	23	136*	95*	95		<.02	0.10	10	0.30	0.16	0.87+			1.29	0.28	2		0.08		0.83	1.81	1.45	C1-S1	High Fe
Maduru Oya at Dam site	5/79	7			7.3	53	227*	159*	6		<.01	<0.10	0.16	0.62	0.44	1.42+			1.70	0.71	4		0.08		0.64	1.95	2.15	C1-S1	High HCO_3
Maduru Oya at Welikanda	11/79	11	29.5	5.4	7.4		300							0.92	0.42	0.76			- 1.77						0.43	0.93	1.21	C2-S1	High HCO_3
Maduru Oya at Valaichchenai	11/79	11	31.5	7.1	6.9		1700							1.21		12.6			- 1.73									C3	High HCO_3, salinity

* = Calculated
T = Trace
+ = Combined values

Table F - 2

Water Quality from the Project Area

Tanks, Villus and Lagoons

Sample Location	Date	Source	Tem. °C	D.O. mg/l	pH	Hard. mg/l	E.C.	TDS mg/l	Tur. JTU	Si (mg/l)	Al (mg/l)	As (mg/l)	B (mg/l)	Fe (mg/l)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	CO_3 (meq/l)	HCO_3 (meq/l)	Cl (meq/l)	SO_4 (mg/l)	NO_3 (mg/l)	PO_4 (mg/l)	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Upaar Lagoon	11/79	11	31	7.1	7.5		32430													3.29									High HCO_3 salinity
Gengala Villu	11/79	11	29	3.7	6.7		175								0.68	0.36	0.69			1.64					0.60	0.96	1.15	C1-S1	High HCO_3
Karapola Villu	11/79	11	31	5.7	6.7		260								0.84	0.42	1.00			1.56					0.30	1.26	1.51	C2-S1	High HCO_3
Kutugalla Villu	11/79	11	32	6.4	6.8		875								1.68	1.21	1.60			1.07					-	1.33	1.86	C3-S1	High salinity
Velankada Villu	11/79	11	32	5.0	7.1		500								2.48	1.80	1.40		0.41	5.27					0.99	0.96	2.11	C2-S1	High HCO_3
Velankada Villu Inlet Stream	11/79	11	30	5.9	7.3		180								0.94	0.51	0.30		-	2.06					0.61	0.35	0.49	C1-S1	High HCO_3
Horabora Wewa	11/79	11	32	9.6	8.1		175								0.64	0.35	0.77		-	1.93					0.94	1.09	1.31	C1-S1	High HCO_3
Giranduru Kotte Tank	11/79	5			7.4	134	300	276							1.70	0.99	0.72			3.21	0.20	T	T		0.52	0.62	1.12	C2-S1	High HCO_3
Allai Tank	11/79	11	30.5	4.7	7.7		525								0.90	0.42	0.63		-	1.85					0.53	0.78	1.01	C2-S1	High HCO_3
Pimburettawa Tank	5/79	7			7.0	57	194*136*	1				<0.01	<0.1	0.08	0.72	0.41	1.06			1.70	0.48	1.5		0.04	0.57	1.41	1.55	C1-S1	High HCO_3
Vakaneri Tank	11/79	11	33.5	11.0	8.4		425								0.79	0.39	1.20		-	1.73					0.55	1.56	1.87	C2-S1	High HCO_3
Parakrama Samudra	11/60	1			7.9		190	120								0.42+	0.19	0.08								0.41		C1-S1	
Parakrama Samudra	12/60	1			7.4		190	120																				C1	
Parakrama Samudra	1/61	1			7.4		190	120																				C1	
Parakrama Samudra	2/61	1			7.5		160	100								0.29+	0.26	0.05								0.68		C1-S1	
Parakrama Samudra	3/61	1			7.9		180	112																				C1	
Parakrama Samudra	4/61	1			8.0		190	120																				C1	
Parakrama Samudra	5/61	1			7.7		200	125																				C1	
Parakrama Samudra	6/61	1			7.9		200	125								2.07+	0.45	0.07								0.44		C1	
Parakrama Samudra	7/61	1			8.5		225	146								2.22+	0.40	0.06								0.38		C1	
Parakrama Samudra	8/65 8/66	3			8.2		221		9.55						1.12	0.78	0.37	0.09		2.22	0.24	3.0			0.32	0.38	0.57	C1-S1	Averages of 1 yr samples High HCO_3
Parakrama Samudra	12/65 2/66	3					175																					C1	Average
Parakrama Samudra	6/66 8/66	3					263																					C2	Average
Parakrama Samudra	11/79	11	30	7.3	7.7		165								0.92	0.49	0.27			2.14					0.73	0.32	0.48	C1-S1	High HCO_3
Parakrama Samudra Downstream Irrigation water	5/64 4/65	2			8.1		225		8.90	0.02				0.02	1.06	0.84	0.38	0.06		2.25	0.36		0.02		0.35	0.39	0.62	C1-S1	Average of 1 yr samples High HCO_3
Parakrama Samudra Inflow	8/79 9/79	12	27.9		8.4		148								0.70	0.68	0.19	0.03		2.74	0.20		35.85	0.06	1.36	0.23	0.37	C1-S1	High HCO_3
Main Lake			28.2		8.8		169								0.94	0.71	0.31	0.04		1.38	0.25		12.84	0.09	-	0.34	0.44	C1-S1	
Outflow			28.1		8.5		166								0.85	0.75	0.32	0.05		1.42	0.37		13.55	0.09	-	0.36	0.47	C1-S1	

(continued)

Table F - 2
(Continued)

Sample Location	Date	Source	Tem. °C	D.O. mg/l	pH	Hard. mg/l	TDS mg/l	Turb. JTU	Si (mg/l)	Al (mg/l)	As (mg/l)	B (mg/l)	Fe (mg/l)	Ca (meq/l)	Mg (meq/l)	Na (meq/l)	K (meq/l)	CO_3 (meq/l)	HCO_3 (meq/l)	Cl (meq/l)	SO_4 (mg/l)	NO_3 (mg/l)	PO_4 (mg/l)	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Minneriya Tank	11/60	1			8.4	250	160							1.05+		0.64	0.29											
Minneriya Tank	12/60	1			8.0	230	148																		0.08		C2-S1	
Minneriya Tank	1/61	1			7.9	200	125																				C1	
Minneriya Tank	2/61	1			7.8	220	145																				C1	
Minneriya Tank	3/61	1			7.6	250	160							1.78+		0.31	0.07								0.33		C1-S1	
Minneriya Tank	4/61	1			7.9	250	160																				C2	
Minneriya Tank	5/61	1			8.0	250	160																				C2	
Minneriya Tank	6/61	1			8.1	250	160							2.19+		1.33	0.16										C2	
Minneriya Tank	7/61	1			8.3	250	160							2.25+		1.20	0.14								1.27		C2-S1	
Minneriya Tank	8/65 8/66	3			8.2	240		6.70						1.20	1.09	0.44	0.11		2.52	0.39	3.5			0.23	1.13		C2-S1	
																									0.41	0.70	C1-S1	Average of 1 yr samples High HCO_3
Minneriya Tank	12/65 2/66	3				191																						
Minneriya Tank	6/66 8/66	3				312																					C1	Average
																											C2	Average
Minneriya Tank	11/79	11	30.5	8.2	7.1	95								0.52	0.29	0.17		-	1.15									
Minneriya Tank Downstream Irrigation water	5/64 4/65	2			8.0	272		6.35	0.05				0.04	1.11	1.13	0.58	0.08		2.52	0.54		0.05		0.34	0.27	0.57	C1-S1	
																								0.28	0.55	0.88	C2-S1	Average High HCO_3
Kaudulla Tank	11/79	11	29	6.3	7.2	155								0.81	0.45	0.30			1.61					0.35	0.38	0.49	C1-S1	High HCO_3
Kantalai Tank	8/65 8/66	3			8.0	218		4.80						0.88	0.82	0.43	0.13	-	1.97	0.45	4.0			0.26	0.47	0.66	C1-S1	Average of 1 yr samples High HCO_3
Kantalai Tank	12/65 2/66	3				163																						
Kantalai Tank	6/66 8/66	3				286																					C1	Average
																											C2	Average
Kantalai Tank	11/79	11	32	7.7	6.9	162								0.73	0.51	0.31			1.81					0.57	0.39	0.55	C1-S1	High HCO_3

* = Calculated
T = Trace
\+ = Combined values

Table V - 3

Water Quality from the Project Area

Groundwater

Sample Location	Date	Source	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l Fe	meq/l Ca	Mg	Na	K	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Mahiyangana Bore hole	6/79	9	6.8		225	150		16	1.0					3.60*	0.34		T					C1	High HCO_3, Fe
System C Well 5	8/78	8	8.4		423					2.42	2.50	0.88	0.07	5.28	0.49				0.36	0.56	1.29	C2-S1	High HCO_3
System C Well 6	8/78	8	6.5		138					0.34	0.21	1.15	0.03	1.08	0.55				0.53	2.19	1.53	C1-S1	
System C Well 7	8/78	8	7.7		169					0.55	0.25	0.89	0.05	1.17	0.73				0.37	1.41	1.27	C1-S1	
System C Well 8	8/78	8	7.5		176					0.32	0.69	0.71	0.10	0.78	1.03				-	1.00	0.80	C1-S1	
System C Well 9	8/78	8	7.6		114					0.34	0.38	0.80	0.05	0.83	0.24				0.11	1.33	1.20	C1-S1	
System C Well 10	8/78	8	7.6		85					0.42	0.11	0.50	0.01	0.98	1.25				0.45	0.97	0.68	C1-S1	
System C Well 11	8/78	8	8.1		367					1.55	1.29	1.90	0.04	1.56	0.97				-	1.59	2.54	C2-S1	High HCO_3
System C Well 12	8/78	8	8.1		578					1.02	1.08	1.70	0.03	6.65	1.03				4.55	1.66	3.32	C2-S1	Very high RSC; High Adj. SAR, HCO_3
System C Well 13	8/78	8	7.4		104					0.53	0.06	0.46	0.01	1.17	0.24				0.58	0.85	0.68	C1-S1	
System C Well 14	8/78	8	7.3		106					0.42	0.28	0.71	0.02	1.76	0.73				1.06	1.20	1.44	C1-S1	High HCO_3
System C Well 16	8/78	8	8.1		176					0.55	0.62	1.10	0.02	2.35	0.49				1.18	1.44	2.02	C1-S1	High HCO_3
System C Well 17	8/78	8	7.9		155					0.69	0.57	0.58	0.02	1.78	0.73				0.52	0.73	0.95	C1-S1	High HCO_3
System C Well 18	8/78	8	7.9		367					0.81	3.39	2.00	0.03	3.72	1.03				-	1.38	2.90	C2-S1	High HCO_3
System C Well 19	8/78	8	8.2		324					2.04	1.31	0.75	0.05	3.72	0.97				0.37	0.58	1.16	C2-S1	High HCO_3
System C Well 20	8/78	8	7.4		190					0.64	1.06	0.49	0.02	2.32	0.97				0.62	0.53	0.80	C1-S1	High HCO_3
System C Well 21	8/78	8	7.8		310					0.76	1.23	1.80	0.04	3.33	0.85				1.34	1.80	3.06	C2-S1	High RSC, HCO_3, Adj. SAR

(continued)

Table F - 3
(Continued)

Sample Location	Date	Source	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l Fe	meq/l Ca	Mg	Na	K	HCO_3	Cl	mg/l SO_4	NO_3	NH_3	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
System C Well 1	7/79	5	7.2	198	400	373				2.15	1.81	1.09	0.08	4.41	0.31	T	-		0.45	0.77	1.62	C2-S1	High HCO_3
System C Well 3	7/79	5	7.0	158	460	359				2.25	0.90	1.70	0.05	3.88	0.70	T	-		0.73	1.35	2.70	C2-S1	High HCO_3
System C Well 6	7/79	5	7.0	107	300	242				1.65	0.49	1.00	0.05	2.72	0.34	T	-		0.58	0.97	1.55	C2-S1	High HCO_3
System C Well 7	7/79	5	6.8	91	250	183				1.00	0.82	0.83	-	2.02	0.31	-	-		0.20	0.87	1.31	C2-S1	High HCO_3
System C Well 11	7/79	5	7.4	150	370	310				1.85	1.15	0.96	-	3.33	0.28	24.0	-		0.33	0.78	1.48	C2-S1	High HCO_3
System C Well 12	7/79	5	6.4	72	180	156				0.70	0.74	0.78	-	1.79	0.17	-	-		0.35	0.92	1.29	C2-S1	High HCO_3, Low pH
System C Well 14	7/79	5	7.6	208	1600	1284				1.35	2.80	11.96	0.69	13.37	0.25	96.1	-		9.22	8.30	20.75	C3-S2	Very high RSC, Adj. SAR, HCO_3, salinity
System C Well 16	7/79	5	6.2	60	170	142				0.30	0.90	0.78	-	1.59	0.27	-	-		0.39	1.01	1.21	C1-S1	High HCO_3, Low pH
System C Well 17	7/79	5	6.4	60	200	182				0.55	0.66	0.96	0.08	2.10	0.28	-	-		0.89	1.23	1.60	C1-S1	High HCO_3, Low pH
System C Well 4	7/79	5	6.8		500																	C2	
System C Well 10	7/79	5	6.0		500																	C2	Low pH
System C Well 20	7/79	5	6.6		750																	C3	
System C Well 22	7/79	5	6.6		570																	C2	
Polonnaruwa Well	None	6	8.1	300	600	420*	18*		0.10						0.82		T	0.01				C2	
Polonnaruwa Well	None	6	7.4	260	480	336*	96*								0.65							C2	
Kaduruwela Well	None	6	7.4	355	480	336*	96*								0.65							C2	
Kaduruwela Well	None	6	7.2	390	650	455*	35*								1.18							C2	

(continued)

Table P - 3
(Continued)

Sample Location	Date	Source	pH	Hard. mg/l	E.C.	TDS mg/l	SS mg/l	Turb. JTU	mg/l Fe	meq/l Ca	Mg	Na	K	HCO_3	Cl	mg/l SO_4	PO_3	NH_3	RSC	SAR	Adj. SAR	Agri. Use Class	Comments
Hingurakgoda Well	None	6	8.1	95	200	140*	0*								0.31							C1	
Hingurakgoda Well	None	6	7.2	850	1500	1050*	210*								7.62							C3	High Cl, High salinity
Hingurakgoda Well	None	6	7.2	685	1700	1190*	280*								14.11							C2	Very high Cl, High salinity
Hingurakgoda Well	1972	4			500															0.20		C2-S1	
Nimmeriya Well	1972	4			300															0.80		C2-S1	
Dutch Point Well	None	6	7.2	300	600	420*	5*								2.14							C2	
Trincomalee Well	None	6	7.2	255	1250	875*	65*								6.32							C3	High Cl, salinity
Trincomalee Well	None	6	8.2	825	7500	5250*	410*								59.24							-	Very high Cl, salinity
Valichchenai Well	None	6	7.7	145	350	245*	100*								0.87							C2	
Palamunmadu Well	None	6	7.4	300	500	350*	62*								1.04							C2	
Batticaloa Well	None	6	7.6	250	500	350*	14*								1.24		-	0.03				C2	
Batticaloa Well	None	6	7.8	650	5000	3500*	0*								47.96							C4	Very high Cl, salinity
Kallady Well	None	6	7.2	60	125	88*	38*								0.34							C1	

* = Calculated
T = Trace

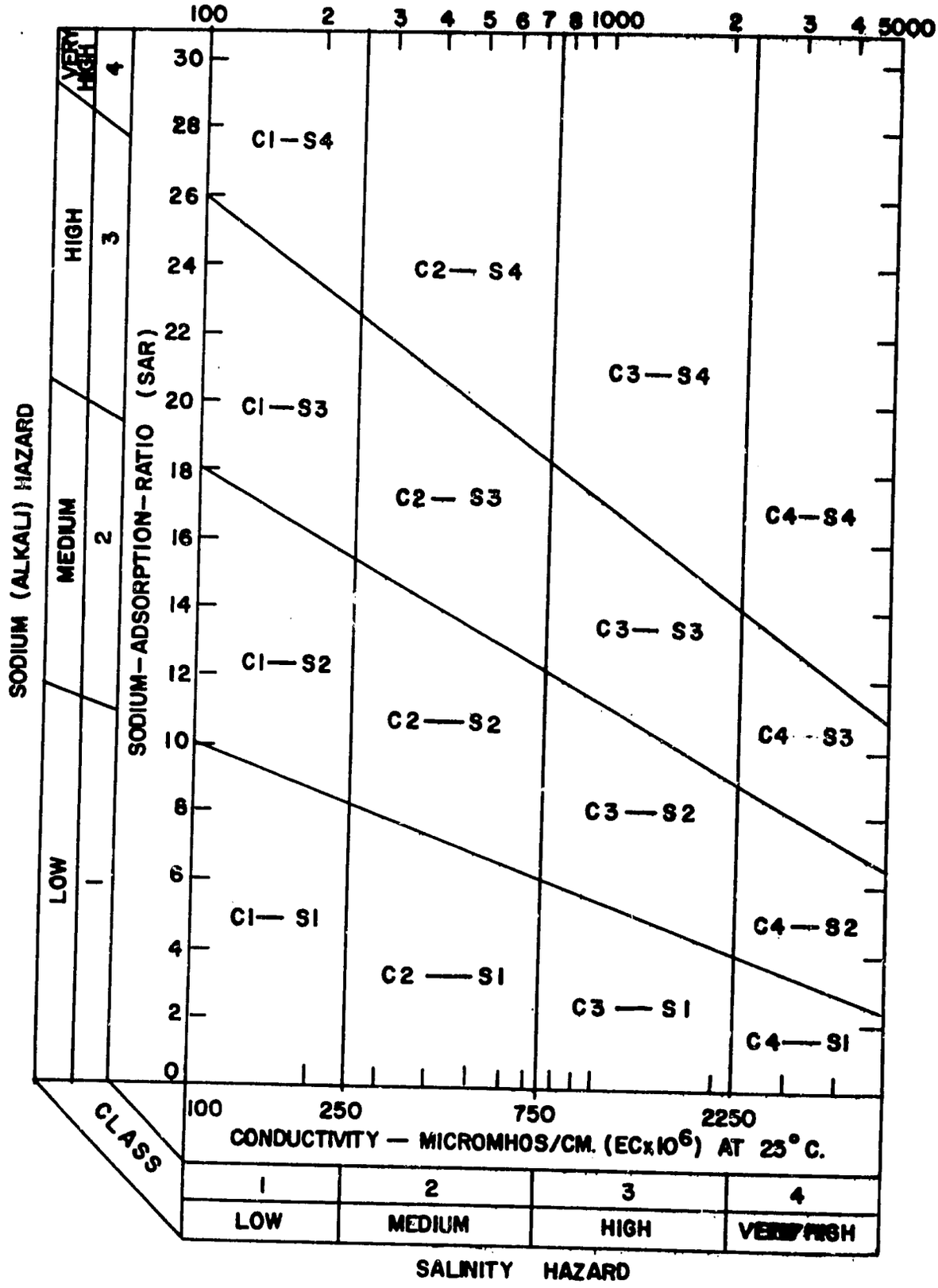

DIAGRAM FOR THE CLASSIFICATION OF IRRIGATION WATER FROM THE U.S. DEPARTMENT OF AGRICULTURE (1954). SEE FOLLOWING TABLE F-5 FOR DEFINITIONS.

TABLE F-4

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Table F - 5

Significance and Interpretation of Quality Class Ratings Presented in Table F - 4 and for Residual Sodium Carbonate

SALINITY

Low-salinity water (C1) can be used for irrigation with most crops on most soils with little likelihood that soil salinity will develop. Some leaching is required, but this occurs under normal irrigation practices except in soils of extremely low permeability.

Medium-salinity water (C2) can be used if a moderate amount of leaching occurs. Plants with moderate salt tolerance can be grown in most cases without special practices for salinity control.

High-salinity water (C3) cannot be used on soils with restricted drainage. Even with adequate drainage, special management for salinity control may be required and plants with good salt tolerance should be selected.

Very high salinity water (C4) is not suitable for irrigation under ordinary conditions, but may be used occassionally under very special circumstances. The soils must be permeable, drainage must be adequate, irrigation water must be applied in excess to provide considerable leaching, and very salt-tolerant crops should be selected.

SODIUM

Low-sodium water (S1) can be used for irrigation of almost all soils with little danger of the development of harmful levels of exchangeable sodium. However, sodium sensitive crops such as stone-fruit trees and avocados may accumulate injurious concentrations of sodium.

Medium-sodium water (S2) will present an appreciable sodium hazard in fine-textured soils having high ion-exchange capacity, especially under low-leaching conditions, unless gypsum is present in the soil. The water may be used on coarse-textured or organic soils with good permeability.

High-Sodium water (S3) may produce harmful levels of exchangeable sodium in most soils and will require special soil management-good drainage, high leaching, and organic matter additions. Gypsiferous soils may not develop harmful levels of exchangeable sodium from such waters. Chemical amendments may be required for replacement of exchangeable sodium, except that amendments may not be feasible with waters of very high salinity.

Very High Sodium Water (S4) is generally unsatisfactory for irrigation purposes except at low and periodic mediur salinity, where the solution of calcium in the soil or use of gypsum or other amendments can make the use of these waters feasible.

RESIDUAL SODIUM CARBONATE

Level (meq/l)	Classification
< 1.25	Generally safe for irrigation use
1.25-2.50	Marginal for irrigation use
> 2.50	Not suitable for irrigation purposes

Source : U.S. Department of Agriculture (1954)

Table F - 6
Guidelines for the Interpretation of Water Quality for Irrigation.
From Ayers and Westcot (1976) for the FAO.

Irrigation Problem	Degree of Problem		
	No problem	Increasing Problem	Severe Problem
Salinity			
EC (micromhos/cm)	< 750	750-3000	>3000
Specific ion toxicity (affects sensitive crops)			
Sodium (Adj. SAR)	< 3	3-9	> 9
Chloride (meq/l)	< 4	4-10	> 10
Boron (mg/l)	< 0.75	0.75-2.0	> 2.0
Miscellaneous effects (affects susceptible crops)			
NO_3-N (or) NH_4-N (mg/l)	< 5	5-30	> 30
HCO_3 (meq/l) - overhead sprinkling	< 1.5	1.5-8.5	> 8.5
pH	Normal Range	6.5 - 8.4	
Recommended maximum levels			
For selected trace elements			
Aluminium - Al (mg/l)	5.0		
Arsenic - As (mg/l)	0.1		
Iron - Fe (mg/l)	5.0		

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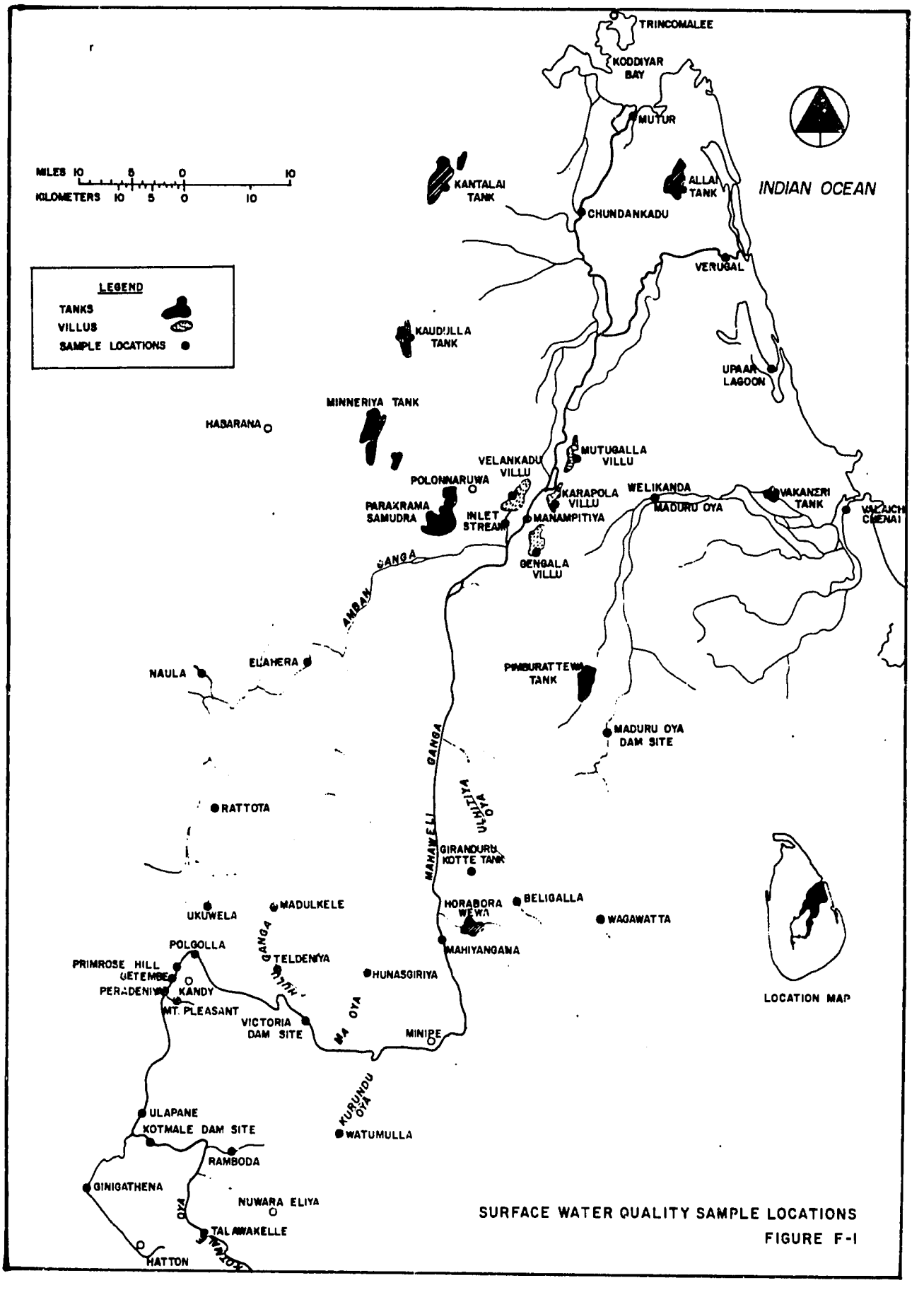

SURFACE WATER QUALITY SAMPLE LOCATIONS
FIGURE F-1

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A refined procedure for estimating potential sodium hazards which combines the concepts of SAR and RSC has been suggested by FAO (Ayers and Westcot 1976). This involves a calculation of an Adjusted Sodium Adsorption Ratio (Adj. SAR) as follows:

$$\text{Adj. SAR} = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}} \cdot \left[1 + (8.4 - pHc)\right]$$

where pHc = $(pk_2 - pkc) + p(Ca + Mg) + p(Alk)$, and
$(pk_2 - pkc)$ is obtained from using the sum of Ca + Mg + Na in meg/l;
p(Ca + Mg) is obtained from using the sum of Ca + Mg in meg/l; and
p(Alk) is obtained from using the sum of $CO_3 + HCO_3$ in meg/l.

The $(pk_2 - pkc)$, p(Ca + Mg) and p(Alk) values are then converted to standardized units (Ayers and Westcot 1976) before determining the pHc. The pHc is a theoretical, calculated pH of the irrigation water.

Rivers and Streams

From the existing river and stream data (Table F-1) the waters of the Mahaweli Ganga, Kotmale Oya, Amban Ganga and Maduru Oya are at present well suited for irrigation use. These waters are characterized by very low RSC, SAR and Adj. SAR values. They also exhibit low mineral content or salinity as evidenced by the conductivity levels. Most of the conductivity levels, especially from the Mahaweli Ganga, are less than 200 micromhos/cm. Water from the Amban Ganga and Maduru Oya has significantly higher mineral content than that found in the Mahaweli Ganga. However, the data are limited, and most of the information pertaining to the Mahaweli Ganga is from the upstream hilly areas where salt levels in most flowing waters are typically low.

As expected, salinity levels near the mouths of the Mahaweli Ganga (Mutur) and Maduru Oya (Valaichchenai) are comparatively high due to tidal effects. Although these locations are represented by single samples, the salinity levels apparently would not, at times, limit use of these waters for irrigation purposes provided that the crops were relatively salt tolerant and adequate drainage was provided.

A few of the crop toxicity criteria (Table F-6) are exceeded in occasional samples collected from the rivers and streams of the project area. The most conspicuous of these are the exceptionally high iron levels found in the Mahaweli Ganga at Manampitiya and in the Maduru Oya at the Dam Site. However, this may not be a common phenomena since a second sample at the Maduru Oya Dam Site had a very low iron level.

Tanks, Villus and Lagoons

In general, the water quality in the project area tanks indicates that these water supplies are presently suitable for irrigation use.

Low RSC, SAR and Adj. SAR values are found for all of the tanks. However, a few of the tanks exhibit some elevated salinity levels, particularly at the Allai Tank and the Vakaneri Tank both of which are downstream tanks located near the coast. Other tanks including the Parakrama Samudra, the Kantalai Tank and especially the Minneriya Tank exhibit occasional salinity levels which slightly exceed the C 1 classification according to the USDA (1954). Tanks in general, have a much higher mineral content than that in the adjacent rivers and streams in the region. In addition, the seasonal measurements made by Amarasiri (1972) clearly show the effect on increasing tank salinities of the drawdown and the increased evaporation rates during the dry season months.

Villus generally have waters which are suitable for most irrigation purposes, although high salinities are often found as a result of high evaporation during the extensive drawdown periods which occur annually. The salinity level in the Upaar Lagoon precludes its use for irrigation, which is expected due to its direct ocean connection. However, the salinity levels here are undoubtedly higher than they normally would be due to the presence of the low culvert bridge at the lagoon entrance. This impedes normal tidal flushing of the lagoon, and combined with high evaporation rates, results in an unusually elevated salt content.

Groundwater

Most of the wells sampled exhibit properties which are suitable for irrigation use. However, several of the wells from System C, including Well 12 (sampled 8/78) and Well 14 (sampled 7/79), had high salinity levels and very high RSC, SAR or Adj. SAR values which would probably prevent their use in most circumstances for irrigation.

Similarly, several coastal wells, notably at Trincomalee and Batticaloa, had very high salinity levels which would limit their use for irrigation. Aquifers here are undoubtedly being recharged, at least partially, with sea water.

Well samples near Hingurakgoda also exhibited a relatively high saline content with the result that chloride concentrations are elevated which could cause some crop toxicity problems.

LIVESTOCK AND DOMESTIC USE

Based on the recommended toxic substance criteria of the National Academy of Sciences and National Academy of Engineering (1972) and of the U.S. Environmental Protection Agency (1976), the project area groundwater and surface waters (including tanks, villus, rivers and streams) which have been sampled, are all suitable drinking water sources for livestock. The only exception would be the waters of the Upaar Lagoon which have a salinity concentration far in excess of safe consumption levels for animals.

The surface waters are apparently suitable for swimming, bathing, clothes washing and other related domestic uses. However, this assumption requires confirmation with additional testing, especially for coliform bacteria counts.

Similarly, the quality of the well waters for human consumption needs verification with coliform bacteria, metal toxicity and other analyses. From the existing data, it is apparent that several wells in the area would be

questionable potable supplies because of high saline content. Waters with total dissolved solids levels of more than 500 mg/l (roughly equivalent to a conductivity of about 700 micromhos/cm)and/or chloride levels of over 7 meg/l are usually considered objectionable due to the salty taste. Project area wells which fall into this category include Wells 14 and 20 in System C and some wells in Kaduruwela, Hingurakgoda, Trincomalee and Batticaloa. The iron concentration found in the Mahiyangana bore-hole also exceeds the safe drinking water criteria of 0.3 mg/l.

AQUATIC LIFE STANDARDS

General Parameters

The surface waters in the project area generally exhibit qualities which are above standards normally associated with healthy fish faunas. The data reveal a few isolated instances where safe levels for aquatic life are exceeded. These include an infrequent high ammonia level and the high iron concentrations found in the Mahaweli Ganga and the Maduru Oya. The recommended iron level for the protection of aquatic organisms is 1.0 mg/l (U.S. Environmental Protection Agency 1976), an amount exceeded six times in the available iron data. The iron present however may not be highly toxic to aquatic life if it exists in combined forms. In addition, a recent World Health Organization study of industrial effluents in Sri Lanka indicate that releases from the paper mill in Valaichchenai have very excessive levels of organic waste materials. Local fishermen have complained that fish catches in the Maduru Oya estuary have declined because of pollution from the paper mill.

Pesticides

Until recently (about 1976), chlorinated pesticides including DDT, BHC, heptachlor, endrin, aldrin and dieldrin were employed for pest control purposes throughout Sri Lanka. The chlorinated (or organochlorine) pesticides are very persistent, often remaining for years before they break down into harmless by-products. Organophosphorous pesticides, on the other hand, while still very toxic, degrade rapidly, remaining in soils only a few days or weeks.

Most of the organochlorine pesticides have been replaced in Sri Lanka by the organophosphate types; however, some organchlorine insecticides are still in use in the country. Ramasundaram et al. (1979), from the Central Agricultural Research Institute in Peradeniya, have recently completed a national survey of organochlorine insecticide residues and found, for example, DDT and BHC residues in 61% and 43%, respectively, of vegetable samples examined. In this study, surface water samples taken at several locations including Parakrama Samudra, Giritale Tank and Minneriya Tank did not contain DDT, but had traces of BHC, dieldrin, heptachlor and endosulphan.

In November, 1979 TAMS collected water samples throughout the project area which were analysed for chlorinated pesticide residues by the Central Agricultural Research Institute. The results of these analyses are presented in Table F-7. Note that the figures are given in micrograms/l (µg/l).

These concentrations are relatively high, especially for DDT, and they often exceed mortality level thresholds for some aquatic organisms (U.S. Environmental Protection Agency 1976). These data require additional

verification, since as pointed out by Ramasundaram et al. (1979), water pesticide analyses are easily contaminated, and the methods have not yet been standardized in the country.

Pesticide usage in Sri Lanka is discussed in further detail in TOPIC REPORT J: PEST MANAGEMENT.

Nutrients and Productivity

In aquatic ecosystems, phosphate levels are usually considered to be the principal limiting factor affecting algal growth and production. High phosphate concentrations are normally associated with a corresponding high organic matter productivity level, a condition often referred to as eutrophication. Eutrophication of a water body is characterized by extensive algal and aquatic plant growth, an increase in organic decomposition rates and a reduction of dissolved oxygen levels. While the term eutrophication often connotes deteriorated water quality conditions and the proliferation of nuisance aquatic weeds, it should be emphasized that eutrophic waters are also highly productive and thus may be very desirable for the enhancement of fisheries development.

The few phosphate readings available from the project area surface waters indicate that nutrient salt concentrations are sufficient to stimulate relatively high levels of algal and plant production. Observations of dense algal blooms on many of the existing tanks in the region indicate highly eutrophic conditions in a number of localities.

The most detailed phosphate data available are the result of analyses performed by Schiemer (1979) in a preliminary survey of Parakrama Samudra. These data are summarized in Table F-2. Assuming that the 0.06 mg/l of total phosphate for inflowing waters is representative of the annual average, the present phosphate loading level (based on operating characteristics presented in Table F-8) for the tank is about 0.60 $gm/m^2/yr$. This level alone is in excess of phosphate loadings normally associated with eutrophic lakes (Vollenwieder 1973; Dillon 1975). Phosphate inputs from other sources, i.e. atmospheric, cow dung, etc. would further elevate the overall loading. Sediment re-cycling will contribute additional nutrients, especially since the lake is relatively shallow. Consequently, Parakrama Samudra would be considered a very highly productive, or eutrophic lake. This is corroborated by the high algal biomas and high primary productivity levels initially found at the lake by Schiemer (1979).

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Table F - 7

Chlorinated Pesticide Residues in Project Area Surface Waters

(Results are in micrograms /liter)

Sample Location	Aldrin	Dieldrin	BHC (Total HCH)	Endosulfan	Total DDT
Mahaweli Ganga at Victoria Dam Site	0.01	0.06	0.17	-	0.05
Mahaweli Ganga at Mahiyangana	0.03	0.04	0.15	0.14	0.23
Mahaweli Ganga at Manampitiya	0.01	-	0.13	-	0.07
Mahaweli Ganga Near Chundankadu	0.14	-	0.23	-	1.63
Mahaweli Ganga at Mutur	0.07	-	0.22	-	0.41
Mahaweli Ganga East Fork at Verugal	0.06	-	0.21	-	0.34
Kotmale Oya at Dam Site	0.02	0.04	0.21	0.06	0.47
Ulhitiya Oya near Beligalla	0.04	0.05	0.17	0.02	0.07
Maduru Oya near Wagawatta	-	-	0.13	-	0.17
Maduru Oya at Welikanda	0.04	0.20	0.16	-	0.20
Maduru Oya at Valaichchenai	0.06	-	0.19	-	0.38
Upaar Lagoon	0.06	-	0.19	-	0.31
Gengala Villu	0.04	-	0.24	0.03	0.21
Karapola Villu	0.07	0.06	0.19	0.10	0.38
Mutugalla Villu	0.12	0.13	0.19	-	0.22
Velankada Villu	0.02	-	0.20	-	0.14
Velankada Villu Inlet Stream	0.01	0.14	0.20	0.04	0.27
Horabora Wewa	0.02	0.04	0.17	0.07	0.06
Allai Tank	0.07	-	0.15	-	0.48
Vakaneri Tank	0.07	-	1.56	-	0.14
Parakrama Samudra	0.04	-	0.22	-	0.13
Minneriya Tank	0.04	0.03	0.17	-	0.25
Kaudulla Tank	0.02	-	0.18	-	0.12
Kantalai Tank	0.06	-	0.23	-	0.53

Source: Samples were collected by TAMS in November, 1979 and analyzed by the Central Agricultural Research Institute, Peradeniya.

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Table F - 8

Morphological and Operational Alterations for Existing Major Tanks

Characteristics		Parakrama Samudra		Minneriya Tank		Kaudulla Tank		Kantalai Tank	
		Present	Future	Present	Future	Present	Future	Present	Future
High water level Elevation (m)		58.5	58.5	93.7	93.7	69.5	69.5	56.9	56.9
Low water level Elevation (m)		51.5	51.8	82.1	82.4	64.0	64.3	46.5	47.4
Mean Water Level	Elevation (m)	55.1	56.1	90.3	89.7	66.9	65.9	54.5	53.8
	Area (km^2)	15.0	17.6	17.0	15.8	12.5	8.8	13.7	12.1
	Storage (mcm)	57	73	81	75	27	18	51	44
	Mean Depth (m)	3.8	4.1	4.8	4.7	2.2	2.0	3.7	3.6
Mean Annual Inflow (mcm)	Natural Inflow	26	26	61	61	21	21	69	69
	Irrigation Return Flows	0	0	-	0	0	0	0	0
	Releases from upstream source	123	197	480	604	157	306	109	184
	Total Inflow	149	222	541	665	178	327	178	253
Mean Annual Outflow (mcm)	Irrigation Releases	145	213	143	149	173	322	164	245
	Releases to Downstream Tanks	0	0	392	504	0	0	0	0
	Evaporation - Evapo-transpiration	6	6	6	6	6	5	5	5
	Flood Spills	0	0	-	3	0	0	9	2
	Total Outflow	151	220	541	663	179	327	179	252
Hydraulic Retention Time (yr)		0.38	0.33	0.15	0.11	0.15	0.06	0.28	0.17
Dangerous Level of Phosphorous Loading ($gm/m^2/yr$)		0.52	0.57	0.70	1.24	0.62	1.03	0.59	0.77

Source : NEDECO (1979) Annex B
Vollenweider (1973)

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IMPACT ANALYSIS

WATER QUALITY OF THE PROPOSED RESERVOIRS

Thermal Stratification

Large, standing bodies of water comparable to the reservoirs proposed for construction in the project area would be expected to exhibit a thermal stratification between the surface and bottom waters. Thermal stratification occurs as surface waters are warmed by solar radiation with the result that warm, lighter water forms a layer over deeper, cooler and denser segments of a reservoir. This creates thermal and density gradients from the top to the bottom of the reservoir which inhibit mixing between the upper and lower waters.

Typically, temperate lakes exposed to extreme variations in climate exhibit a sharply delineated thermal stratification with summer surface temperatures of 20 - 25° C and bottom temperatures of only 4° C. However, in these lakes, the seasonal climate changes produce uniform surface and bottom temperatures which equalize respective water densities and enable winds to more or less thoroughly mix upper and lower reservoir layers. This mixing or "overturn" may occur once or twice annually and sometimes more frequently.

On the other hand, tropical lakes usually exhibit weak vertical temperature gradients and little seasonal change of temperature at any depth. However, even thermal differences of a few degrees centigrade in a tropical lake are capable of causing the formation of stable density layers which can persist throughout the year. This has been observed for most of the man-made lakes in southern India (Ganapati 1972, 1973). Overturns are irregular events, and deep tropical lakes like the proposed Kotmale, Victoria and Randenigala Reservoirs, usually undergo only partial mixing of the lower layers unless a storm occurs with exceptionally high wind velocities. On the other hand, the relatively short hydraulic retention times for the proposed reservoirs combined with the seasonally high winds in the project area will probably result in one or more complete turnovers for the shallower reservoirs (Moragahakanda, Rotalawela, Ulhitiya Oya and Maduru Oya).

Temperature data from the man-made lakes in southern India reveal that surface temperatures range from 24-33° C and bottom temperatures from 22-30° C (Ganapati 1973). The vertical differences vary from 0.3 to 6.6° C. These differences are sufficient to cause stratification because the change in density for a temperature difference of 1° C between 29° and 30° C is 2-3 times as great as that for the same difference in temperature between 14° and 15° C.

Surface temperatures for the proposed reservoirs would be expected to be similar to those found in the man-made lakes of southern India. This is in general agreement with the existing tanks in Sri Lanka (Table F-2). Stratification patterns will also be similar to the Indian reservoirs, although because of the great depth of the up-country reservoirs bottom temperatures in those lakes will probably be somewhat lower.

Chemical Stratification

In addition to thermal stratification, the proposed reservoirs will exhibit vertical chemical stratification as well. Oxygen levels in the uppermost layer of the reservoir should be relatively high due to the contact of surface waters with the atmosphere and because of the photosynthetic activity of free-floating algae. Oxygen is an end product of photosynthesis and is released by algae into the water. On the other hand, oxygen concentrations in water below the upper layer will decline significantly. This will be due to two principal factors. One is that as depth increases in the reservoir, the effectiveness of sunlight penetration decreases rapidly. This limits photosynthetic activity, and thus oxygen releases, to a zone of water relatively close to surface. Second, the chemical processes involving the decomposition of organic matter, especially algae, as it settles to the bottom of the reservoir, consumes oxygen. These chemical processes will occur at a faster rate in tropical reservoirs in comparison to temperate ones, because at the expected bottom temperatures of the proposed reservoirs (roughly 20-30° C), the rate of biochemical reactions will be 4-9 times greater than in temperate reservoirs which have deep water temperatures of 4° - 10° C (Ganapati 1972).

As time passes, continuous decomposition activity depletes dissolved oxygen in the lower layers of a reservoir. Overturns will annually replenish oxygen throughout a reservoir due to turbulent mixing and exposure to the atmosphere. However, if partial overturns occur for the deeper reservoirs, the bottom waters may have very low oxygen concentrations for long periods of time.

In the southern Indian lakes, oxygen concentrations in the surface waters are usually high, ranging from 3.5 to 8.8 mg/l (Ganapati 1972). However, the bottom layers exhibit considerable depletion in all of the reservoirs, especially in the summer months when oxygen levels may drop to less than 1 mg/l. These reservoirs range in average depth from 9 to 43 meters.

Similar oxygen gradients would be expected to occur within the proposed project area reservoirs. The upper zone of higher oxygen concentration may be extended slightly downward in the lower or downstream part of the reservoir. This may occur since turbidity causing suspended materials will settle in the upstream reaches of the reservoir; thus permitting deeper light penetration and a corresponding expansion of the area of photosynthetic activity. Consequently, the proposed reservoirs would be expected to have oxygen concentrations of between 5 to 10 mg/l occurring in surface waters and continuing down to a level of roughly 10-15 meters of water. Below this point, dissolved oxygen will be reduced and may fall to less than 1 mg/l at the bottom of the reservoir, particularly during the dry season.

The virtual absence of dissolved oxygen from the deeper portions of a reservoir will result in the formation of reduced chemical compounds such as odor-causing hydrogen sulfide and ammonia. These substances will be formed mainly from the leaching of organic sediments which have accumulated on the bottom of the reservoir. Thus, these compounds would be expected to appear in higher concentrations near the bottom with a diminishing gradient formed as the oxygenated surface layers are approached.

For most fish species and other aquatic life, exposure to less than 1 mg/l of dissolved oxygen and/or to even small amounts of hydrogen sulfide

and other reduced substances, results in mortality or at least strong avoidance behavior. Thus, most aquatic organisms, especially fish species, which are present in the reservoir will find suitable habitat conditions in only the upper layer near the surface. Only the more tolerant species will inhabit the deeper reservoir waters.

Downstream Reservoir Releases

The quality of the immediate downstream releases will be dependent upon the water quality conditions within the reservoir and, in particular, at the depths where the intake release structures will be located. Due to the anticipated nature of the thermal and chemical stratification of the proposed reservoirs, water released from the surface over the spillways should be of relatively good quality, i.e. well oxygenated and highly buffered.

On the other hand, water released from lower levels of the reservoirs will be of comparatively poor quality. Oxygen concentratons may be very low and reduced substances such as hydrogen sulfide will be present. Water of this nature usually has a dark color, and often an objectionable odor; it may also be harmful to aquatic life.

Due to head requirements for power generation, it is expected that water will be released from lower levels of most of the proposed reservoirs. Thus, relatively poor quality water will occur below the dams. However, because of the high gradient, torrential nature of the rivers, water released from the dams should be reaerated, and its quality improved within a short distance downstream.

Level of Productivity

The degree of production of organic matter within the reservoir ecosystems will be largely dependent upon the availability of nutrient salts to aquatic plants and especially to floating or attached algae. The level of productivity can affect water quality conditions throughout a reservoir including the rate of oxygen depletion in deeper waters. Higher production implies increased decomposition rates as algae die off, and thus a more rapid reduction of oxygen concentration occurs.

In the filling stage of the reservoirs a large amount of nutrients will be available from topsoil, leftover vegetation or ashes remaining after clearing and burning. Thus, in the first few years of reservoir operations algae growth would be expected to be very high.

Typically, most reservoirs, especially warm tropical ones, will be highly productive during the initial 4 or 5 years of operation. Following this period, the proposed reservoirs would be expected to exhibit a decline in production levels as the nutrients available from the inundated land settle to the bottom and are prevented from recirculating by density stratification. Consequently, the deeper up-country reservoirs which are likely to undergo only partial overturns will lose a substantial amount of their nutrients to the bottom sediments. Thus, these reservoirs will probably be less productive than the shallow, low-country reservoirs where more complete overturns are expected which will replenish the surface water with nutrient salts needed for algae production.

Following the initial years of high photosynthetic activity, productivity in a reservoir usually levels off and thereafter depends upon the supply of nutrients, and in particular phosphate, which is recycled from sediments or which enters from outside sources. Phosphates and other nutrients enter a reservoir from leaching of natural minerals, direct absorption from the atmosphere, rainfall, human and animal waste disposal and from runoff through fertilized cropland and pastures.

An additional source of nutrient salts will be available to the proposed reservoirs because of the anticipated annual drawdown of the water levels. This will expose inshore sediments, leaf litter and other organic debris which will oxidize due to atmospheric contact. The ensuing inundation of the exposed drawdown zone will then provide nutrient salts in a form suitable for algae usage. If drawdowns are of a sufficient length of time, terrestrial herbs may take root; when the area is re-inundated the decomposition of this grassy vegetation will provide further nutrients to the reservoir. Similarly an important source of nutrients are those assimilated from dung from grazing animals along the shorelines or even within the drawdown zones of the reservoirs. This is obviously one of the most significant nutrient sources for many of the existing tanks in the project area.

The available data are too limited to accurately predict nutrient loadings for the proposed reservoirs. However, since it is apparent that many surface waters in the project area are highly productive, it is likely that eutrophic conditions may occur in some of the new reservoirs, particularly the shallow, low-country ones.

On the other hand, all of the proposed reservoirs will act as nutrient (and sediment) traps, retaining nutrients which would normally reach downstream areas. Due to the sequential arrangement of the reservoirs, a progressive downstream reduction in the river supply of nutrients may affect some reservoirs. Thus, downstream reservoirs will have to rely to a large extent upon nutrient inflows from their individual catchment areas. This may be particularly evident for the Randenigala Reservoir, since the Victoria Reservoir will prevent river nutrients from reaching it. However, if withdrawals from the Victoria Reservoir are near the bottom of the lake, then some of the nutrients trapped on the bottom may be released into the Randenigala Reservoir and thus increase its fertility. A similar series of events may occur below the Randenigala Reservoir and the Ulhitiya Oya Reservoir in relation to the nutrient supplies to the further downstream reservoirs.

Summary of Anticipated Reservoir Water Quality

All of the proposed reservoirs are expected to undergo vertical thermal and chemical stratification, with reduced oxygen levels occurring in the bottom waters for some part of the year. The reservoirs will probably overturn once or more annually, although the deep reservoirs including Kotmale, Victoria and Randenigala will not have the thorough surface to bottom mixing expected in the shallow, low-country reservoirs. The latter, due to increased nutrient availability through recycling and drawdown should be more productive than the deep reservoirs.

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IMPACTS RELATED TO IRRIGATION USE

Quality of Initial Sources

The quality of the initial irrigation supply sources including the new proposed reservoirs and the upstream river sections should remain highly suitable for irrigation purposes. They are not expected to undergo any significant water quality changes which would alter their value for irrigation usage. High iron levels occasionally found in these waters could be detrimental to crop yields, but further investigations will be necessary to clearly identify potentially harmful iron concentrations since this metal forms many complexes with other ions.

Effects on Major Tanks

Likewise, the major tanks in the project area, including Parakrama Samudra, Minneriya, Kaudulla and Kantalai should maintain suitable quality for irrigation. The quality in these tanks should improve slightly due to the increase in the water volumes which will pass through them (Table F-8). This will tend to dilute salinity concentrations in the tanks. According to NEDECO (1979) ANNEX B, none of these tanks should receive appreciable return flows from upstream irrigation systems. This will tend to preserve the present high quality in these tanks.

Effects on Medium Tanks

Generally, the medium and smaller sized tanks within the project area are expected to continue as high quality sources for irrigation of their respective command areas.

However, some degradation of the water quality in the downstream tanks such as Punai, Vakaneri and Allai may occur, particularly during dry season months, as return flows from upstream irrigation systems enter them. The return flows undergo a progressive downstream accumulation of salts which may result in an increase in the overall solids content in these tanks. The salinity in both the Vakaneri and Allai Tanks is already relatively high. In addition, salinity and related SAR values could be further increased in these tanks (or others) during the dry season months due to high evaporation rates. Significant increase of salinity has been observed in tanks of System H during dry season irrigation periods (Gunawardhana and Kumudini 1980). However, it should be noted that a substantial increase in salt concentrations would be necessary to inhibit the effectiveness of these downstream tanks as irrigation supply sources.

Return Flow Reuse

In a few localized areas water quality in return flows may deteriorate significantly, preventing their immediate reuse for irrigation. This may occur where salt accumulates due to improper drainage or in areas, where sodic sub-soils exist which, when irrigated, release sodium into drainage waters. However, in most of the project area, adequate drainage and the flushing action of heavy rains during the wet season should prevent salt build-up in the soils or high sodium concentration problems.

A partial study of the water quality in the irrigation system for System H indicates that the drainage waters there remain suitable for reuse

and application (Gunawardhana and Kumudini 1980). Overall, the quality of return flows is not expected to limit their immediate usage for additional irrigation. Cumulative effects may cause problems in some downstream areas as mentioned above.

Impacts of Salinity Intrusion

There are no available physico-chemical measurements describing the nature and extent of the tidal intrusions in the lower Maduru Oya and Mahaweli Ganga estuaries. An examination of recent aerial photography taken in these areas indicates that, due to the presence of salt tolerant mangrove vegetation and the extent of tidal backwaters, tidal effects penetrate upstream in the Mahaweli Ganga and Maduru Oya at least 6 and 4 kilometers, respectively.

The planned annual diversion of water from the Mahaweli Ganga is likely to result in a significant reduction of its dry season flow with a corresponding increase in the extent of its tidal wedge. Increased salt concentrations in the already highly saline lower river sections would probably make these waters undesirable for irrigation use. In addition, salinity levels in adjacent groundwater supplies would increase thus deteriorating their overall quality.

However, similar problems should not occur in the Maduru Oya estuary. The dry season flows of the Maduru Oya should in fact increase to some degree due to the large amount of water diverted into System B which will subsequently drain into the river in return flows. Consequently, it is anticipated that dilution effects will slightly reduce the salinity content in the lower Maduru Oya waters, improving their suitability for irrigation usage.

Details pertaining to the impacts of altered river flows and salinity intrusion are presented in TOPIC REPORT A: CLIMATE AND HYDROLOGY.

EFFECTS OF ALTERED NUTRIENT SUPPLIES

Nutrient Loading on Major Tanks

The existing major irrigation tanks, Parakrama Samudra, Minneriya, Kaudulla and Kantalai, will undergo significant changes in water balance with the implementation of the Accelerated Program. The existing and proposed morphological and operational characteristics of these tanks are presented in Table F-8. Although the high and low water levels will not differ appreciably from the existing ones, the amount of inflow and outflow for the tanks will increase substantially.

In order to evaluate the impact on the potential change in eutrophication of the tanks, a sensitivity analysis was made using the nutrient loading model derived by Vollenweider (1973). This simplistic model has been used successfully on many reservoirs for determining phosphorous loading levels which, when exceeded, may result in eutrophic conditions. Vollenweider

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empirically defined "dangerous" loading tolerance levels based on encountered ranges of mean reservoir depths and hydraulic retention times. The derived formula for the dangerous level of phosphorous loading is:

$$L = 0.22 \frac{\bar{z}}{Tw} + 0.30$$

Where L = phosphorous loading in $g/m^2/yr$;

$\bar{z}$ = mean depth (volume ÷ area of the lake); and

Tw = Hydraulic retention time (lake volume ÷ outflow volume).

The Vollenweider model can be used to give an indication of the effect on phosphorous loading due to the proposed changes in inflow-outflow volumes for the tanks. For each tank, the hydraulic retention time will decrease, i.e. the flushing rate will increase. The resulting effect in each case will be to increase the amount of phosphorous loading which may occur at the lakes before highly eutrophic conditions are exhibited (Table F-8).

However, the data collected by Schiemer (1974) indicate that the phosphorous loadings for the tanks may be so high that even the future increases in loading tolerance levels due to the decreased hydraulic retention times will be exceeded. Consequently, these tanks would be expected to remain relatively highly productive or eutrophic.

Effects of Return Flow Nutrients on Smaller Tanks and Villus

Unlike the major irrigation tanks, many smaller tanks and especially villus are expected to receive relatively large amounts of nutrient salts from irrigation return flows. The latter will contain high nutrient levels due to the fertilizer runoff from paddy and other crops. Very high levels of phosphorous and other nutrients have been found in the irrigation drainage waters of System H (Gunawardhana and Kumudini 1980).

Overall, there will probably be a significant increase in eutrophic conditions for many small tanks and most villus. Algae blooms and an overall degradation of existing water quality is likely to occur in these water bodies. This may be exacerbated by the fact that the villus will be reduced in area (see TOPIC REPORT H: WETLANDS).

Impacts on Estuaries

The construction of a series of large reservoirs on the mainstream Mahaweli Ganga and Maduru Oya will result in a reduction of nutrients which normally reach the estuarine portions of these two rivers. The reservoirs will act as effective nutrient traps. On the other hand, irrigation return flows are likely to contribute nutrient salts to the rivers which will be inorganic nutrients; much of the organic nutrients will remain in the upstream reservoir sediments.

The net effect may be an overall alteration of the organic production and energy cycles in the estuarine systems. The water quality for a portion of the Maduru Oya estuary may be further deteriorated due to the additive

effects of high nutrient input from irrigation return flows with the existing pollution due to the paper mill effluent. Normally, changes in the nutrient balance and cycling patterns in estuaries have a detrimental effect on aquatic life, especially fish and shrimp species which utilize estuaries as breeding or nursery grounds.

IMPACTS ON LIVESTOCK USE/AQUATIC LIFE STANDARDS

Most of the effects due to water quality changes as they pertain to aquatic life have been discussed in prior sections or will be covered in TOPIC REPORT G: FISHERIES. However, one particular serious potential impact on aquatic life not previously mentioned is the likely increase of pesticide levels in project area waters receiving agricultural runoff. The proposed large scale cultivation schemes will require considerable pesticide use to enhance crop yields. Organochlorine pesticide levels may already be relatively high in project area waters. An increase in these pesticide concentrations in tanks, villus, rivers and estuaries may have significant adverse impacts on fishery resources and other aquatic life. Impacts of this nature are often magnified by the continuous accumulation of pesticide residues in the tissues of aquatic organisms.

Similarly, an increase in pesticide concentration in project area surface waters, especially in villus, could limit their use for livestock consumption. In addition, increased tidal intrusion may render some downstream river sections and groundwaters unsuitable for livestock drinking purposes. In general, however, water quality alterations in the project area waters are not expected to significantly reduce livestock usage.

IMPACTS ON DOMESTIC USE

Surface waters in the project area, including those in the proposed irrigation and drainage systems, should remain suitable for swimming, bathing, clothes washing and related domestic uses. However, the use for bathing and swimming will depend upon the provision of adequate human waste disposal systems. Without them, it is likely that contamination of the surface waters with human wastes will occur and thus increase the potential for the spread of various waterborne diseases (See TOPIC REPORT K: PUBLIC HEALTH for further details). In addition, it is unlikely that surface water in the project area will be suitable for human consumption, especially the return flows from irrigation use, since these waters will have high pesticide concentrations and elevated nitrate levels which can cause serious, and occasionally fatal, poisoning of infants due to methemoglobinemia.

The latter problem may also arise in existing wells which are downstream from irrigated crop lands. Percolation into the aquifers of irrigation waters can result in high levels of pesticides, nitrates and other toxic substances appearing in wells which are used as drinking water supplies. Salinity may also increase to unpalatable levels in groundwater via the same transport mechanism. These should be relatively isolated impacts, although potentially significant ones, especially where present wells already exhibit comparatively poor water quality conditions (Table F-3).

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RECOMMENDED ACTIONS

PROPOSED RESERVOIRS

There is little which can be done to prevent or significantly improve the poor quality conditions which are anticipated, due to stratification, for the deeper parts of the reservoirs. Artificial reaeration of the bottom layers of reservoirs with great depths would be impractical and would not be economically feasible.

Immediate downstream releases from the proposed reservoirs are also expected to be of low quality. The quality of these releases could be improved by means of installation of multi-level towers for reservoir outlet releases. However, towers of this nature may be very costly and as stated above, the release water should be reaerated by the natural steep river bed gradients. However, this may not occur for all of the proposed reservoirs. In the latter case, it may be advisable to install an artificial reaeration device, such as a baffle system, downstream from a dam which would facilitate oxygenation of the water through atmospheric contact. The need for this type of structure can be further investigated following commencement of operations at the reservoirs.

Due to the nutrient trapping effect of the dams, the productivity of some downstream reservoirs may be diminished by a reduced nutrient supply. To increase potential productivity of the reservoirs, cattle grazing should be encouraged on the shorelines and within the drawdown zones of the proposed lakes. Lake productivities can be further enhanced by seeding the drawdown areas with fast growing herbs, which will produce a large amount of organic detritus following re-inundation. Productivity can also be increased by the introduction of sewage or other organic wastes or possibly by means of an articifial upwelling pump.

QUALITY OF WATER FOR IRRIGATION USE

Soil salinity, permeability and perhaps even toxicity problems (high iron levels) may occur due to the quality of the irrigation or reuse water in some localized cultivation areas. Yield reduction which may result from these kinds of problems can be minimized by altering cultivation or irrigation practices. This could include some of the following:

- Improved drainage of surface and sub-surface waters;
- Use of more salt tolerant crops;
- Change of irrigation method;
- Improvement of the slope or level of land to allow for more uniform water application;
- Determination of leaching requirements and use of extra water for adequate leaching;
- Alteration of seeding patterns, fertilizer application, etc.;
- Change or blend water supplies; and
- Addition of chemicals such as gypsum, sulfuric acid and sulphur dioxide to the soil or to the irrigation water to improve the sodium to calcium ratio.

These recommendations can be implemented on a case by case basis at specific localities. Problem identification and the most amenable means of minimizing the adverse effects of poor quality irrigation supply would be greatly facilitated by a monitoring program and through the agricultural extension system.

CONSERVATION FLOWS

It is recommended that dry season conservation flows be maintained where necessary in the Mahaweli Ganga and Maduru Oya to provide the following benefits:

- Prevention of the formation of isolated pools in the river bed which are prime anopheline mosquito breeding habitats;
- Dilution of saline return flows; and
- Maintenance of riverine habitats for aquatic life.

In addition, the conservation flows could contribute to the control of salinity intrusion in the mouth of the Mahaweli Ganga should this prove to be a problem following project implementation. Augmentation of dry season flows may not be necessary in the Maduru Oya, since it is likely that return flows to this river will slightly increase overall flows. Specific conservation flows can be formulated after water balance studies are completed and on the basis of a salinity intrusion survey which is discussed below. A dry season conservation flow of about 10 cumecs should be sufficient in the Mahaweli Ganga (Hydrology Division, Irrigation Department, personal communication).

PESTICIDES

The large proposed cultivation schemes may result in a significant accumulation of pesticides in various receiving waters. This could have serious effects due to the cumulative magnification of pesticides through the food chain on fish, wildlife, cattle and even local residents.

A strong recommendation is made here to limit the use of the persistent organochlorine pesticides throughout the project area. Organophosphate pesticides degrade relatively rapidly, and thus, their hazardous effects are considerably less than those of the organochlorine varieties. Organophosphate pesticides should be employed where possible and, if necessary, the use of organochlorine pesticides should be strictly controlled.

The most effective means of minimizing unavoidable adverse impacts of pesticides is to ensure that proper handling and application procedures are followed. This necessitates the provision of an adequate agricultural extension service and a detailed monitoring program. These are discussed in further detail in the following section and in TOPIC REPORT J: PEST MANAGEMENT.

WATER QUALITY MONITORING PROGRAM

Monitoring in many cases is often the only means whereby water quality problems may be adequately identified in order to permit the formulation of sound mitigating measures for the prevention of potentially serious adverse impacts.

It is recommended that a multi-purpose water quality monitoring program be implemented for the project area. The collection and analysis of water samples should be integrated where possible with various monitoring systems involving groundwater studies, salinity intrusion, sedimentation, pest management control, irrigation usage, potable and related domestic supplies, protection of aquatic resources, livestock usage and soils. Specific aspects of the water quality monitoring requirements are detailed in the following sections. Information pertaining to related monitoring is provided in other TOPIC REPORTS.

Background Sampling

For any water quality monitoring program to be effective, it is essential that baseline or background data on present conditions be obtained prior to project implementation. This will enable subsequent monitoring to reflect the various water quality changes as each phase or portion of the Accelerated Program is inaugurated. With this approach, adverse effects on or of water quality as well as the cause of these effects may be identified and resolved in sufficient time to limit futher detrimental impacts on a specific resource.

Background or baseline samples should be collected for analysis a minimum of twice annually to represent dry and wet seasons at stations selected in the following areas:

- Major rivers;
- Existing irrigation tanks;
- Existing canals and drainage systems;
- Villus;
- Lagoons and estuaries; and
- Wells.

Background parameters should include temperature, pH, dissolved oxygen, major anions and cations, conductivity, nutrient salts, heavy metals, pesticides and coliform bacteria. More specific information concerning suggested sampling localities and parameters is discussed below.

Irrigation Supplies

As part of the background monitoring, detailed surveys should be made of the existing irrigation systems in the project area. Dry and wet season samples should be collected at irrigation tank inflow and outflow points and in the canal and drainage waters. Specifically, irrigation systems related to Horabora Wewa, Dumbara Tank, Pimburettawa Tank, Punai Tank, Vakaneri Tank, Allai Tank, Kantalai Tank, Kaudulla Tank and Minneriya Tank should be investigated. This would provide baseline examples for Systems A, B, C and D for anticipating problems related to water usage and return flows following project implementation. Parakrama Samudra could be omitted from the survey, since a relatively large amount of background water quality data is already available for that system.

The above survey of present conditions will also provide key information relating to irrigation use suitability of the downstream tanks, i.e. Allai, Punai and Vakaneri. Following implementation, recharges to these tanks must

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be monitored to determine if the tank water quality is deteriorating to a point which would limit its effectiveness as an irrigation source.

Once new cultivation programs are underway, monitoring should be made of irrigation supplies and return flows to identify potential salinity, sodium or toxicity problems. Specific attention should be given to iron analysis, since iron values have been occasionally very high. These problems can then be ameliorated by changes in various irrigation or management practices to improve crop yields. Also, proper fertilizer and pesticide application rates and techniques can be investigated.

The routine analyses which should be conducted in a bi-annual survey of irrigation sources and systems are the following:

- Temperature
- Electrical Conductivity
- pH
- Cations
  - Sodium
  - Calcium
  - Magnesium
- Anions
  - Chloride
  - Sulfate
  - Carbonate
  - Bicarbonate
- Trace Elements
  - Boron
  - Lithium
  - Iron
- Nutrient Salts
  - Nitrate
  - Ammonium
  - Phosphate
  - Potassium
- Pesticides

Data from analyses of these parameters can then be used to determine RSC, SAR and Adj. SAR values to evaluate permeability problems. A number of other trace elements can be tested initially as a single sample from proposed irrigation sources and then subsequently if special crop toxicity problems arise. These trace elements are mostly heavy metals such as lead, nickel, copper, cobalt and zinc. Detailed lists and criteria are provided by Ayers and Westcott (1976) and the U. S. Environmental Protection Agency (1976).

Potable and Domestic Water Supplies

The most critical parameter required in the analysis of potable/domestic water supplies is fecal coliform bacteria which is an indicator of human waste contamination. Fecal coliform samples should be collected for analysis from a well in each village center (of which there will be about 300) on a quarterly basis. The samples must be preserved in cold storage during transport and should be analysed within 24 hours following collection.

Other parameters which should be analysed on an annual basis for potable supplies include nitrates, organochlorine pesticides and a number of potentially toxic metals including arsenic, cadmium, chromium, cobalt, copper, lead, mercury, zinc and others (U.S. Environmental Protection Agency 1976).

Fisheries/Aquatic Life

For the protection of aquatic resources, dry and wet season samples should be analysed for temperature, pH, dissolved oxygen, conductivity and pesticides. Pesticide analyses should be extended in the dry season to

include tissue samples of fish, shrimp, crabs and fish-eating birds to determine the extent of pesticide accumulation in these animals. More details on pesticide monitoring is included in TOPIC REPORT J: PEST MANAGEMENT.

Sampling should be conducted in tanks, villus, rivers and especially estuaries, since agro-chemicals are likely to accumulate there. Special attention should be given to monitoring the paper mill effluents and their receiving waters of the Maduru Oya estuary. Improvement of effluent treatment facilities at the paper mill may be required to upgrade the quality of the receiving waters. An initial heavy metal analysis should also be completed on the surface waters to identify any particular problem areas.

The monitoring program should also investigate downstream reservoir releases to determine the need for the installation of reaeration devices. Nutrient analyses should be conducted and productivity evaluated for the proposed reservoirs in order to determine the need for nutrient enrichment of these water bodies.

Livestock Supplies

An initial survey for potentially toxic substances for livestock is recommended. This would also indicate the suitability of various surface waters for wildlife consumption. Sampling should focus on tanks, new reservoirs and especially villus. Parameters of concern would include nitrates, arsenic, cadmium, chromium, copper, lead, mercury, zinc and others (Ayers and Westcott 1976). In addition, dry season samples of conductivity or total dissolved solids should be taken to determine if some low lying areas are accumulating too many salts from return flows.

Salinity Intrusion

It is recommended that a salinity intrusion study be made of the existing tidal range in both the lower Mahaweli Ganga and the Maduru Oya which would include sampling for temperature and electrical conductivity or salinity in the estuaries. Samples need to be collected in a depth profile along an axis of the lower river beds at high and low water slack periods, for both spring and neap tides, and for various freshwater discharges. Once the extent of the present tidal wedges has been identified, some specific conservation flow recommendations can then be formulated if required. Details concerning a salinity intrusion survey are provided in TOPIC REPORT A: CLIMATE AND HYDROLOGY.

Laboratory Facilities and Manpower

At present, there is no government agency which is conducting a water quality sampling or monitoring program in the project area. However, a well equipped laboratory with a highly qualified technical staff is presently operating at the Central Agricultural Research Center in Peradeniya.

It is recommended that an integrated water quality monitoring program be directed from this center in Peradeniya for the project area. This would require an expansion of the existing facilities, the provision of some additional equipment and vehicles and an increase in lab technicians and other staff.

An estimate of the materials, manpower and capital costs required is provided below:

Investment Items	Rupees
Expansion of Facilities	140,000
Equipment: (Incubator, Refrigerator, Field Meters, Glassware and Chemicals)	350,000
Vehicles : (Four Jeeps and four Cold Storage Units)	480,000
Total	970,000

Additional Manpower	Annual Salary (Rupees)
8 Laboratory Technicians	48,000
4 Field Officers	20,000
4 Drivers	18,000
2 Maintenance/Clerical	9,000
Total	95,000

It is proposed that samples be collected in the field by local agricultural extension officers. It is estimated that about 2000 samples will be analysed per year. These samples would be sent to district offices and collected there for transport to Peradeniya. A short training program would be necessary for the extension officers to familiarize them with sample collection and preservation procedures.

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ACKNOWLEDGEMENTS

We would like to express our appreciation to the following institutes, agencies and individuals for providing information and assistance in the preparation of this report on WATER QUALITY:

- B. A. Abeywickrama, MAB Chairman
- ACRES International Limited
- K. D. Arudpragasam, Colombo Campus
- Bureau of Standards
- Central Agricultural Research Institute, especially S. Nagarajah and N. Ramasundaram
- Central Engineering Consultancy Bureau
- Central Institute of Industrial and Scientific Research
- Department of Irrigation
- Geological Survey Department
- Government Analyst's Department
- Greater Colombo Economic Commission
- H. D. Gunawardhana, Colombo Campus
- Hunting Technical Services Limited
- Hydrology Division
- Land Use Division
- Mahaweli Authority
- Mahaweli Development Board
- A. M. J. Meijerink, Colombo Campus
- National Water Supply and Drainage Board
- NEDECO
- Occupational Hygiene Division, Labor Department
- W. Peters, World Bank
- F. Schiemer and members of UNESCO Parakrama Samudra Limnology Study Team
- J. A. Shut, Ruhunu Campus
- S.S. de Silva, Ruhunu Campus
- M. Smith, ODA and Colombo Campus
- Water Resources Board
- World Health Organization

G. FISHERIES

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EXISTING CONDITIONS

FISH FAUNA OF SRI LANKA

There are about 60 species of fish found in the freshwaters of Sri Lanka (Munro 1955; Fernando and Indrasena 1969; Fernando 1973). About half of these species are cyprinds, including small very abundant minnows like Barbs, Rasbora and Danio which serve as forage for small carnivorous fishes.

About 20 of the freshwater species are valued as food fish (Indrasena 1965; Fernando and Indrasena 1969). These are the following:

SCIENTIFIC NAME	COMMON NAME
Barbus dorsalis	Long Snouted Bard
Barbus sarana	Olive Barb
Carassius carassius	Crucian Carp
Cyprinus carpio	Common Carp
Labeo dussumieri	Common Labeo
Tor khudree	Mahsier
Clarius teysmanni	Spotted Catfish
Wallago attu	Freshwater Shark
Ompok bimaculatus	Butter Catfish
Heteropneustes fossilis	Stinging Catfish
Macrones spp.	Catfish
Ophiocephalus striatus	Striped Snake Head
Ophiocephalus marulius	Giant Snake Head
Etroplus suratensis	Banded Etroplus
Tilapia mossambica (Sarotherodon mossambicus)	Tilapia
Anabas testudineus	Climbing Perch
Glossogobius giuris	Bar-eyed Goby
Macrognathus aculeatus	Lesser Spiny Eel
Mastacembelus armatus	Spiny Eel

At least 15 foreign species have been introduced as potential food fish (Fernando 1976; KTS 1979), of which four have established sizeable populations. These are Common Carp, Crucian Carp, Tilapia and Giant Gourami. Tilapia (T.mossambica) has increased freshwater catches significantly since its introduction, and this species normally comprises 50% to 90% of the catch by weight from tanks and villus (Fernando and Indrasena 1969; Department of Fisheries and Department of Census and Statistics 1973; Fernando 1976; de Silva and Fernando 1979).

ENDEMIC FISH SPECIES

Cruz and Nugaliyadde (1978) report that there are a total of 16 endemic species which occur on the island of Sri Lanka. Most of these can be found in the wet zone of the country.

Data on endemic fish species (as well as other endemic flora and fauna) pertaining to their distribution within the Mahaweli Accelerated Program area were gathered at a workshop as part of the "Endemic Species Seminar" sponsored by TAMS in December, 1979 and held at the Natural

History Museum in Colombo. The data collected represent the most up-to-date information concerning the distribution of endemic fishes within the project area. These data are summarized in Table G-1 along with other relevant ecological information about the species. Of the eight endemic fishes listed in Table G-1, all but one have relatively widespread distribution in other parts of the country. The Sri Lankan Barb, which is a newly identified species, is restricted to a few small tributaries within the Amban Ganga drainage.

Most of the endemic fishes inhabit small up-country torrential streams. Two species, Two Spot Barb and Mountain Labeo, undergo annual upstream spawning migrations. The Mountain Labeo may in fact move out from tanks and up the main rivers to its breeding grounds.

INLAND FISHERIES DEVELOPMENT

The Sri Lankan Ministry of Fisheries has recently (March 1980) issued a five-year Master Plan for country-wide development of both marine and inland fisheries resources. The Master Plan established the following targets for increasing fish production from the estimated 1978 catches:

	(1000 TONS)	
	1978	1983
Coastal fishing	122	196
Off-shore fishing	3	29
Deep sea fishing	0	2
Inland fishing	14.5	45
Total	139.5	272

The Ministry of Fisheries reports that the annual per capita consumption of fish had declined from 14.5 kg in 1972 to 11.4 kg in 1978. A major objective of the Master Plan, in addition in increasing overall catches, is to raise per capita consumption to 20 kg. Other goals include improving incomes and standards of living for fishermen and increasing employment opportunities in the fisheries sector. To achieve these objectives, the Master Plan proposes a number of projects and programs including the introduction of new boats and gear, establishment of credit and subsidy programs, provision of fiscal incentives for private investors, improvement of marketing and handling, provision of housing and the development of research and training.

Although the Master Plan emphasizes the expansion of marine fisheries, the development of inland resources is also given consideration. The newly established Inland Fisheries Development Division of the Ministry of Fisheries is charged with administrating, promoting and coordinating fisheries activities on inland water bodies (including brackish water areas). Various development strategies are presently being formulated in conjunction with the overall Master Plan, including the assemblage of reliable statistics, upgrading of existing breeding stations, improvement of stocking programs and the sponsoring of some research and pilot projects (Ministry of Fisheries 1979, 1980a, 1980b).

Table G-1
Endemic Fish Species in the Project Area

SPECIES	DISTRIBUTION and ABUNDANCE	HABITAT	COMMENTS
TWO SPOT BARB (Barbus bimaculatus)	Common in wet zone especially Gin, Kalu and Kelani Gangas. Present in upper Maduru Oya and small tributaries of Mahaweli Ganga. Found at the bottom and top of Gunner's Quoin.	Small, clear, rocky substrate streams of up to 5 m in width. Moves up torrents all the way to stream head-waters to spawn.	The endemic status of this species is somewhat in question since it may also occur in southern India.
CUMMING'S TWO BANDED BARB (Barbus cummingi)	Very common throughout the wet zone and the North Central Province. Could possibly occur in up-stream tributaries of the Mahaweli Ganga.	Small, clear, fast flowing hill streams.	
SRI LANKAN BARB (Barbus sri lankensis)	Very restricted distribution. Confined within Amban Ganga Drainage to several small tributaries to the Kalu Ganga.	Small streams. Gem operation and resultant siltation is causing disruption of its limited habitat.	This species has been just recently discovered. The description of this species was submitted for press in January, 1980.
CHERRY BARB (Barbus titteya)	Very common in wet zone drainages even down to tidal areas. Could possibly occur in the upper part of the Mahaweli Ganga Drainage.	Small, often very narrow streams down to 0.25 m wide. Clear water, pool habitats with dense aquatic plants	
LEAF LATES (Belontia signata)	Very common and widespread in the wet zone. Found in the Amban Ganga and Mahaweli Ganga System.	Inhabits both streams and ponds. It is a predator and is even found in paddy fields.	
SMOOTH BREASTED SNAKE HEAD (Channa orientalis)	Very common in the North West, North Central and Western Provinces. May occur in the Mahaweli Ganga Drainage.	Found in ponds or turbid backwaters adjacent to streams. Prefers quiet waters with large amounts of detritus.	The endemic status of this species is somewhat in question, since it may also occur in India.

Table G-1
(Continued)

SPECIES	DISTRIBUTION and ABUNDANCE	HABITAT	COMMENTS
STONE SUCKER (Garra lamta)	Very common in all wet zone drainages. Probably the most wide-spread of all endemic fish species. Found in dry zone rivers as well including Maduru Oya and Mahaweli Ganga.	Found in both small hill streams and in lower main streams.Prefers rocky substrates	
MOUNTAIN LABEO (Labeo fisheri)	Relatively widespread. Found in the Matale Oya system near Dambulla. Occurs in Mahaweli Ganga System including the main river below Kandy.	Prefers clear, fast flowing water. May migrate upstream to spawn.	

Source: Endemic Species Seminar sponsored by TAMS in December, 1979. Data on fishes provided by H.H. Costa, P.R. Karunaratne, R.Senanayake, S.De.Silva, G. Shut.

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The Master Plan production target for 1983 for inland waters has been broken down approximately as follows (Ministry of Fisheries 1979):

Freshwater	Tons Present	Tons Target
Major tanks	11,000	25,500
Medium and minor tanks	3,500	12,500
Brackish water lagoons and tidal flats	0	7,500
	14,500	45,500

The principal strategy for attaining this target is focussed upon repeated supplemental stocking of fingerlings in all inland waters. However, to accomplish the desired output, the Ministry of Fisheries (1979) estimates that from 55 to 70 million fingerlings must be produced each year.

The government presently maintains nine fish breeding stations, including one in the project area at Polonnaruwa. However, these stations collectively produced only about 2 million fingerlings in 1979 (Ministry of Fisheries 1980c). The Polonnaruwa station, which is probably the most efficient, has produced an average of about 450,000 Tilapia, Carp and Gourami fingerlings over the past four years. As part of the new Master Plan, the Ministry of Fisheries proposes to improve the existing breeding stations and develop several new ones. The latter includes a breeding cum demonstration centre at Dambulla to serve System H which is to be constructed in collaboration with the Mahaweli Development Board and UNICEF.

Other activities at various stages of planning and development which are aimed at improving the inland fisheries sector include:

- Establishment of new extension centres;
- Increased training through the expansion of the existing Sri Lankan Fisheries Training Institute and the establishment with UNDP assistance of a Central Aquaculture Development and Training Institute at Anuradhapura;
- Increase in the number of trained aquaculturalists, fisheries inspectors and extension assistants;
- Provision of subsidies and credit for boats, gear and fish ponds;
- Development of a reliable statistics collection system;
- Removal of obstacles affecting gear operation in some tanks;
- Provision of welfare programs for housing and sanitary facilities for fishermen; and
- Development of research in small tanks, fish ponds and cage culture.

RIVER FISHERIES

Data concerning the fish fauna of rivers and streams is very limited for Sri Lanka. Interviews recently conducted with local residents and biologists in conjunction with some recent TAMS collections, reveal that the more commonly found fish species in the Mahaweli Ganga are the following:

SCIENTIFIC NAME	COMMON NAME
Anguilla nebulosa	Long Finned Eel
Barbus dorsalis	Long-Snouted Barb
Barbus filamentosus	Filamented Barb
Barbus sarana	Olive Barb
Cypinus carpio	Common Carp
Labeo dussumieri	Common Labeo
Labeo fisheri	Mountain Labeo
Rasbora daniconious	Common Rasbora
Tor khudree	Mahsier
Garra lamta	Stone Sucker
Wallago attu	Freshwater Shark
Macrones keletius	Dwarf Catfish
Ompok bimaculatus	Butter Catfish
Ophiocephalus marulius	Giant Snake Head
Ophiocephalus striatus	Striped Snake Head
Tilapia mossambica	Tilapia
Osphronemus gouramy	Giant Gourami
Mastacembelus armatus	Spiny Eel

Local residents also report the capture of large freshwater shrimp (Macrobrachium) from the river at different times of the year. In addition, in the lower reaches of the river a number of salt water species are often found including sharks, rays and an occasional sawfish. Several of the river species are known to undertake annual upstream spawning migrations, especially the Labeo species and the Mahsier.

There are no commercial fisheries operations on the Mahaweli Ganga, Maduru Oya nor any other stream in the project area. Even subsistence level fishing activities are limited except in the mainstream Mahaweli Ganga. Here occasional handline fishing is observed; some sport fishing occurs in the Upper Mahaweli particularly for the Mahsier which can reach a size of up to 25 kilograms. No records are maintained of the fish catches from rivers or streams in the country. An arbitrary estimate of the fish yield (the amount caught by fishermen) from the country rivers and streams was given by Indrasena (1965) as roughly 5 kg/ha/yr. However , the average standing stock of all fish present in a section of the river will be considerably higher than the amount of desirable food source fish which fishermen are capable of capturing. This concept is applicable to all aquatic environments. Thus, for example, while the yields realized from a river may only be 5-10 kg/ha/yr, the standing stock or population density of the entire fish community which is supported by the river may be in the range of 100 to 600 kg/ha, typical figures observed for tropical rivers in general (Welcomme 1979).

VILLU FISHERIES

Villus in the lower reaches of the Mahaweli Ganga form a major part of the river floodplain. Villus are highly productive and are excellent spawning and nursery habitats for many fish species. A number of fish species tend to spawn in these warm, shallow waters as they rise during the wet season. Consequently, eggs hatch simultaneously with the inundation of surrounding land which results in the availability of a large amount of organic matter for feeding the juveniles (Welcomme 1979).

Few studies have been conducted on the fisheries of the villus. Fernando (1969) reported that at the Karapola Villu (See Figure G-1) fish catches from 1960 to 1966 ranged 25 to 50 tons or a yield of roughly 35 to 70 kg/ha/yr, respectively. The common species in the catches were Tilapia, Labeo, Freshwater Shark, Butter Catfish, Banded Etroplus, Snake Heads, Giant Gourami and Barbs. A recent interview (November, 1979) with fishermen at the Karapola Villu indicated that the same species are still being captured plus the freshwater shrimp and a few eels. There are 25 virtually full-time fishermen presently operating at the villu. Gill nets set from canoes are the main gear utilized. During the peak fishing season (January-April), fishermen take about 10 kg per day; in the remainder of the year, average daily catches are about 2-3 kilograms. Combined with part time fishing activities, the total annual catch in recent years has been about 40 tons/year, or around 57 kg/ha/yr.

These figures compare favorably with Fernando's and others given as estimates for villu fish yields. Indrasena (1965,1970) gave an average catch for the Mahaweli Ganga floodplain of about 34 kg/ha/yr. The Ministry of Fisheries uses an estimate of 56 kg/ha(50 lbs/ac) for all villus when projecting annual national production. Similarly, floodplains of the tropical rivers world-wide have average yields of about 50 kg/ha, while a reasonable estimate of the average standing stock of the floodplain would range from 300 to 1000 kg/ha (Welcomme 1979).

PADDY FIELDS AND IRRIGATION CHANNELS

During floods,paddy fields, like villus, serve as large areas of open water where many fish species breed (Fernando 1969). Considerable numbers of small sized fish have been caught in this habitat, and Fernando (1956) reported a total of 34 species occurring in the western lowland rice fields. Larger food fishes including Butter Catfish, Common Labeo and Freshwater Shark have been found in the irrigation canals.

TANK FISHERIES

General

More than 80% of Sri Lanka's inland fishery catch is from tanks; most of this is from the low-country major irrigation tanks. The deep, up-country reservoirs have very low, often negligible, fish yields (Fernando 1969; Fernando and Furtado 1975). Low-country, medium tanks also contribute to inland fishery output, but activities in these and smaller seasonal tanks are usually confined to occasional or subsistence level fishing.

Major Tanks

Fishery operations, of varying intensity, using gill nets and beach seines have been underway at the major tanks for 25-30 years (Fernando 1969). These remain the prevalent catch methods, although cast nets, handlines and occasional traps are also employed. Fishing is done from the shoreline or from canoes and small rafts. There are about 1000 fishing craft presently operating on the major tanks (Ministry of Fisheries 1979). Fishermen at some tanks have indicated that uncleared trees remaining in the tank pools often interfere with use of some nets and limit their effectiveness.

With the introudction of Tilapia (T. mossambica) in 1951, commercial fishing became well established at a number of the major tanks. Marine fishermen migrated to the freshwater tanks, at first seasonably, and later developing full time fisheries operations. The seasonal emigration of marine fishermen to some tanks still occurs.

Tilapia expanded rapidly after being stocked and comprises up to 90% of the catch at some tanks. Other species which contribute appreciably to the catches include the Banded Etroplus, Labeo, Barbs, Freshwater Shark, Giant Gourami and Catfishes. The distribution of species by weight in catches for the major Sri Lankan tanks is given in Table G-2.

The major tanks in the project area include Parakrama Samudra, Minneriya Tank, Kaudulla Tank and Kantalai Tank. These tanks, especially Parakrama Samudra, contribute a significant amount of the inland fish catch for the country. Available information concerning catches, number of fishermen, etc. for these tanks is summarized in Table G-3. In general, catch data for the existing tanks are of varying reliability. The Ministry of Fisheries is presently re-structuring the catch data gathering program to improve the quality of fisheries statistics for future management and planning.

The existing data does reveal several trends. One is that catches increased significantly since the introudction of Tilapia to the tanks. Further, there appears to have been no significant decline in any of the indigenous fish fauna following the stocking with Tilapia (Fernando 1969). The catch data also indicates that many of the existing tanks are under-exploited. In addition, fluctuations in catch probably reflect the number of individuals fishing rather that a natural variation in the fish stocks. This is evident from the changes in catch which result from the periodic migration and emigration of coastal fishermen (HTS 1978).

Table C-2

Species Composition of Fish Catches from Different Reservoirs and a Villu in Sri Lanka

Reservoir or Villu	Year(s)	Total Catch (kg)	Percent Fish Catch by Weight							
			Introduced	Indigenous to Freshwaters					Introduced	
			Tilapia	Etroplus	Labeo	Wallago	Other Predators	Barbus	Geramy	Common Carp
North Central Province										
Parakrama Samudra	1964-66	1 516 010	77.4	6.6	15.3	0.7	1.0	0.6	0.1	0
Minneriya Tank	1964-67	563 906	90.7	1.4	5.0	0.4	1.2	0.6	negligible	0
Karapola Villu	1964-67	84 490	65.0	3.7	10.3	5.4	8.3	2.3	4.9	0.06
Eastern Province										
Senanayake Samudra	1961-64	498 592	40.3	8.5	44.7	4.5	0.05	1.6	negligible	0
Southern Province										
Muruthawela Tank	1974	21 223	81.0	4.0	0	0	5.6	6.4	2.7	0
Ridiyagama Tank	1974	541 641	95.0	1.3	0	0	2.0	1.0	0.08	0
Badagiriya Tank	1974	648 485	91.0	2.7	0	0	2.6	1.4	1.3	0
Udirkiriwewa	1974	48 008	2.0	71.0	0	0	10.7	11.4	4.8	0
Java Province										
Chandrikawewa	1974	33 570	84.0	5.2	0	0	3.7	3.5	3.7	0.001
Java Sabaragamuwa Provinces										
Udawalawe Reservoir	1974	473 597	96.0	0.5	0	0	2.0	0.3	0.7	0.02

Source : Fernando (1976)

Table G-3
Data Pertaining to Existing Major Tanks in the Project Area

Tank	Year (s)	Yield (kg/ha/yr)	Output (Tons/yr)	Fishing Crafts	Number of Fishermen
Parakrama Samudra	1961 to 1964	225	1,511	49	88
	1972	260			
	1975	475	1,201		
	1976	498	1,237	52-93	
	1977	452	1,124		
	1978	322	800		
Minneriya Tank	1955 to 1967	75	564	25	52
	1972	82			
	1975	219	559		
	1976	127	319	15-38	
	1977	110	275		
	1978	159	400		
Kaudulla Tank	1972	28		20	34
	1975	405	1,028		
	1976	257	640	18-65	
	1977	154	383		
	1978	120	300		
Kantalai Tank	1961 to 1962	50	96	62	64
	1972	44			
	1976	18	42	12-20	
	1977	18	42		

Sources : Mendis (1964), Department of Fisheries and Department of Census and Statistics (1972), Mendis (1976), HTS Annex Z (1978), Ministry of Fisheries (1979).

Data provided by the Ministry of Fisheries (1979) indicate that the major tanks in the country had fish yields in 1978 ranging from about 20 kg/ha to over 500 kg/ha. The average yield for these tanks is estimated at 182 kg/ha/yr (163 lb/ac). Catches of up to about 2000 kg/ha/yr have been reported from some of the shallow, eutrophic lakes in the country (Mendis 1964; Fernando 1976).

Standing stocks of all fish in the major tanks in the project area would be expected to be relatively high. Data collected by de Silva and Fernando (1979) and by Schiemer (1979) reveal that at Parakrama Samudra fishermen catches of 400 kg/ha/yr may in fact be exceeded by the amount taken by birds which is estimated about 800 kg/ha/yr. The latter figure may be high since it is derived from data collected during a peak feeding period. Based upon these figures, the yields mentioned previously, and on data from other tropical reservoirs (Balon 1973), standing stocks from the major tanks are likely to be within the range of 500 to 1500 kg/ha.

At most of the tanks, fishermen sell their catch directly after capture to traders or vendors who transport the fish to nearby market centers for sale. The Department of Census and Statistics (1972) reported that 65% of the landed catch was sold fresh to consumers, 32% was sold after salting and drying or smoking, and 3% was used for home consumption. Interviewed fishermen reported that wholesale prices for fresh fish at tank landing points average about four rupees per kilogram. Generally, wholesale and market prices for Tilapia are slightly less than for other species such as Catfishes or Carps. However, it is unknown whether this reflects the abundance of Tilapia in catches and at the markets, or if some other factor such as taste or size preference influences the prices.

Medium Tanks

Background data are very limited for any of the medium and smaller seasonal tanks. The Ministry of Fisheries estimates that these tanks produce annual yields of about 56 kg/ha (50 lbs/ac). This estimate may be conservative; Fernando and Ellepola (1969) report yield figures of 79 and 112 kg/ha (70 and 100 lbs/ac) for two small tanks near Polonnaruwa. Seasonal "mud fishing", i.e. hand collection of fish, is common where small tanks dry out annually (Fernando 1969). However, yields from most seasonal tanks are negligible, since they dry out completely each year and are not re-stocked.

ESTUARINE FISHERIES

Fishing activities are well developed in the estuarine portions of the Maduru Oya and Mahaweli Ganga. These areas, like others along the coast, provide nursery grounds for shrimp (*Penaeus sp.*). On the east coast, shrimp fry enter inshore waters in December-January and the peak catches are made from March to May (Ministry of Fisheries, personal communication). Interviewed fishermen confirmed this, indicating that the best fishing season was from January through August for shrimp as well as for fish. Shrimp yields have been closely associated with the extent of salt marsh and mangrove vegetation and for Sri Lanka have been estimated at roughly 170 kg/hectare of intertidal vegetation/year (Turner 1977).

The estuaries are also breeding, nursery or feeding grounds for a number of economically valuable food fish species including Anchovies (Anchoviella), Wolf herring (Chirocentrus), Whitefish (Chanos chanos), Bonefish (Elops), Mullet (Mugil), Perch (Lates), Snappers (Lutjanus) and several Jacks (Caranax). These comprise the main fin fish catch from the intertidal waters on the east coast (Ministry of Fisheries, personal communications).

According to the Department of Fisheries and the Department of Census and Statistics (1972), there are over 1300 fishing management units (boat, gear and crew) operating from Trincomalee. Of these about 350 fish inshore waters, chiefly in Koddiyar Bay. About 150 full-time fishermen were recently observed from the town of Mutur. A similar number conducts fishing activities around the Valaichchenai area. The main gear employed are cast nets and gill nets worked with one or two helpers from canoes. Beach seines are also used.

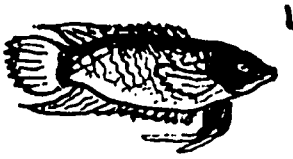
Fishermen reported that their average daily catch was about 20 kilograms of all species. This fluctuates however from only a few kilograms to as much as 180 per day depending upon the season. Catches are usually sold to a vendor at the landing point. This year small shrimp brought a wholesale price of about 20 rupees/kg. Fin fish prices ranged from 4 to 10 rupees per kilogram, depending upon the species and its size.

Fishermen in both the Mahaweli Ganga and Maduru Oya estuaries have complained that catches in recent years have declined. This is difficult to confirm without adequate documentation. However, increased sedimentation due to poor soil conservation practices upstream, the clearing of mangroves and salt marshes and the paper mill pollution at Valaichchenai could singly or in combination adversely affect the fisheries production of the estuaries.

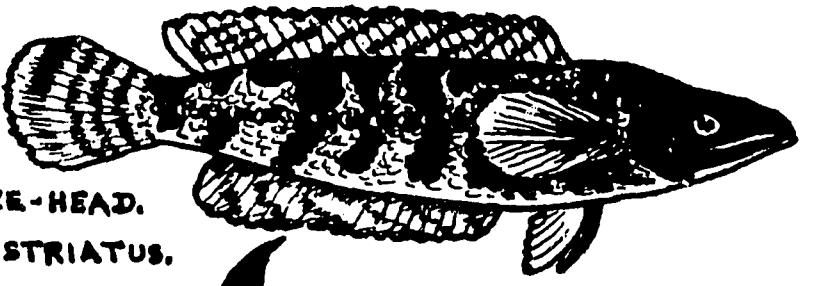
AQUACULTURE

Fish culturing or farming is very limited in Sri Lanka. At present, eel and shrimp farms are being operated by private concerns; but these are only on an experimental basis.

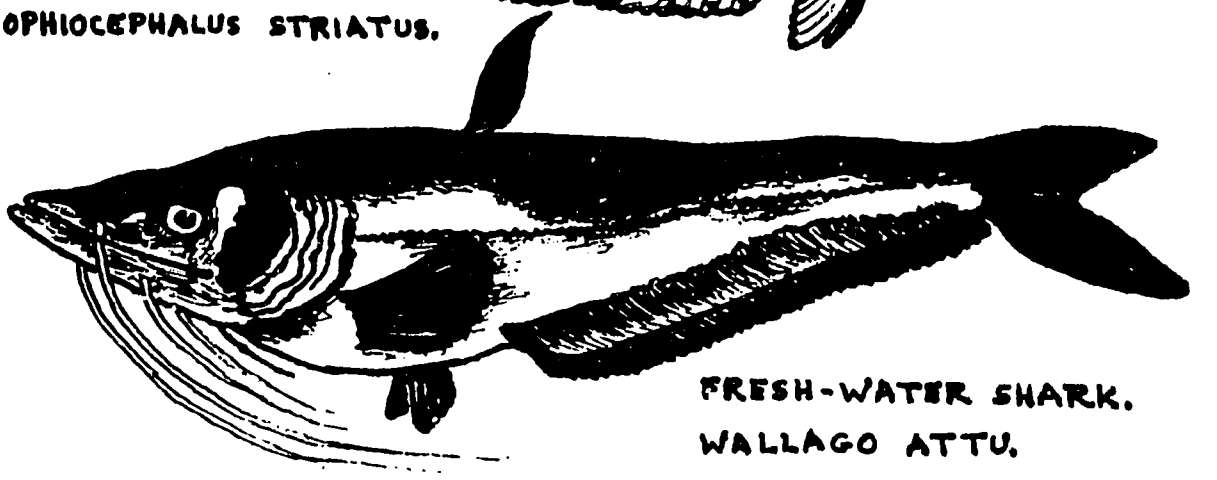
Several other cultural operations have been attempted, mainly by the fishery research and breeding stations which are maintained by the Ministry of Fisheries. One successful attempt produced nearly 2,000 kg/ha of mullet and milkfish at the Pitipana Station (Pillai 1965). The fishery stations, have successfully bred a number of species including Tilapia, Common Carp, Chinese Carps, Gourami and others. In addition, several pilot projects have recently been initiated including polyculture of Carp and Tilapia in ponds and cage culture.



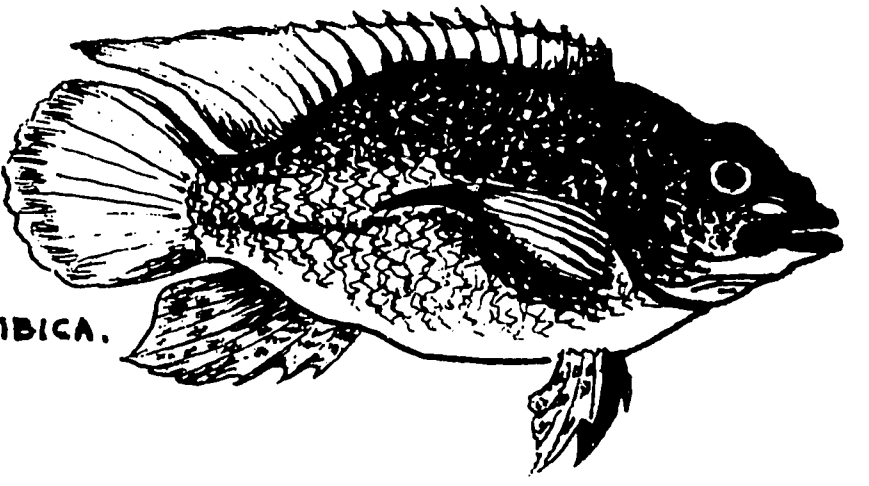
LEAF LATES.
BELONTA SIGNATA.



STRIPED SNAKE-HEAD.
OPHIOCEPHALUS STRIATUS.

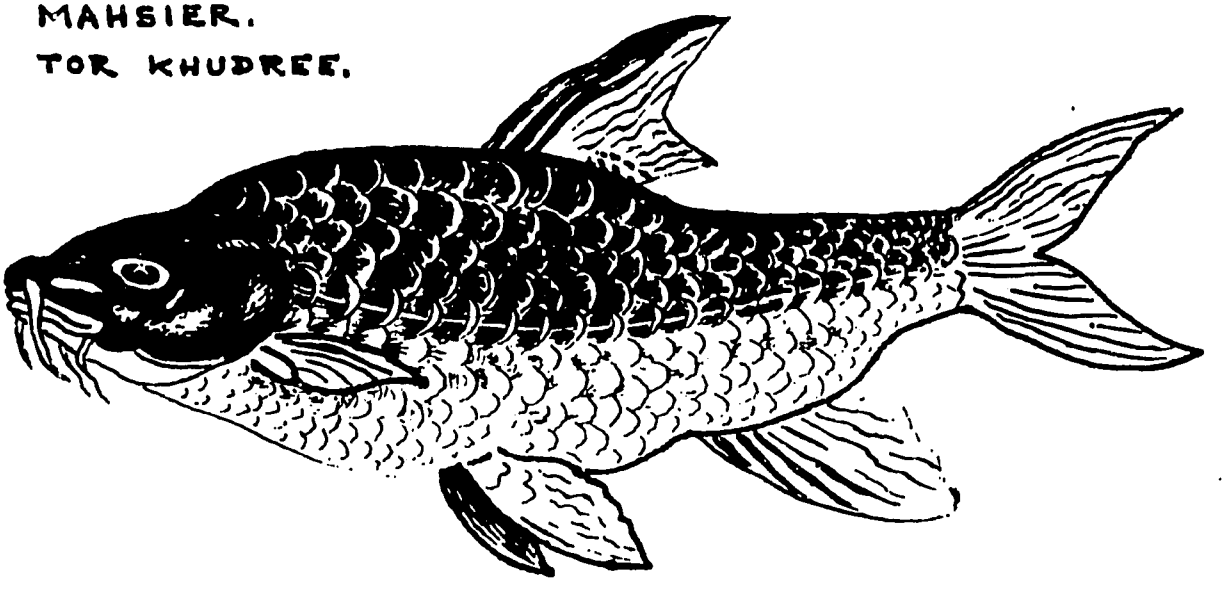


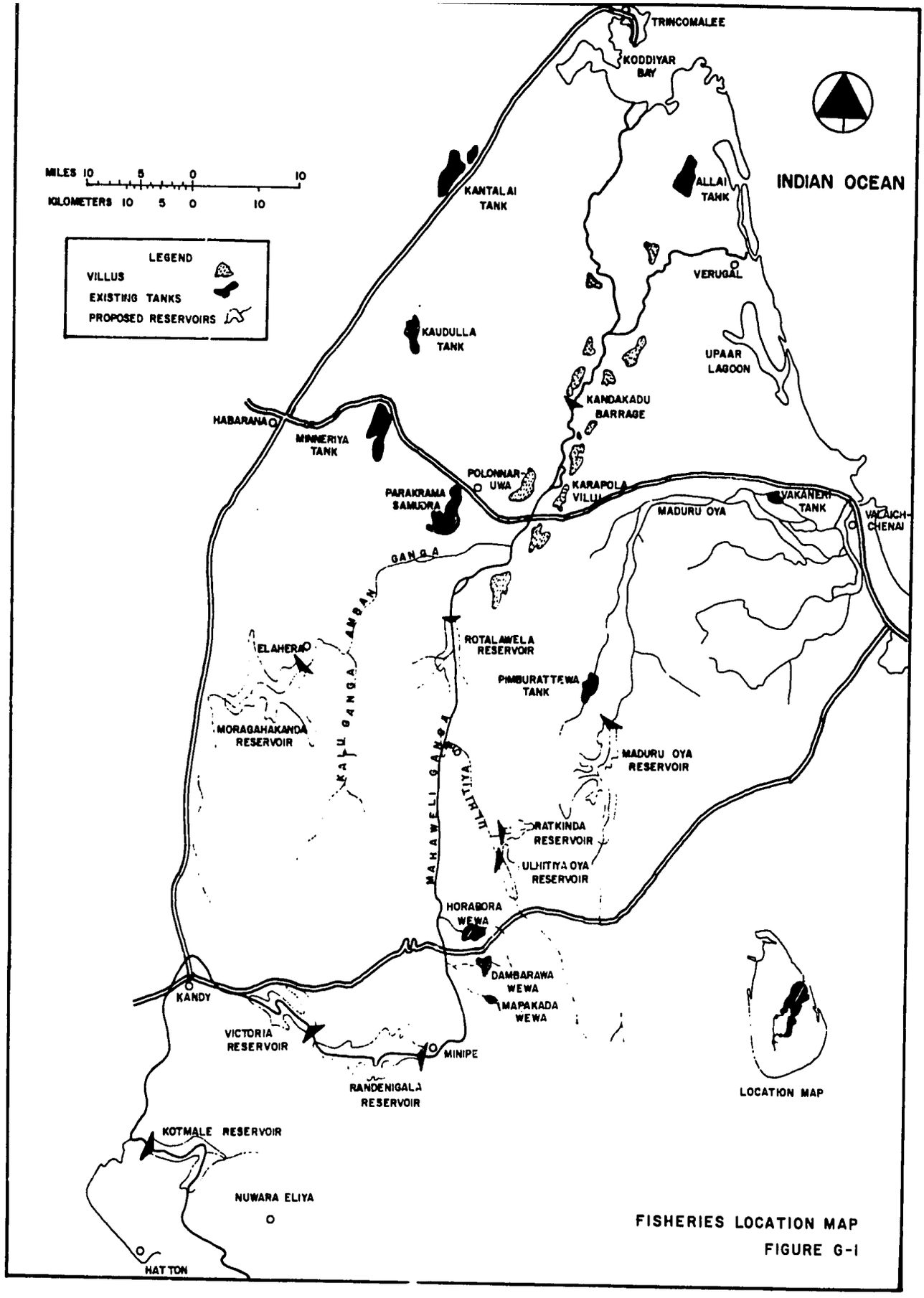
FRESH-WATER SHARK.
WALLAGO ATTU.



TILAPIA.
TILAPIA MOSSAMBICA.

MAHSIER.
TOR KHUDREE.





FISHERIES LOCATION MAP
FIGURE G-1

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IMPACT ANALYSIS

FORMATION OF PROPOSED RESERVOIRS

Changes in Species Composition

The formation of the proposed reservoirs will result in the replacement of riverine ecosystems with lacustrine ones with a subsequent elimination of some fish species and an enhancement of others. Species which prefer running water habitats or require highly oxygenated, hard gravel substrates as breeding or feeding grounds would not be expected to survive a transition to a lake environment. On the other hand, fishes which occur in the rivers, but are found primarily in quiet waters along the shoreline or in backwaters, will not only survive the impoundment but may increase their population sizes substantially.

Changes in species composition following inundation of rivers in Southeast Asia have been reported by Bhukaswan and Pholprasith (1976), Natarajan (1976), Sreenivasan (1976) and Sirinivasan and Screenivasan (1976). Generally, these studies report a significant increase in catfish and carp species after creation of reservoir pools. Concomitantly, there was a decrease in the abundance of many riverine species, with a noticeable disappearance of some fishes, particularly the Mahsier.

Comparable shifts in the fish community structures are anticipated for the proposed reservoirs. The fish species which are likely to dominate the reservoirs are those which presently inhabit tanks, villus and other quiet water habitats. Thus, the predominant natural reservoir food fish population will be comprised of Tilapia, Banded Etroplus, Labeo, Barbs, Giant Gourami, Snake Heads and the catfishes, especially the Freshwater Shark (*Wallago attu*) which has appeared in large numbers in several man-made lakes in Asia. On the other hand, it is likely that Mahsier and a number of other species will be eliminated from the river sections which undergo impoundment.

Projected Yields and Standing Stocks

Background - Several estimates have been made of annual average potential fish yields for the proposed reservoirs. These are the following:

SOURCE	ESTIMATED YIELDS kg/ha/yr
ACRES (1979)	150
HTS (1979)	100
NEDECO (1979) ANNEX F	400
Ministry of Fisheries (1979)	280

These estimates vary considerably, reflecting the basis of their selection. All of them are arbitrary estimates established by a comparison with the present yields realized from tanks in the country. These yield estimates have been applied uniformly to all of the proposed reservoirs (except the ACRES estimate which was selected for the Maduru Oya Reservoir only).

Morphoedaphic Index - In order to account for individual morphological and productivity differences in the proposed reservoirs, a separate method of estimating potential fish yields (i.e., the potential harvestable fishery resource) is applied here. The method takes into consideration

anticipated physical and bio-chemical features of the proposed reservoirs. It is based on a ratio involving the electrical conductivity (or dissolved solids concentration) and the mean depth of a reservoir.

This ratio was described initially as a "morphoedaphic index" (MEI) by Ryder (1965) for use as a rapid method of yield assessment for northern temperature lakes. The MEI has since been modified for application to tropical lakes through a regression analysis by Henderson and Welcomme (1974). The MEI has been widely used as an approximation of potential yields for reservoirs in Africa, South America, United States and Canada (Welcomme and Henderson 1976)

A regression analysis relating MEI values and fish yields from tanks in Sri Lanka was recently completed by Wijeratne and Costa (1979). The relationship is as follows:

$$C = 19.0677\ MEI^{0.7050}$$

C = potential fish yield in kg/ha/yr; and

MEI = conductivity in micromhos/cm ÷ mean depth in m.

Using this formula and the available water quality and reservoir morphological information, the potential fish yields of each of the proposed reservoirs was calculated. These figures and the supporting data are presented in Table G-4. Total annual estimates for potential fish landings at the proposed reservoirs are also included in Table G-4 and were based upon the mean areas of the reservoirs.

The calculated yields clearly indicate that the deep, up-country reservoirs are likely to be much less productive (20 to 35 kg/ha/yr)in terms of fish output than the shallower,low-country ones (100 to 300 kg/ha/yr). This corresponds well with information concerning fish yields from other reservoirs throughout Southeast Asia and within Sri Lanka (Fernando and Furtado 1975; Fernando 1976). The deep reservoirs in Southeast Asia produce low fish yields of only 10-40 kg/ha/yr in comparison with the shallower lakes. Low fish yields in deep reservoirs are the result of low levels of incoming nutrient supplies, pronounced thermal and chemical stratification and a limited shallow inshore area which is usually the most highly productive zone of a reservoir.

Estimated Standing Stocks - Since the MEI estimates provide an indication of the optimum yields from the proposed reservoir environments, they can be used as a basis for predicting the standing fish stocks which the reservoirs would maintain in order for those optimum yields to be produced. An exploitation rate of about one-third of the standing stock has been suggested as a reasonable estimate of the annual harvest level in a reservoir (University of Michigan 1971). Consequently, based upon the yield estimates presented in Table G-4, the standing stocks of the respective proposed reservoirs may be from about 65 to 900 kg/ha.

Table G-4

Estimated Potential Fish Yields for the Proposed Reservoirs Based on the Morpho-Edaphic Index from Wijeratna and Costa (1979)

RESERVOIR	Mean Water Level 1/				Electrical 3/ Conductivity	Estimated Fish Yields	
	Elev. m	Area km^2	Storage mcm	Mean 2/ Depth m	Micromhos/ cm	kg/ha/yr	Annual Reservoir Total (Tons)
KOTMALE	690	5.2	120	23.1	33	25	13.0
VICTORIA	420	13.0	624	48.0	60	22	28.6
RANDENIGALA	219	19.5	810	41.5	95	34	66.3
MORAGAHAKANDA	176	18.0	280	15.5	169	103	185.4
ROTALAWELA	63	25.0	70	2.8	108	250	625.0
KANDAKADU BARRAGE	30.5	29.0		2.5	136	319	925.1
ULHITIYA/ RATKINDA OYA	105.6	20.2	122	6.0	107	145	292.9
MADURU OYA	944	34.8	536	9.7	138	124	431.5

1/ Mean water elevations, reservoir areas and reservoir storages are estimated from area-capacity curves using the 50% levels presented in the duration tables in NEDECO (1979) ANNEX O. RUN 372 was selected for Kotmale, Victoria and Randenigala Reservoirs and RUN 374 for Moragahakanda Reservoir. Estimates for Rotalawela Reservoir were derived from an average of the high and low water elevations and using the area capacity curve in NEDECO (1979) ANNEX O. The Kandakadu Barrage is assumed to always remain at full storage. Data for Ulhitiya/Ratkinda Oya and Maduru Oya Reservoirs are from NEDECO (1979) ANNEX B.

2/ Mean depth is calculated as mean storage ÷ mean area, except for the Kandakadu Barrage where the mean depth is approximated since storage data is not available.

3/ The EC values used were taken from available water quality data (SEE TOPIC REPORT F: WATER QUALITY). Mean values were used where possible and/or simple mass balance estimates were made using inflow data from NEDECO (1979) ANNEX B.

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Other Factors Affecting Yields and Standing Stocks - Fisheries yields and standing stocks from a reservoir are of course affected by other factors besides the mean depth and total dissolved solids input as related in the MEI. An important factor will be the age of the reservoir. In the first 4 or 5 years, yields are often substantially higher than in later years. One reason for this is that during the initial flooding large amounts of organic matter are suspended, serving as direct fish food or as a nutrient supply for algae. The subsequent large algae growths may trigger a chain reaction in the food web of the reservoir which can be manifested by accelerated fish growth and reproduction. An additional reason for high initial fish production could be that the rising waters stimulate nearly continuous spawning behaviour in some species. The onset of river flooding stimulates immediate spawning responses from many species, and this behavior may be accentuated by reservoir filling. However, initial high fish yields in Asian reservoirs have not always occurred. This may be due to a lack of suitable fish species in the areas inundated or a failure of fishermen to mobilize soon enough to take advantage of the high productivity in the first few years of reservoir operations.

Other factors which will affect fish production include an irregular shoreline which may occur along the edges of the reservoirs. This will enhance fishery development by providing added cover and feeding grounds. On the other hand, the acticipated steepsided character of the up-country reservoirs will limit the amount of shallow inshore areas which are common spawning grounds for many species.

Drawdown can also have a detrimental effect on fisheries by exposing eggs and nests of inshore areas. However, this should not be a significant factor, because most species which will inhabit the proposed reservoirs will spawn during periods of reservoir filling. Drawdowns may, in fact, benefit fish populations by providing organic detritus for feeding juvenile fish as waters rise.

Net Yields and Standing Stocks of the Proposed Reservoir - A comparison of standing stock estimates from the existing rivers with those predicted for the reservoirs which would inundate sections of those rivers, indicates that on a unit area basis, the differences may be relatively insignificant. Standing stocks supported by the new reservoirs of 65 to 900 kg/ha may not differ appreciably from the present (estimated) river levels of 100 to 600 kg/ha, except perhaps for the more highly productive low country reservoirs. The total standing stock per reservoir will, of course, exceed totals in the inundated river sections substantially due to the large areal differences (see below).

On the other hand potential yields of food source species (for human consumption) from the proposed reservoirs will greatly exceed existing river yields both on a unit and total area basis. This latter is shown in Table G-5.

Table G-5

Net Fish Yields For Proposed Reservoirs In Comparison To River Section Inundated

	River Section Affected		New Reservoir Pools		
Proposed Reservoir	Mean Area Lost to inundation (ha)	Total Yield Lost (tons/yr)	Mean Surface Area (ha)	Total Estimated Yield (tons/yr)	Net Yield (tons/yr)
Kotmale	80	0.8	520	13.0	12.2
Victoria	155	1.6	1300	28.6	27.0
Randenigala	240	2.4	1950	66.3	63.9
Moragahakanda	70	0.7	1800	185.4	184.7
Rotalawela	480	4.8	2500	625.0	620.2
Kandakadu	360	3.6	2900	925.1	921.5
Ulhitiya Oya	20	0.2	2020	292.9	292.7
Maduru Oya	60	0.6	3480	431.5	430.9

Total Net Yield 2553 Tons

This clearly shows that potential yields from the new reservoirs, assuming optimum catch efforts are employed, will be significantly larger than present river yields.

IMPACT ON MIGRATION PATTERNS

The series of dams which will be constructed on the rivers and streams in the project area will effectively block upstream fish migratory movements. Several species will be adversely affected, although it is difficult to adequately assess the overall effects on fish movements because little is known of the migration patterns in the island waters.

One species which may be significantly affected is the Mahsier (*Tor khudree*), a popular game fish. The Mahsier has been observed by local residents and biologists to undergo seasonal upstream spawning migrations. The presence of the proposed dams combined with an inability of the Mahsier to adapt to lake habitats will probably result in a significant decline in the population of this species in the Mahaweli Ganga.

Other fishes which may be adversely affected by interference with migration patterns are probably the endemic Mountain Labeo (*Labeo fisheri*), Olive Barb (*Barbus sarana*) and Long-Snouted Barb (*Barbus dorsalis*). These species are all believed to migrate annually up the main rivers to spawn in very small hill streams. The Barbs often leave tanks or villus to enter upstream rivers and streams. Occasionally large concentrations of these fish are found in very small streams. The numbers are often so large that monkeys have been observed capturing them by hand (Dr. W. Dittus, Smithsonian Institute, personal communication).

Young eels also migrate upstream annually, returning after several years to spawn at sea. The higher upstream dams will undoubtedly block their passage, although they may be capable of negotiating the smaller downstream ones.

In addition to fish species, the freshwater shrimp (Macrobrachium) will also have its migratory patterns affected by the dams. This impact may be mostly due to the construction of the downstream Kandakadu Barrage which could block breeding migrations to and from the estuary.

Downstream fish movements will also be blocked by the proposed dams. However, fish may be swept over the spillways or drawn into the power intakes. Generally, about 75% fish which pass through power turbines will survive; the remainder usually perish due to physical injury.

IMPACT ON TANK FISHERIES

Major Tanks

Although the flushing rates in the major tanks will increase (see TOPIC REPORT F: WATER QUALITY), nutrient availability to these systems should be more than sufficient to maintain their high potential productivities. Return flows from the proposed irrigation systems are not expected to enter the four major tanks, i.e. Parakrama Samudra, Minneriya Tank, Kaudulla Tank and Kantalai Tank. Consequently, nutrient cycling and its ultimate effect on the fish community should be generally unchanged due to increased cultivation schemes.

On the other hand, each of the four major tanks will experience a change in the surface area inundated due to planned operational changes in water balance and irrigation requirements (NEDECO 1979 Annex B). Changes in surface area would result in concomitant increases or decreases in standing stocks and potential yields from these tanks. To evaluate these impacts quantitatively, potential yield estimates were made using the MEI as previously described and from data presented in TOPIC REPORT F: WATER QUALITY. Potential yields for all four of these shallow, highly productive tanks are more than 300 kg/ha/yr. Using a conservation estimate of about 250 kg/ha/yr the net effects on the potential resources of the tanks are shown on Table G-6.

Table G-6

Effects on Potential Fish Yields of two Major Tanks

TANK	Present Mean Area (ha)	Future Mean Area (ha)	Change in Yields (tons/yr)
Parakrama Samudra	1500	1760	+ 65
Minneriya	1700	1580	- 30
Kaudulla	1250	880	- 98
Kantalai	1370	1210	- 40
		Net Total	- 98

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Consequently, gains from increased habitat area for Parakrama Samudra would be negated by losses to the other three tanks. It should be noted that the present high and low water levels for the tanks may still be reached after project implementation; however, the duration that these levels will be maintained will be much shorter than under present operations. Thus, the changes in mean water levels are believed the best indication of future areal habitat changes in these aquatic systems.

Medium Tanks

A number of medium tank irrigation systems in the project area, particularly systems at Allai Tank, Pimburettawa Tank and Vakaneri Tank, will undergo changes in flushing rates and areal habitats comparable to those of the major tanks as described in the previous section. However, details of these changes are not yet available, and thus specific increases or decreases in fish standing stocks or yields for these tanks cannot be made at this time.

Some of the medium and smaller tank fisheries may be adversely affected due to the inflow of pesticide runoff from irrigation projects. In particular, the downstream tanks such as the Vakaneri and Allai tanks may eventually be seriously affected as pesticides accumulate in the tissues of food fish species.

In addition, high levels of nutrient salts may accumulate in the waters which will eventually provide inflow to these downstream tanks. This could increase eutrophication rates substantially in these tanks and may result in subsequent changes in the fish community. Herbivorous fish may increase growth rates which would be beneficial, although other species may be adversely affected by changes in the nutrient cycle and the possible deterioration of water quality.

IMPACTS ON VILLU FISHERIES

The alteration in the present Mahaweli Ganga flood peaks and dry season flows will result in an overall decrease in the water surface areas of the flood plain including the villus. The reduction in floodplain area with implementation of the Accelerated Program could be up to 50%. (Details are provided in TOPIC REPORT A: CLIMATE AND HYDROLOGY.) The total floodplain area for the project area is about 12,800 hectares.

The reduction of inundated floodplain area will result in a corresponding loss to the fisheries resources. Based upon a present estimated yield of 50 kg/ha/yr, the total loss in fish yield would be about 320 tons/year. This would be decreased further with additional diversion of river waters into other basins.

The above figures represent losses to the capture fisheries operations for the villus only. A further, non-quantifiable adverse impact would be the fisheries resource losses in the villu total standing stocks and throughout other parts of the Mahaweli Ganga system. This will result since the flood-

plain areas which will be reduced provide spawning and nursery grounds for a number of species which inhabit rivers, streams, backwaters, ponds and tanks of the entire system.

In addition, villus have a high potential for fish culture (see following section), provided water levels are maintained for a growing season (6 to 8 months). A drop in villu water levels due to river flow reductions would significantly decrease the value of these habitats for future fish culture operations.

Since many of the villus will receive irrigation return flows, pesticide accumulations could become a problem for the villu aquatic biota. The increased nutrient inflow from agricultural runoff will affect the productivity of the villus, very likely accelerating it to produce highly eutrophic conditions. This may benefit some areas but the resultant deterioration of water quality in the villus could have overall negative impacts on the fisheries resources such as changing species composition, inhibiting life cycle patterns, causing partial fish kills or tainting fish flesh.

IMPACT ON ESTUARINE FISHERIES

The alteration of natural flow regimes coupled with a downstream accumulation of agrochemicals is likely to have an overall negative effect on the estuarine fishery resources at the mouths of the Mahaweli Ganga and Maduru Oya. This may be especially evident for the shrimp nursery grounds, since shrimp juveniles require a delicate balance of organic matter cycling to coincide with their feeding cycles. Changes in the nutrient loading of the estuaries is liable to upset this balance with an overall detrimental effect upon shrimp and fish populations.

A secondary adverse impact on estuarine fisheries may result due to the further reduction of mangrove swamps and the reclamation of salt marsh areas. The remaining mangrove swamps and salt marshes are very limited, but fuelwood needs and pressures from settlement areas due to the increased population in the region could result in added encroachment to these sensitive habitats. Removal of this intertidal vegetation would decrease spawning and nursery grounds for shrimp and a number of estuarine dependent fish species. This in turn would be very detrimental to the present commercial operations in the estuarine portions of the project area.

IMPACT ON ENDEMIC FISH SPECIES

Most of the endemic forms occurring in the project area inhabit small, upland streams. Some of these habitats may be inundated by the upcountry proposed reservoirs, i.e. Kotmale, Victoria, and Randenigala Reservoirs. This would probably eliminate endemic species occurring there, since few of these fishes appear to be adaptable to reservoir habitats. In general, the loss of these habitats would not be considered a highly significant impact, since the endemic fish species affected also occur in high numbers in many other river drainages throughout the country. The endemic species populations in tributaries of the Mahaweli Ganga and Maduru Oya which are not inundated are expected to remain unaffected by project developments.

The Mountain Labeo (Labeo fisheri) may, in fact, be doubly affected since the proposed dams will inhibit its normal upstream migration route. The Sri Lankan Barb (Barbus srilankensis), the most restricted of the endemic fish in the area, should be relatively unaffected by the project, since no developments are presently planned which would involve the Kalu Ganga drainage system. Two endemic species, Leaf Lates (Belonita signata) and especially the Smooth Breasted Snake Head (Channa orientalis), will probably benefit by the project since they prefer quiet waters, and thus their populations are likely to expand with the formation of the reservoirs and the presence of large paddy areas.

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RECOMMENDED ACTIONS

PLANNING FOR FISHERIES DEVELOPMENT

Overall, the potential for fisheries development in the project area is very high and its realization, in fact, may become essential as the demand for protein increases in the future years of settlement growth. Fish presently are a predominant source of protein in the rural communities of Sri Lanka. With full development of the Mahaweli Accelerated Program, the nutritional and market demands for fish and fish products will increase significantly in the project area.

Some of this demand can be met by improving capture fishery yields from existing sources; however, maximum yields will soon be harvested from the marine fisheries operations (Ministry of Fisheries 1980c) and the present freshwater catches (mostly from the major tanks) are all marketed and consumed locally. Consequently, it is likely that the majority of the required demand will have to come from the development of new fishery resources.

It appears that a master plan for fisheries development within the project area is needed. Some programs, including the development of a new fish breeding station, a stocking plan and permanent settlement of fishermen, have been initiated in varying degrees for the existing System H. irrigation project. These programs are being developed through the combined efforts of the Inland Fisheries Development Division and the MDB. However, comparable planning for the Accelerated Program area has only been at a very preliminary level. In the following sections, recommendations are discussed for the mitigation of adverse project impacts on fisheries, some new potential fishery resources to meet future demands, and for fisheries development planning in general for the project area.

CAPTURE FISHERIES

Proposed Reservoirs

The total capture fisheries yield which could be provided from the combined outputs of the major proposed reservoirs (Table G-4) is estimated at roughly 2570 tons per annum. However, the yields from the three upcountry reservoirs (Kotmale, Victoria and Randenigala) are likely to be marketed outside the agricultural development regions of the project area. This could reduce available yields to the new settlers to about 2,450 tons/yr. Further, if the proposed Rotalawela and Moragahakanda Reservoirs are not constructed, the available yields will decrease to only 1,640 tons/yr.

It is apparent that the estimated need for fish products within the project area will not be met solely by the natural capture fisheries of the new reservoirs and other sources,discussed in following sections, will have to be utilized. In any event, the potential yields from the proposed reservoirs will be substantial. Moreover, in order to capitalize upon this potential resource, several planning measures may be necessary.

Nature of the Reservoir Fisheries - It is recommended that planning for fisheries development of the new reservoirs be conducted with the aim of promoting small-scale fishery operations, comparable to those on the existing major tanks. This would involve the use of small fishery management units, consisting of a single fisherman with perhaps an assistant operating from non-motorized canoes and using primarily gill nets along with handlines, cast nets, beach seines or traps where they are applicable.

This type of fishery is labor intensive and attracts more individuals, since input costs and maintenance are low. Use of large,relatively expensive boats especially ones equipped with outboard motors, is not recommended. The additional costs for the boats, motors,fuel, etc. and especially maintenance problems are an unnecessary burden to the fishermen. Further, the small scale operations are well suited to effect maximum exploitation of the fishery resources on what will be relatively small sized reservoir areas. Collection gear, however, can be modified with new gears introduced to harvest the different fish stocks. It is recommended that gear selectivity studies be initiated once the reservoirs are operational in order to determine the most appropriate gill net mesh sizes, the best trap designs, etc.

Subsidy and extension programs will also be needed to fully develop fishery potential on new lakes. These programs have been proposed as part of the new Master Plan for country-wide fisheries development (Ministry of Fisheries 1980c). The subsidy of 35% for boats and gear recommended in the Master Plan for fishermen at major tanks should be extended to the new proposed reservoirs to stimulate fisheries development there. Likewise, additional extension service officers should be trained as part of the government's new training program for administering the future reservoirs.

Removal of Reservoir Vegetation - The MDB has planned to clear as much vegetation as possible from the proposed reservoir sites. There are various issues concerning fisheries development which require consideration in the planning of vegetation removal from a reservoir site prior to inundation. Trees and other woody vegetation which remain within a reservoir after flooding often impede lake navigation and usually prevent or limit fishing activities because of damage to nets and other gear. On the other hand, this vegetation provides a suitable substrate for food-chain organisms used by fish and also serves as protective cover and spawning sites for many species.

Recommendations made here take both of these conflicting aspects into consideration along with the nature of the proposed reservoirs. It is essential that much of the woody vegetation be removed from all of the proposed reservoirs if effective fishing of the natural stocks is to take place. However, to enhance natural fish productivity in the reservoirs, especially for the deep up-country ones, it is advisable to permit small tracts of forests to remain in selected areas of the reservoirs. Approximately 20-25% of the inshore drawdown zone vegetation should be maintained. However, it should be subdivided into small blocks of 5 to 10 hectares, which are separated by open water (where vegetation has been removed) zones of one-half kilometer, or more. The remaining vegetation blocks should be about 100 to 200 meters from the shore. The inshore area between the beaches and the banks should be cleared as completely as possible. During any clearing,

it is unnecessary to actually remove or burn all of the vegetation and other debris from the site. Instead, it is advisable to form large brush piles where possible as part of the vegetation blocks which would be left. In fact, the brush piles can substitute as remaining vegetation blocks; the system of creating and leaving brush piles has been effective in increasing fish production in other tropical reservoirs (Dr. J.M.Kapetsky, FAO, personal communication).

A clearing pattern of this nature will permit utilization of all types of fishing gear with minimal risk of damage and simultaneously provide a feeding and nursery area to replenish natural fish stocks. This clearing plan will be well suited to small scale fishing activities. Fishermen can employ cast nets and seines in the cleared, shallow inshore areas,use gill nets at the edges of the vegetation blocks and traps within the vegetated areas.

Introduction of Species - While indigenous fish populations are likely to contribute a sizeable portion of the reservoir yields, it is likely that other species will have to be introduced in order to maximize outputs.

The most likely candidate for stocking in the new reservoirs is the common Tilapia species, *Tilapia mossambica*, which is already prevalent in many of the freshwater areas of Sri Lanka. The MDB in collaboration with the Ministry of Fisheries is planning to construct a new fish station in Dambulla for the purpose of producing Tilapia fingerlings to stock in the waters of the System H area. The MDB has indicated similar intentions for the Accelerated Program area, and the Ministry of Fisheries is embarking on a program to raise and stock Tilapia in many of the island inland waters, mostly tanks.

It is suggested that within these proposed planned stocking programs, consideration be given to the fact that *Tilapia mossambica* is a prolific breeder in Sri Lankan waters and that repeated stocking of the species into tanks and reservoirs may be unnecessary since its own reproductive potential may be sufficient to maintain high populations in the reservoirs. Thus, *Tilapia mossambica* could be introduced into the proposed reservoirs in order to allow the establishment of self-sustaining populations, while other species would be considered for annual stocking and restocking programs.

Tilapia mossambica has been introduced widely throughout Southeast Asia and is likely to appear in many of the new reservoirs even if it is not intentionally stocked. One problem which is often associated with Tilapia introductions is that due to its high reproductivity, crowding may occur which results in stunting of the growth of individual fish which in turn may limit their marketability. This has been observed in a number of reservoirs and especially in small ponds in Asia. On the other hand, high fishing intensity and/or high predator pressure often control Tilapia populations and thus prevent or limit stunting (Sreenivasan 1967; Balarin and Hatton 1979). In fact, predators are often deliberately stocked with Tilapia to control their growth rates in fish culture operations. Natural predators which are likely to occur in the proposed reservoirs include the Snake Heads and various Catfishes, especially the Freshwater Shark (*Wallago attu*). The latter is an especially voracious predator which may reach up to six feet in length and whose stomach contents have occasionally been observed to include human limbs (Alikunhi 1957).

Until recently, stunting of Tilapia mossambica had not been observed in Sri Lanka waters (Fernando 1976). It had been believed that predation from piscivorous birds as well as fishing controlled potential stunting of the species. However, de Silva and Fernando (1979) report that the mean sizes of Tilapia in fish catches from Parakrama Samudra have decreased significantly. The causes for this are unclear, although it may simply be due to overcrowding following high spawning productions. It may, however, be the result of heavy fishing pressure on fish species which prey on Tilapia. A relatively low abundance of piscivorous fish species was recently observed at this tank (Dr. F.Schiemer, Limnological Institute of the Austrian Academy of Science, personal communication).

In any case, since stunting of Tilapia mossambica has occurred, it would not be advisable to introduce this species into the new reservoirs until further information is available concerning its population dynamics in Sri Lanka. However, since the species is well distributed in the country, it is likely that it would appear in any event within the new reservoirs. Even though it may then stunt at some time, the species could still be valuable at a small size - currently, many small sized fish are marketable, especially smoked or dried. It may also be possible to limit stunting through heavy fishing with small mesh beach seines.

One further concern in the stocking of Tilapia mossambica is that the species is unlikely to be successful in the three up-country reservoirs. Its growth and reproduction have been very low in the existing hill tanks (Fernando 1976). On the other hand, different Tilapia species which are better adapted for deeper waters and/or colder habitats may be amenable to the up-country reservoirs. These Tilapia species include Tilapia sparmanni an omnivore, and Tilapia galilaca which feeds on phytoplankton.

Common Carp (Cyprinus carpio) is also a likely candidate for the upland reservoirs. However, it is not recommended to stock this species in shallow reservoirs, since it often destroys inshore fish nests, and it may not grow well in these warmer waters (Dr. C.H.Fernando, personal communication). Crucian Carp (Carassius carassius) would be another possible species for introduction into deeper reservoirs, since it breeds and thrives well in that type of habitat.

For the low-country reservoirs, exotic species which may be considered for introduction would include other Tilapia species, Banded Etroplus, the Indian carps and the Chinese carps. The Tilapia species could include Tilapia nilotica, Tilapia zillii and Tilapia rendalli all of which have been introduced previously to Sri Lanka. The latter two may be particularly valuable, since they are herbivores which have been used successfully in other reservoirs to partially control aquatic weeds (Balarin and Hatton 1979). Other species recommended for the low-country reservoirs would be the native fishes which are prevalent in fish catches from the major tanks. These would include the Common Labeo (Labeo dussumieri),Olive Barb (Barbus sarana), Snake Heads and Catfishes.

Some relevant data may be available before the reservoirs are filled from a proposed experimental stocking program involving Tilapia and Carp species in various combinations presently being initiated by the Ministry of Fisheries.

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This type of polyculture experimentation is highly endorsed, and it is recommended that further trials be attempted in order to develop sound stocking policies for both the proposed reservoirs and the existing tanks in the project area.

Additional introductions in project area waters should be considered for the control of mosquito larvae since malaria may be a substantial problem. Mosquito fish or Gambusia have been recommended for introduction to assist mosquito control (HTS ANNEX Z 1979),but a species native to Southeast Asia called the Lesser Top-Minnow (Panchax panchax) is considered superior to Gambusia (WHO 1973). This species is native to Sri Lanka and could be easily captured and transferred to the project area waters. An additional species, Aplocheilus dayi, has been very effective against anopheles larvae in trials conducted by the Anti-Malaria Campaign here and thus may also warrant consideration for introduction (de la Motte et al. 1980).

Fish Ladders

At the present time, it is not recommended that consideration be given to installing fish ladders or comparable conveyances to permit upstream passage of fish during spawning migrations. There are few species adversely affected by blockage of migration routes; and none of these species are of exceptional economic value. If further study warranted by-pass devices, it is likely that they could be installed after the dams are constructed. One area in which investigations should be considered is for the Kandakadu Barrage where the continued passage of estuarine species including Macrobrachium may significantly benefit upstream fisheries. However, this barrage may not be constructed and is presently under study.

Rivers and Estuaries

The negative impact on river and estuarine fishing resources due to the accumulation of runoff agrochemicals can be mitigated in part by the maintenance of downstream conservation flows, the judicious application of fertilizers and the use of rapidly degradable pesticides in place of the persistent organochlorine types. Further recommendations and discussions of these topics, including a pesticide monitoring program are presented in TOPIC REPORT F: WATER QUALITY.

It is not recommended that any measures be instituted to further intensify fishing activities in the estuaries of the Mahaweli Ganga and Maduru Oya. These areas are presently heavily fished. In fact, some regulations may be warranted in terms of mesh size or limited fishing seasons in order to protect fish and shrimp stocks.

Tanks and Villus

Major Tanks - The major irrigation tanks in the project area have been designated for improved fisheries management programs by the Inland Fisheries Development Division. This includes additional stocking and subsidy programs for boats and gear. The Ministry of Fisheries plans to increase fish yields from these tanks up to maximum potential yields. Based upon the MEI yield predictions and the area changes which will result from project implementation,

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the major tanks could potentially yield about 1358 tons per year, which would be an increase over present yields of more than 20%. These estimates are based upon mean tank surface area; present estimates are very arbitrary since the catch statistics available are very unreliable.

Medium Tanks - Medium Tanks in the project area include Mapakada Tank, Dambarawa Tanks, Horabora Wewa Tank, Pimburettawa Tank, Vakaneri Tank and Allai Tank. Collectively, these tanks have a total surface area of approximately 3,250 hectares.

Plans to improve fisheries output from the medium tanks in Systems B and C (all except the Allai Tank from the above list) have been formulated by ACRES (1979) and HTS (1979, Annex I). These plans involve supplemental stocking tree clearance and the provision of boats and gear. In addition, three new medium tanks totalling about 1,000 hectares are scheduled for construction in System C.

Present yields (50 kg/ha/yr) at the medium tanks are low basically due to the lack of fishermen and/or suitable gear. Yield estimates for the above plans were selected at 100 to 150 kg/ha/yr. However, these are below potential maximum sustainable yields for these tanks which due to their shallowness and eutrophic conditions, should produce yields comparable to those of the major tanks (250 kg/ha/yr), or even higher. These yields should be attainable from natural stock production, some limited supplemental stocking and the provision of adequate gear. It is thus recommended that the program planned for the major tanks by the Ministry of Fisheries be extended to the medium tanks. Total potential yields from these tanks in the project area should be about 1,060 tons/yr, an increase of 6 to 7 times over present yields.

Villus - Villu fishery resources, along with those of some of the downstream medium tanks, may be adversely affected by the runoff of pesticides and fertilizers. Monitoring of these chemicals is recommended as mentioned in TOPIC REPORT F: WATER QUALITY. In addition, it may be feasible to route return flows around some villu and tank areas to prevent or limit their poulltior with agrochemicals.

With project implementation, the loss in floodplain fisheries may be mitigated in a few selected villus by essentially converting them to tanks through control by means of weirs or dikes at the villu mouths. Subsequent stocking of these areas could then be undertaken to increase potential yields in a manner comparable to that suggested for the major and medium tanks. However, the cost of the civil works may be prohibitive except in a few cases.

Irrigation Canals

Fisheries, at least at the subsistence level, can also be developed within the irrigation canal systems. The canals themselves will support some species, while pools or backwaters which are created naturally or for storage along the canals may be very suitable habitats for food source species. Stocking of these waters is thus recommended where feasible.

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POTENTIAL YIELDS FROM CAPTURE FISHERIES

From the preceding sections, and taking into account impacts on present water regimes, the potential fish yields which will be available from project area waters would be:

SOURCE	POTENTIAL YIELD (TONS)
Proposed Reservoirs	2570
Major Tanks	1360
Medium Tanks	1060
Villus	320
River/Irrigation Systems	100
Total	5410 tons/yr

These figures do not include estuarine fisheries yields, although they are somewhat inflated by including yields from all of the proposed reservoirs. In addition, it is assumed that the maximum potential estimated yields for the major and minor tanks could be realized.

FUTURE PROJECT AREA DEMAND

The future required supply of fish and fish products in the project area will be based on the nutritional needs of the population and the market demand. Generally, an average individual should consume approximately 14.5 grams of animal protein daily to maintain a healthy nutritional status (Dr.M.Smith, Colombo Campus, personal communication). With a projected population of about one million for the Accelerated Program area, the total annual animal protein required would be approximately 5,290 metric tons.

Fish are of course an excellent source of animal protein. Other sources include beef, dairy products, eggs, etc. About 16% of the net weight of landed fish is animal protein content. Consequently, potential yields from the capture fisheries sector in the project area could contribute about 865 tons or 16% of the future animal protein requirement.

Reliable market demand data for fish products are unavailable. It is apparent though that the market easily absorbs all fish captured from inland and marine resources. The Ministry of Fisheries (1980c) reports that per capita consumption in 1978 was 11.4 kg, while the goal is to increase this to 20 kg per annum. For the project area population this would imply an annual demand of about 11,400 tons of fish based on present consumption levels and around 20,000 tons for future targeted consumption.

Consequently, even assuming that potential yields could be fully realized from project area waters, it is evident that the capture fisheries sector will not provide sufficient amount of fish products to meet future nutritional and market demands. Thus, additional sources of fish production will be necessary.

AQUACULTURAL POTENTIAL

A program to investigate aquacultural potential within the project area is highly recommended if future fish product demands for the region are to be met. A series of pilot projects should be implemented to determine the most feasible fish farming techniques which can be used for the areas. Some of these, including cage culture and a few pond experiments, are under way or at least planned by the Inland Fisheries Development Division. A more extensive program is needed however. Particular attention should be given to the use of small seasonal village tanks which follow an annual filling and drainage cycle which is easily adaptable to many fish farming methods. Some additional pilot projects to be considered are discussed briefly below.

Cage Culture

Production of harvestable fish in floating cages has been successful in other parts of Asia and may be highly feasible for the shallow major tanks and new reservoirs in the project area. Dr.K.D. Arudpragasam (Colombo Campus) has undertaken preliminary studies to determine the technical and economic viability of cage culture in Sri Lanka. Initial findings are that eight cubic meter volume cages made of bamboo, PVC and nylon net can be constructed for about 200 to 600 rupees and will last about two years. A yield of about 100 kg has been obtained using Tilapia over a six months growing period with supplemental feed costing about 0.60 rupees per day.

Cages are often a very feasible means of raising Tilapia, since the cage limits further breeding and thus prevents stunting. Additional trials with cages are advisable using different species and testing the adaptability of the cages to various environments including tanks, rivers, backwaters and villus.

Pen Culture

Somewhat similar to cage culture, the use of a fixed pen enclosure constructed of bamboo and nets can also be considered a highly feasible means of raising fish in the project area. Pen culture has met with a high degree of success in a number of Southeast Asian countries,especially in the Philippines.

Fish pens installed in shallow bodies have been highly productive with yields usually averaging about 2000 kg/ha/yr, and levels of 5000 kg/ha/yr are not uncommon. This type of aquaculture could contribute significantly to regional fish demands and a study of the feasibility of pen culture is highly recommended for the project area waters including new reservoirs, existing major and medium tanks, and villus.

Polyculture

Polyculture involves the raising of a combination of various species in a single system, i.e. pond, cage or pen. Polyculture systems normally produce much higher yields than mono-culture operations. Some polyculture research has been planned by the Inland Fisheries Development Division involving

Tilapia, Chinese Carps, Indian Carps and Common Carp. It is recommended that this be extended to include an examination of a combinatiion of the different Tilapia species with various predators (Snake Heads and Catfish) to test stunting control. Other species to be considered would include Banded Etroplus, Common Labeo and other native species.

Integrated Farming

Integrated farming practices may be highly amenable to certain areas which could accommodate a combined poultry and fish raising system. This would involve maintaining chicken or duck flocks around ponds or small tanks which are stocked with fish.

Manure generated by the chickens or ducks provides fertilizer to stimulate primary productivity in the ponds. In addition, ducks in particular, can obtain highly suitable forage in and around a fish pond without causing detrimental effects on the fish population; this of course also reduces the cost of supplemental feed for the ducks.

A pilot integrated system is recommended to demonstrate technical and economic feasibility. This system can produce animal protein from the poultry, eggs and fish as well as contribute to future market demands.

Estuarine Aquaculture

The potential for using salt barrens as pond sites and for utilizing lagoons, especially the Upaar Lagoon for pen cultures should receive additional study. These areas would appear to be ideal for raising higher value species such as shrimp, mullet and milkfish. Juveniles of these species could be collected from nearby ocean waters and stocked in ponds or pens where they may be raised to harvestable sizes.

Low Level Technology

Generally, the aquacultural practices discussed above require relatively high level technological inputs, especially suitable training, to be successful. Implementation of these types of fish culture will require research and field trials or pilot studies before more broad application can be adopted.

A more immediate program to substantially increase project area fish yields is recommended here involving supplemental stocking of seasonal tanks in the project area. This program is highly feasible economically and financially and requires low level technological inputs. The proposed program is discussed in detail in the following section.

SEASONAL TANK PROGRAM

Background

An examination of 1979 aerial photography indicates that there are approximately 4000 hectares of small, seasonal tanks in Systems A,B,C and D. Most of these tanks are less than 10 hectares in surface area. It is proposed that these tanks be annually stocked with fingerlings and serve as rearing areas until harvestable sizes are attained.

Stocking and Harvesting

The tanks would be stocked at a density of 5000 fingerlings per hectare of Indian Carps. Indian Carps were selected due to the fact that they would be well accepted by consumers, and since aquacultural and breeding procedures for these species are well established.

Several species would be stocked in order to take advantage of all of the major food niches available in the tanks. The three principal species are Catta catla, Labeo rohita and Cirrhina mrigala which are surface, column and bottom feeders, respectively. However, other species could be easily substituted if desired. This could include the Cauvery Carps which have been successfully cultured in Southern India in polyculture with the Indian Carps listed above (Bardach, Ryther and McLarney 1972). The Cauvery Carps include the Fringe-lipped Carp (Labeo fimbriatus), the White Carp (Cirrhinus cirrhosa) and the Cauvery Carp (Labeo konitus). Consideration should also be given to using the Common Labeo which is native to Sri Lanka; experiments as presently underway to determine the adaptability of this species to hatchery operations (Dr.M. Smith, Colombo Campus, personal communication). Different Tilapia species could also be used and in fact a mixture of some or all of the above species may be the most advantageous approach (Dr. C.H. Fernando, personal communication).

The fish are to be stocked near the end of the wet season when the tanks are full. Individuals of all three principal species should reach a size of at least 0.5 kilograms in the 8 or 9 months while the tanks retain water. Many of these tanks will no longer be required to release as much water for irrigation purposes due to project implementation. Assuming a 50% mortality, the initially stocked fish should produce a yield of at least 1000 kg/ha/yr without supplemental feeding.

The fish will be harvested using traditional non-motorized canoes, gill nets and seines. It may be possible to selectively harvest faster growing individuals at an earlier stage in the rearing period by using large mesh sized nets which would allow smaller fish to escape and continue growing.

The tanks will be upgraded with the addition of nets or screens to prevent escape through the release outlets. Also, some vegetation clearance and bund repair may be necessary. It has been assumed that the government's program to renovate many small tanks in the dry zone would bear much of the costs of dredging where necessary.

Hatchery

Location and Administration - In order to provide the roughly 20 million fingerlings needed to annually stock the tanks, it is proposed that a jar hatchery be constructed in a centrally located position in the project area. A preliminary site would be in the vicinity of Manampitiya. A new hatchery is recommended since the facilities necessary to produce the desired fingerlings are fairly substantial. Renovation of an existing breeding station would essentially require complete remodelling and construction. It is suggested that the existing station in Polonnaruwa be maintained with efforts there directed at producing suitable species for stocking in the new reservoirs and the major and medium tanks and for providing extension services.

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Physical Plan - The proposed hatchery would be a jar-type hatchery (see Figure G-2). This type of hatchery has been implemented successfully in India, and a prototype is presently being developed by Dr.M.Smith of the Colombo Campus.

The proposed hatchery site would occupy an area of about 25 hectares. It would include a hatchery building (150 m^2), staff quarters, laboratory, garage and offices. There will be six brood stock holding ponds with a total area of about 3.0 hectares and about 15 hectares of nursery and rearing runways.

Operation and Administration - Hatchery operation would be administrated through the Inland Fisheries Development Division of the Ministry of Fisheries. There are a number of existing Ministry staff members sufficiently trained to conduct the necessary technical operations of the hatchery, although some further training may be needed for assistant aquaculturalists and field assistants.

Induced breeding operations via pituitary injections will take place with selected brood stock at the onset of the rainy season, which corresponds to the natural breeding cycle of the carps (November to March). Eggs are collected and hatched in jars (Figure G-2). About 1.5 million fry will be available for stocking into small nursery runways every 3 days. Thus, in a little more than two months, a total of more than 33 million fry will be produced.

Fry will be intensively fed and transferred to large rearing runways when they reach 25-30 mm in a few weeks. The mortality in the nursery runways is expected to be about 25%. Thus, around 25 million fry enter the rearing runways and are raised to fingerling size in about two months. With a 75% survival rate in the rearing runways, the net production of fingerlings (120-150 mm) would be around 20 million.

The fingerlings would be transported to the tanks for release in aerated storage containers. The figures presented above are conservative; the hatchery could produce more fingerlings, and if so, surplus should be stocked in medium tanks, but not in major ones.

Costs and Benefits

The capital costs for this entire proposed seasonal tank program, including the hatchery and tank upgrading, would be approximately 31 million rupees. Recurrent costs are estimated at roughly eight million rupees per annum. Detailed cost estimates are presented in Tables G-7 and G-8, respectively.

The program would provide employment for over 1300 fishermen with a net return to them of about 8200 rupees annually. Even though cost and yield estimates (from the hatchery and the tanks) are conservative, the internal rate of return for the program would be about 25%. Details of the economic and financial analyses pertaining to the program are presented in TOPIC REPORT M: ECONOMICS.

Table G-7

Seasonal Tank Program
Capital Costs

HATCHERY	RUPEES
Water Supply and Filter Systems	1,000,000
Access Road (1 Km)	500,000
Land Fill and Levelling	100,000
Hatchery Building and Equipment (150 m^2)	210,000
Staff Quarters	500,000
Laboratory, Garage and Office	100,000
Cement Breeding Tanks (five - each 5 m^3)	54,000
Laboratory Apparatus and Installation	375,000
Fencing	220,000
Ponds and Runways (18 ha)	3,000,000
Culverts, Screens and Drainage	1,062,000
Walkways	75,000
Generator and Engine	160,000
Workshop Tools	50,000
Refrigerator	18,000
Spare Parts	270,000
Vehicles (One two-wheel drive and 4 two-wheel drive)	2,520,000
	10,214,000
Contingency (20%)	2,042,000
Sub-total	12,256,800

SEASONAL TANKS	
Boats, Gear and Nets (Rs. 1533/ha with 35% subsidy)	2,146,130
Tank Preparation (Rs. 4100/ha for screens, weed control,etc.)	16,400,000
Sub-total	18,546,130
TOTAL CAPITAL COSTS	30,802,930

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Table G-8

Seasonal Tank Program
Recurrent Costs

HATCHERY	RUPEES
LABOR	
Hatchery Manager	9,500
2 Aquaculturalists	15,000
2 Assistant Aquaculturalists	12,000
4 Field/Laboratory Assistants	20,000
5 Drivers	22,500
2 Watchmen	9,000
2 Secretaries/Clerks	9,000
4 Maintenance Workers	18,000
SUPPLEMENTAL FEED (Rs. 1000/Ton)	
Nursery and Rearing Runways	16,000
Brood Stock Ponds	14,400
FERTILIZER (500 kg/ha)	
Nursery and Rearing Runways	8,500
Brood Stock Ponds	1,700
OPERATION AND MAINTENANCE	
Vehicles	150,000
Depreciation	100,000
Runways and Ponds	300,000
Buildings	81,000
Equipment	123,000
Roads, Walkways and Fencing	80,000
Culverts, Screens and Drainage	106,000
Sub-total	1,096,000
SEASONAL TANKS	
Tank Maintenance (10% of Capital Cost)	1,640,000
Gear Maintenance	613,000
Gear Replacement	1,226,000
Harvesting Labor (Rs. 14/day)	3,359,160
Sub-total	6,838,160
TOTAL RECURRENT COSTS	7,934,160

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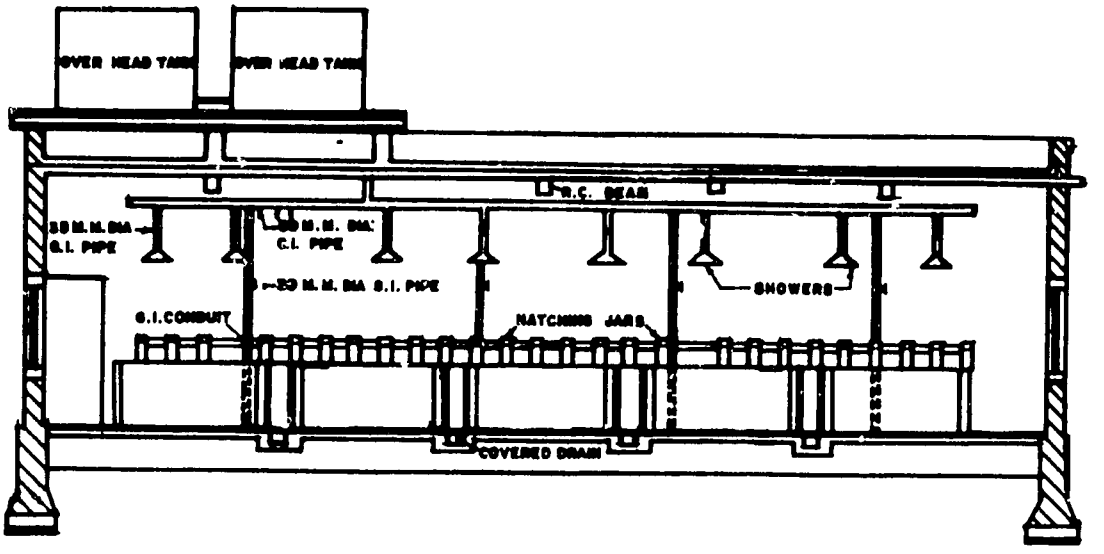
The program when fully implemented would result in a significant additional fish yield of at least 4000 tons/yr for the project area. Combined with the capture fisheries yields, the inland waters could produce close to 28% of the animal protein requirements for the future population.

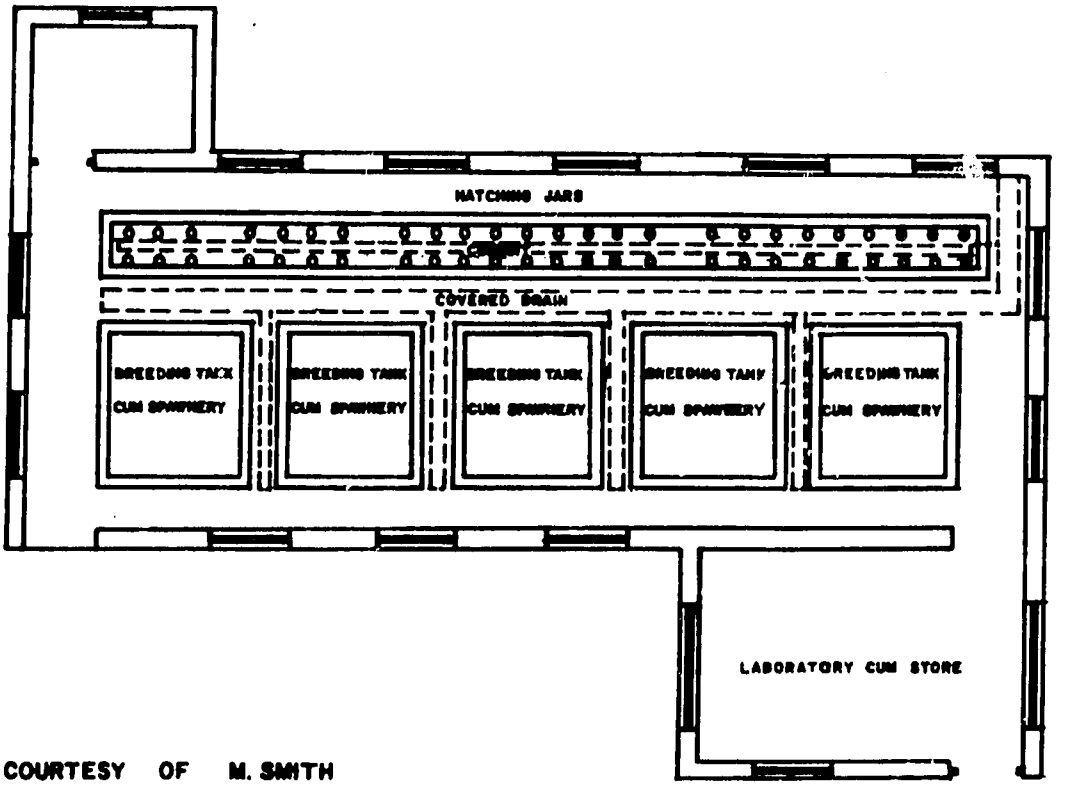
SETTLEMENT OF FISHERMEN

To fully realize potential fisheries resources in the project area, a relatively large number of fishermen will need to be mobilized. Some additional training and extension will have to be provided through the Ministry of Fisheries' new Master Plan.

Provision for the settlement of fishermen and their families will also be required. Settlement plans for fishermen have been made by the MDB for the System H area. These include attracting coastal fishermen to migrate to the inland tanks and then settle permanently there in specifically designated fishery villages. The fishermen will also be given a small plot of land for agricultural use. This concept may be very successful in establishing permanent fishing communities near the larger tanks, since it eliminates the landless status which fishermen are often relegated to and promotes stability by providing added family income. A comparable scheme is thus recommended for the Accelerated Program area.

In addition, the welfare program proposed by the Master Plan for coastal fishermen should be extended to inland fishermen as well. This program includes the provison of permanent houses (each unit costing Rs.11,175) with attached latrines (Rs. 3000) plus wells (Rs.3000-5000) and associated infrastructure.





COURTESY OF M. SMITH

SCHEMATIC DESIGN OF JAR HATCHERY

FIGURE G-2

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ACKNOWLEDGEMENTS

We would like to express our appreciation to the following institutes, agencies and individuals for providing information and assistnace in the preparation of this report on FISHERIES.

- ACRES International Limited
- K.D. Arudpragasam, Colombo Campus
- H.H. Costa, Kelaniya Campus
- W. Dittus, Smithsonian Institute
- C. Felsinger, Illustrator, Kandy
- C.H. Fernando, Waterloo University, Canada
- Food and Agriculture Organization of the United Nations
- Hunting Technical Services Limited
- A. Jayatunge, Colombo Campus
- P.R. Karunaratne, Natural History Museum
- Mahaweli Authority
- Mahaweli Development Board
- Ministry of Fisheries, especially

  Hon. Festus Perera, Minister
  K. Thayaparan
  G.H.D. de Bruin
  Y.I. Raphael
  J.A. Ross

- National Science Council
- NEDECO
- R.T. Oglesby, Cornell University, USA
- F. Schiemer and Members of UNESCO, Parakrama Samudra Limnology Study Team
- T. Scudder, California Institute of Technology
- R. Senanayake, University of California at Davis

- J.A. Shut, Ruhuna Campus
- P.K. de Silva, Peradeniya Campus
- S.S. de Silva, Ruhuna Campus
- M. Smith, ODA and Colombo Campus
- USAID
- Wildlife and Nature Protection Society
- World Health Organization

H. WETLANDS

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INTRODUCTION

Wetlands are areas which are covered by water or have saturated soil moisture conditions over a significant portion of the annual climatic cycle. Their characteristic feature is an importance of, or dominance of, water tolerant plants (hydrophytes) in the biological community. In this way they differ from more permanently wet and usually deeper, water covered areas such as lakes and from less often wet, essentially terrestrial habitats; but there are frequently rather subtle intergradations between these different kinds of habitats as will be evident in this consideration of the wetlands of the Mahaweli Ganga area. Wetlands vary considerably in their characteristics according to factors such as duration of wet condition (hydroperiod), depth of flooding, salinity of water and quantities of nutrients available.

Certain kinds of wetlands, especially those of alluvial floodplains, deltaic plains and tidally affected lands, are the most highly productive zones of the biosphere. This was the conclusion of Whitaker and Likens (1977) in their survey of primary productivity of world ecosystems. They found that such swamps and marshes have a mean net primary production of 3000 g of organic matter (dry weight) per square meter per year. This figure is 20% higher than the next highest category which is the algae reef ecosystem and three times higher than the mean for all world ecosystems. Thus, there can be no doubt that these wetlands are a very important component of the biosphere. Their high net primary production sustains numerous other organisms, including human beings, by complex food web relationships.

This tendency for high production under wet conditions has shaped human culture in various ways. Wet rice agriculture is a notable example. To engage in this practice people have over millenia engineered various ways of using wet areas and artificially created wetlands for this purpose.

The following sections describe existing conditions and future anticipated conditions with regard to wetlands in the project area.

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EXISTING CONDITIONS

GENERAL DESCRIPTION OF WETLANDS

In the project area marshy areas, or villus, occur in association with the Lower Mahaweli Ganga floodplain and deltaic plain. These freshwater wetlands occupy depressions between natural levee ridges of the channels of the Mahaweli and its various active and former distributaries or between these levee ridges and adjacent upland areas. The floodplain villus are typically characterized by water tolerant grasses and a wide variety of aquatic plants. The deltaic plain villus tend to have trees as well, especially along their margins.

The first of the villus going downstream are the inter-connected Handapan and Bendiya Villus, which are located a few kilometers upstream from the Mahaweli Ganga bridge near Manampitiya. At this point the alluvial valley begins. The deltaic plain may be said to begin with the first distributary, the Kandakadu Aru, which takes off from the right bank and flows on the eastern side of the Mahaweli before it rejoins not the Mahaweli but another Mahaweli distributary, the Verugal Aru. Locations of some of the more important villus are shown on Figure H - 1.

The combined flow of the merged streams enters the sea near Verugal. Some of this water is diverted at the Verugal anicut for irrigation supply. Below the Verugal Aru there is one other major distributary, the Koddiya Aru, which reaches the coast at Mutur. Both this and the Mahaweli Ganga main channel discharge into Koddiyar Bay, a large and deep re-entrant of the continental margin formed at the head of a submarine canyon.

The shore region of Koddiyar Bay near the mouth of the Mahaweli Ganga is a sandy beach ridge terrain of variable width, with saltwater tolerant mangrove swamps fringing small lagoons and tidal streams (Figure H - 1). The shore of the extreme western part of Koddiyar Bay opens into the elongated and shallow Tambalagam Bay and its surrounding mangrove swamps. Tambalagam Bay is of interest because it receives run-off waters and irrigation return flows from the Kantalai Tank of System D and will receive additional amounts after project implementation. Mangrove swamps also occur to some degree in various large and small lagoons along the Indian Ocean shore. The southern limit of the mangrove area of concern in this report is the estuary at the mouth of the Maduru Oya, known as the Valaichchenai Aru.

Extensive tracts of wet paddy cultivation exist in areas irrigated by water which is stored in the several large tanks and numerous smaller tanks of the area. These "wetland" areas are cropped primarily in the wet season and a smaller area is cultivated in the drier period as well. In some cases, aquatic weeds invade these paddy fields, their associated irrigation channels and drains, and the smaller tanks. Details pertaining to aquatic weed infestation in the project area are presented in TOPIC REPORT I: AQUATIC VEGETATION.

The tanks, especially shallow ones, are also wetlands of a kind. Some shallow tanks have many resemblances to villus at least in their aquatic plant communities. But such shallow tanks are seldom more than a few hectares in extent. The Allai Tank of System A is a notable exception. This large shallow tank has many of the features of a villu which apparently is what it

was before it became a tank, as suggested by its morphometry.

The deeper tanks (which are generally the larger tanks) may have little or no resemblance to any of the kinds of wetlands described here. This appears to be the case primarily because of their rather extreme fluctuations of water level. Even deep water tolerant wetland species such as Nymphaea do not do well in the high water conditions; and low water conditions lead to extensive dessication of the tank beds. When exposed, the few grasses and annuals that can invade the drawdown zone are subject to heavy grazing. For these reasons the drawdown zones of large tanks tend to have a barren appearance due to their thin vegetation cover.

VILLUS

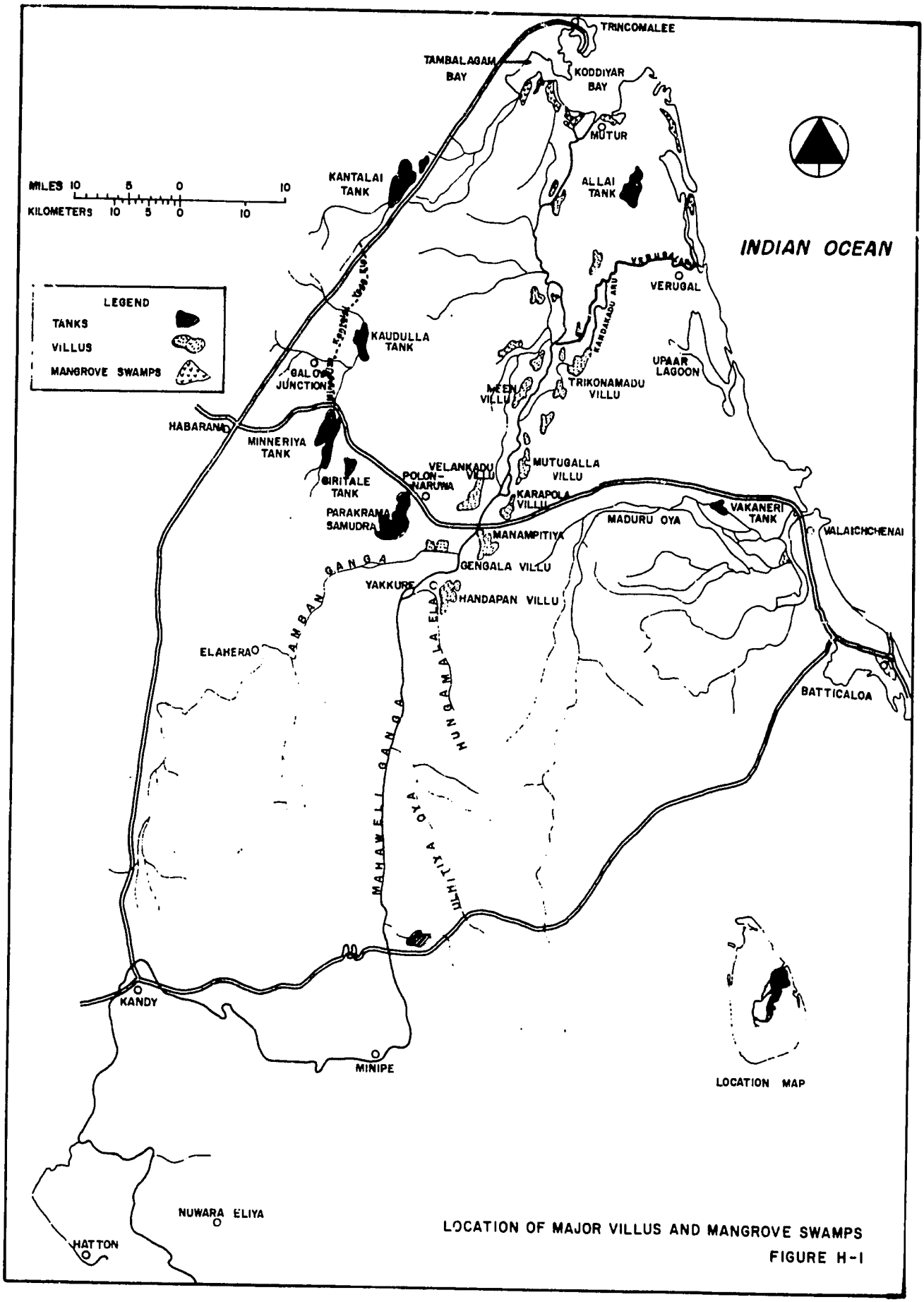
Water Levels

The surface area of a villu generally consists of two portions. One portion is the ponding area or pool which is more or less constantly filled with water; and the other is the floodplain which is inundated by water only during the flood period.

Water which enters the villu comes from three sources. These are rainfall, runoff from adjacent higher areas and river water which enters during high river stages. The fluctuation of water level in the villus is a complex result of changing rainfall patterns and river stages. During rainy periods water levels in the villus may be higher than the river level and where there are interconnecting channels there is an outward flow to the river. When the river is high, the flow may be the reverse although heavy rains may produce outward flow even during high river stages. When villus are receiving river waters, their waters are quite turbid with fine-textured river borne sediment. At other times the water is usually quite clear although heavy rains may carry in much sediment from adjacent uplands.

Most of the villus have direct connections to the Mahaweli or its various distributaries by means of small channels. When the river is low, much, but usually not all of the water of the villus may flow out through these channels. Usually these channels are so small and shallow that a certain amount of water remains in the villu. This water may also be lost through evaporation and transpiration during the driest months, but some of the villus do retain certain amounts of water as a ponded area year round in most years. Others become dry, or virtually so, for short periods nearly every year. Even when surface water is gone there may still be wet soil conditions.

Villus may also lose water due to seepage, although the amount is probably very small since the subsurface of the pool is constantly saturated. In addition, the volume of inflow due to rainfall and runoff is almost balanced by the estimated evaporation losses. Consequently, the main determinants of water inflow and outflow for the villus are the varying river stages. Water balance for the villus is discussed in more detail in TOPIC REPORT A: CLIMATE AND HYDROLOGY.



LOCATION OF MAJOR VILLUS AND MANGROVE SWAMPS

FIGURE H-1

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Areas of Villus

There are more than 50 identified villus in the project area. An examination of 1979 aerial photography indicates that presently the Mahaweli Ganga floodplain with its associated villus occupies a total area of about 12,800 hectares. The smaller villus are about 10 to 25 hectares in area, while the largest including Handapan Villu, Karapola Villu and Velankadu Villu cover approximately 700 to 900 hectares each.

A report by Hunting Surveys, Ltd. (1961) states that there were 40,000 acres (16,200 hectares) at that time which would imply that a sizeable diminution of villu area may have already occurred due to diversion of river flows. A Ministry of Fisheries paper on development of inland fisheries (Ministry of Fisheries 1979) gave an estimate of 10,000 acres (4,050 hectares) which is obviously an underestimate. Without detailed vegetation surveys it is not possible to make an accurate estimate of the size of swamp forest areas, but it is probably around 3,000 hectares.

Vegetation of Villus

The distribution of vegetation in the villus of the alluvial valley tends to show a characteristic pattern which is related to the hydroperiod and the depth of flooding. On the margins where wet conditions are brief and depth of flooding slight, there are creeping grasses such as Cynodon dactylon and various, essentially terrestrial annual plants which are capable of surviving the brief inundations or can produce new growth from seed rapidly enough to occupy this zone during drier periods.

Further from the margin, the duration and depth of flooding increases, and various truly hydrophytic species appear including some that can grow well in terrestrial conditions also. Alternanthera sessilis and Polygonum sp. are common in this zone and may be found at different times growing in or out of the water. Jussiaea repens, Scripus grossus, Juncus effusus, Ipomoea aquatica and Monochoria hastata are often present in this zone. The most abundant species are various grasses, including Panicum repens, Hygrorhiza aristata, Digitaria longifora, Brachiaria mutica, Sacciolepsis interrupta, Echinocloa colonum, Paspalum vaginatum, Oryza spp. and Paspalidium spp. Many of these grasses are important as grazing sources for cattle and water buffaloes. Unfortunately, the grasses in a number of villus are presently being replaced by a burr, Xanthium strumarium, which is unsuitable for grazing. The replacement may have occurred due to recent changes in river flow regimes or from over-grazing or a combination of several factors.

Some of the grasses, especially Hygrorhiza, extend into deeper water where floating leaved forms occur such as Aponogeton crispum, A. natans, Nymphoides sp. along with the submerged-floating plant Ceratophyllum demersum. Nelumbo nucifera which has floating and emergent leaves is sometimesabundant in this zone. Beyond this zone in still deeper water and with a more prolonged hydroperiod, an association of Nymphaea stellata and Ceratophyllum demersum is characteristic.

The floating aquatic plant community can move in and out of all of these zones with the rising and falling of water levels. Common floating plants are Salvinia molesta and Trapa bispinosol. Pistia stratiotes and Azolla pinnata are sometimes abundant. Spirodela polyrhiza and Neptunia

oleracea occur occasionally. Some villus are at times heavily covered by Salvinia (floating fern).

Some trees occur in wet conditions around the margins of the floodplain villus. Among these are Terminalia arjuna, Madhuca longifolia, Barringtonia asiatica and Mitragyna parvilflora. In the deltaic plain villus, depth of inundation at times of flood peaks is not so great, since the flood waters spread far and wide over the delta lands. Here trees are more common and more widespread throughout the villus and include, besides the above, extensive areas of Hibiscus tiliaceus. Villus in this area are transitional with what are essentially areas of swamp forests.

Livestock and Grazing

Water buffalo and cattle are very important species in villu ecology due to their heavy utilization of these lands for grazing. In addition, the large amounts of dung generated by the grazing animals are an important nutrient input to this wetland ecosystem.

Seasonal Grazing Patterns - Villus and the associated floodplains are of particular value as they provide dry season grazing for both domesticated stock and wildlife. Under a natural grazing pattern during the wet season, animals move from the inundated floodplain onto the better drained upland or damana areas, grazing back toward the rivers as the dry season begins. It is at this time that the villus are becoming less saturated allowing for fresh grass growth with high digestible crude protein (D.C.P.) and simultaneously when surrounding damana lands are being highly grazed, resulting in a lowering of the D.C.P. in their respective grasses.

The present seasonal grazing patterns and their effects on villu and upland grasses is depicted in Figure H - 2. This figure demonstrates the importance of villu grasses on an annual grazing basis.

The damana grasses begin losing their D.C.P. at the end of the maha rains and gradually decrease through the dry season with a small increase from yala rains. The villus, meanwhile, have been flooded during the maha rains and only come into vegetative production after the river flood stage has recessed, and the resulting swampy area has become less saturated. This occurs around the middle of February which is about the same time that the damana grasses have not only been well grazed but also are approaching marginal protein values. Animals move onto the villus at this time and are supported at least through a maintenance level until mid-July. The critical grazing period with the villu/damana association is from mid-July to early October or the onset of maha rains.

Carrying Capacity - An initial estimate of the livestock carrying capacity of villus was about 1 Animal Unit (A.U.) per acre/per year or 2.5 A.U. per hectare (Perera 1967). An Animal Unit is defined as 1000 pounds of herbivore, regardless of the specific type of livestock.

Estimates made from present on-going studies (Joint Venture Randenigala, personal communication) of current villu carrying capacities over a seven month grazing period are effectively 1 A.U./ha. About 80% of the drawdown zone of the inundated floodplain after flood stage lowering

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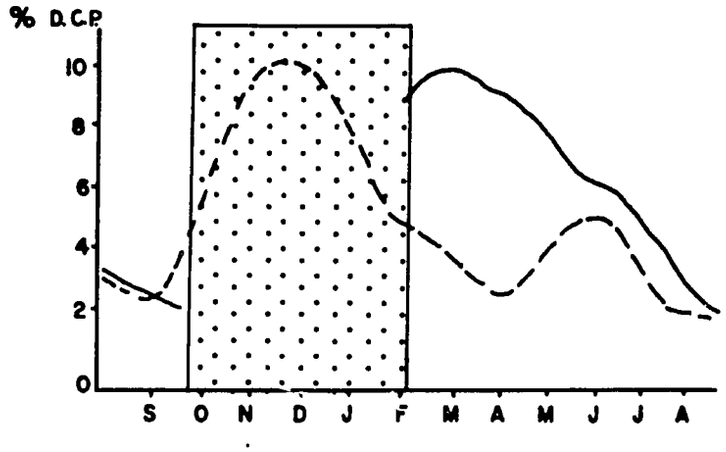
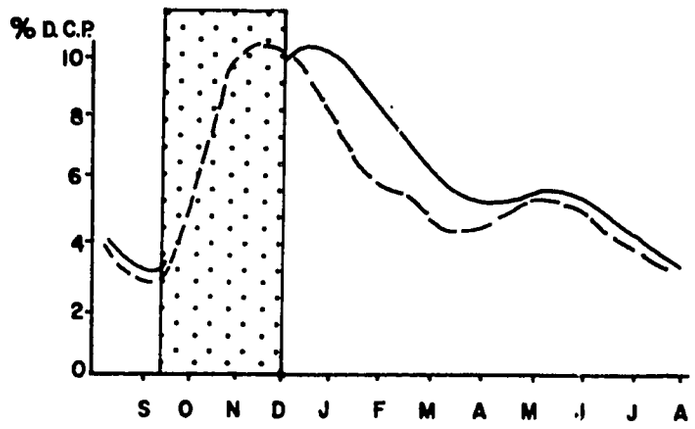


A. Existing Grazing Pattern



B. Grazing Pattern Following Project Implementation and Decreased River Flood Stages

Damana

Villus

Period of villu inundation

ESTIMATED PATTERNS OF SEASONAL DIGESTIBLE CRUDE PROTEIN FLUCTUATION IN DAMANA AND VILLU GRASSES.

FIGURE H-2

will be accessible for grazing. Thus, with 20% of the floodplain remaining in pools, the total livestock carrying capacity for the project area villus would be approximately 8,190 A.U. per year.

A comparison of Perera's 1967 estimates with the present one indicates that carrying capacities for livestock have declined considerably in the last 10 - 15 years. This may be the result of altered river regimes or perhaps overgrazing as mentioned previously.

Wildlife

Villu habitats are very favorable for many wildlife species and high concentrations of birds and mammals are usually observed there. Many wild herbivores utilize villus in the same grazing pattern as domesticated stock. This has been very evident for elephant populations. In addition, the entire floodplain of the Mahaweli Ganga provides nesting and feeding grounds for numerous migratory bird species which annually frequent Sri Lanka. Wildlife in wetlands are discussed in greater detail in TOPIC REPORT E: WILDLIFE.

Fisheries

A number of fish species are permanent inhabitants of villu pools, being tolerant of the fluctuating water levels. The more abundant resident forms include catfishes and snake heads (see TOPIC REPORT G: FISHERIES). In addition, the floodplains provide important spawning and nursery grounds which are essential to the life cycle of many fish species which inhabit other areas of the entire river basin ecosystem. These fish normally enter the floodplains at the onset of the rainy season where they spawn. Newly hatched fish larvae may consequently take advantage of the large amounts of organic matter released due to the recent inundation of drier lands for feeding. An average fish yield for all the floodplain areas would be about 50 kg/ha/yr. However, the villus support a much higher total fish population which may be in the range of 300 to 900 kg/ha.

MANGROVE SWAMPS

Distribution

Mangrove swamps occur in a narrow coastal strip. Those likely to be affected by the project extend from Tambalagam Bay along the southern shore of Koddiyar Bay and down the Indian Ocean shore almost to Valaichchenai (Figure H - 1). The mangrove swamps have already been substantially impacted by cutting, conversion to other use, and obstruction of tidal exchange. The recent cyclone (November, 1978) also did considerable damage to the remaining mangrove forests especially in the southern part of the area.

An examination of the Survey Department one-inch to one mile scale maps made 10 to 15 years ago reveals that approximately 1,000 to 1,500 hectares of mangrove swamps existed from roughly Tambalagam Bay to Valaichchenai. Field reconnaissance and the recent aerial photography (1979) indicate that this amount has greatly declined, with less than 25% of the above estimate extant. The mangroves adjacent to the project area are probably limited to only a few hundred total hectares. It should be noted that Turner reports

in 1977 that only 3,700 hectares of total intertidal vegetation remain on the entire island.

However the remaining mangrove swamps and the estuarine water bodies around which they exist support important fisheries resources in the Koddiyar Bay area, the Valaichchenai Aru estuary at the mouth of the Maduru Oya and in the coastal waters between these places.

Various authors have described mangrove associations for particular areas of Sri Lanka or in a general way for the island as a whole (Tennant 1859; Abeywickrema 1966; Aruchelvam 1968; Kugathasan 1969). None of these studies specifically refers to the area of concern in this report. It is clear from these and other studies (Gaussen et al. 1968) that mangrove swamps throughout Sri Lanka have been subject to heavy exploitation for a long time and that virtually no effort has been made to protect or reforest these areas.

Mangrove Vegetation

It is apparent that the mangrove swamps adjacent to the project area are substantially different from those described from other parts of the island. This is reflected in a less diverse group of species among which only a few account for most of the vegetation cover. Some species have probably disappeared entirely from the area, but since previous accounts are lacking this cannot be proven. The genus Bruguiera which is a valued source of fire-wood, charcoal and pole timber throughout tropical Asia and which is represented elsewhere in Sri Lanka, is absent or rare in the area, probably due to over-exploitation. Some types of mangroves, including Bruguiera, do not reproduce well from seed especially when heavy cutting leads to extensive clearing. The seedlings are heavily preyed on by crabs and other organisms, and clear-ings may also be quickly invaded by species which form exceptionally dense thickets such as Acanthus ilicifolius and Hibiscus tiliaceus which further reduce reseeding of cut over areas. Thickets of these two species are com-monly observed around the project area where stumps of other species are still present indicating that these changes have occurred.

The major species which are relatively common in the area are Rhizophora mucronata, Avicennia marina, Acanthus ilicifolius, Lumnitzera racemos, Aegiceras corniculata and Scyphiphora hydrophyllacea. Sonneratia caseolaris is an uncommon species.

According to Dr. Balasubramaniam of the Botany Department at the University of Sri Lanka at Peradeniya, there is a very rare endemic species, Sonneratia apetala, which is known to exist only from several specimens in the project area near Mutur. This was reported to him by Dr. W. Macnae, one of the world's leading authorities on mangrove swamps.

Mangrove associates, including Acrostichum aureium and Hibiscus tilliaceus exist along the inner margins of the mangrove swamps in the zone of transition to riverine forest. Just inland of these, there are scattered small stands of the giant reed, Phragmites karkis. The higher, less fre-quently flooded parts of the tidal lands are hypersaline barren flats which are extensive in the area. Along the fringes of these, halophytes such as Arthrocaemum indicum and Suadea monoica are common along with Acanthus ilicifolius.

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OTHER WETLANDS

Smaller shallow tanks of the project area often support an aquatic plant community that is similar to the villu community, but usually of a reduced variety of species. Such tanks may have wide fluctuations of water levels and may become completely dry in the yala season which result in a selection for species capable of withstanding dessicated conditions. Those with rhizomes that endure the dry period tend to become dominants. Nelumbo nucifera is a good example, and it is often the principal species in the shallowest tanks or in the shallower parts of tanks. In deeper water situations, Nymphaea stellata, another form with drought resistant rhizomes, is common. Species of Aponogeton are also common in shallower and intermediate depths and are also favored by their drought resistant underground organs. Other plants that can survive dry conditions for prolonged periods are also abundant. These include many of the same grasses typical of the villus and also forms such as Polygonum sp. In such tanks, Ceratophyllum demersum is common. Floating plants are also abundant in some of the more permanent tanks including the problem species, Salvinia moleste.

The elevated irrigation canals which distribute the water from larger tanks in the area usually are constructed with bunds on their downslope side. Where they cross terrains of low slope, water may spread over wide areas on the opposite side, and wetland areas characterized by various grasses and Typha javanica exist. Certain other areas of wetlands exist where bunds of irrigation channels cross depressions in the terrain and create impounded drainage conditions. Typically these become areas for water weed infestation and are described in TOPIC REPORT I: AQUATIC VEGETATION.

IMPACT ANALYSIS

EFFECT OF CHANGING RIVER FLOWS

The impacts on the project area wetlands will be closely linked with the resultant alterations of existing river flows. This is because river flow regimes are largely responsible for the recharge and drainage of villus and for controlling salinity intrusion which in turn affects mangrove distribution. Projected changes in river flows are summarized here, although a more comprehensive discussion may be found in TOPIC REPORT A: CLIMATE AND HYDROLOGY.

With development of the Accelerated Program diversion schemes described by NEDECO (1979), about 60% of the total annual Mahaweli Ganga flow (as measured at Manampitiya) will be diverted. Much of this flow will be diverted to other drainage basins and not return to the Mahaweli Ganga, but of the 60% probably only 20% is likely to re-enter the Mahaweli as irrigation return flow and perhaps less than this during the dry season. Consequently, flow in the Mahaweli Ganga will be reduced by about 50% (40 + .2 X 60).

During the wet season, both flood peaks and the frequency of flood occurrence will also be reduced due to the presence of the proposed storage reservoirs. Dry season flows will also be lowered from present levels.

Historically, the minimum discharge of the lower Mahaweli Ganga usually occurs in March. Since this will be immediately after the period of greatest water accumulation in the reservoirs it may be possible to keep the flows for March at their historical levels, but then will follow a six month long period (April to September) of heavy demand for diversion waters with no net accumulation in the reservoirs (except for a minor increment in August). This will result in a fall of river flow during much of this period to levels even lower than the March level. This low water level will not only be lower but more prolonged as well. During exceptionally dry years there may be almost no flow in the lower river.

On the other hand, the increased diversion and subsequent high return flows will serve to raise dry season flows in the Maduru Oya over their present levels.

IMPACT ON VILLUS

Reduced Flow Impacts on Villus

The annual cycles of rainfall and river flooding are basic factors in the existence of villus in their present forms. These bring about prolonged periods of flooding in the low-lying areas and also transport nutrients into them, supporting a high level of net primary productivity which in turn supports high populations of wildlife and fish. Around the villus there are also sizeable populations of domesticated grazing animals which depend largely on this primary production source as do those families whose food or

livelihood depends upon grazing animal or fisheries resources. This dependence of animals and humans on the villus is especially critical during the dry season and drier than normal periods.

The impact of the reduced flood stage and dry season flows of the lower Mahaweli on the floodplain villus will be a substantial reduction in their surface areas. The area of reduction on the total floodplain could be up to 50% of the present estimated 12,800 hactares. The size of the villus would be further decreased if additional diversion schemes are implemented in the future. Further, construction of the proposed Rotalawela Reservoir and the Kandakadu Barrage would in both instances permanently inundate large portions of the present river floodplain.

Another impact from altered river flows will be that the duration of inundation of flood water in the villus will be decreased since the frequency of floods will be reduced (Figure H-2). Overall, one-half of the floodplain villu will be more or less permanently lost (except during very exceptional flood years) and much of the remaining villu areas will be inundated for shorter periods.

Impacts on Villu Vegetation

The reduction of high river flows will mean that the higher, less frequently flooded areas of the villus will no longer be subject to inundation and will no longer have the characteristics of wetlands. Different kinds of terrestrial vegetation will become established, or the villus may become altered in other ways such as by cultivation of paddy or utilization for other purposes.

Reduced dry season flow will lead to prolonged exposure of some formerly water covered villu areas to such an extent that even larger areas may essentially lose their character as wetlands. These areas will be flooded only briefly by the diminished river floods. Much of the reduced areas will retain essentially wetland characteristics.

From the standpoint of plant succession, the outer margin of the floodplain villus will undergo a shift from the present annual high water content grasses (Brachiaria mutica, Cyondon dactylon and Digitaria longifora) to low water content terrestrial grasses and eventually to perennial woody vegetation. This will effectively alter the watershed characteristics of the villus, resulting in a change in quantity of runoff produced by storm rainfall. However, the impact on villus resulting from the change of runoff volume will be insignificant because water contributed from surface runoff is small, compared with rainfall and river flow.

Impacts on Villu Grazing Patterns and Capacities

The livestock carrying capacity of a villu will be affected primarily by the decreased duration of the river flood stage. Even though the floodplain villus will be reduced in size by up to 50%, this will not initially

affect the quality of vegetation associated with the redefined villu area. However, while the vegetative cover will still be of high quality and protein value, the grazing duration will have been increased to nine months instead of the original seven. This will result in additional grazing pressure causing an adjustment in carrying capacity to 0.75 A. U./hectare. This constitutes a 25% reduction from the present capacity levels.

Figure H-2 shows the altered crude digestive protein patterns which will occur as a result of the shifting of the villus' curve to the left as the villu comes out of a flood stage in late December instead of the mid-February emergence under the present situation. The altered grazing duration is now nine months, but gives a dry season advantage of only two months over damana grazing and a lowered carrying capacity. The result is that the damana/villu association now can only support maintenance levels through to mid-May, and the critical grazing period will be extended from mid-May to early October.

The 6,400 ha of land foregone to the villu grazing regime will be absorbed into the damana. This land will have heavier grazing pressures than previously due to the longer grazing period associated with damana lands. It is anticipated that these newly formed "intermediate" damana lands will have a lower carrying capacity than established upland damana due to plant succession following hydrological changes. In addition, grazing is expected to remain heavy causing an overgraze condition before desired plant species are established. Thus, woody perennials and scrub may become the predominant cover. This will precipitate a change in associated grazing species causing a shift favoring neat cattle (i.e. local Singhala stock of zebo derivation) and goats over the buffalo which previously thrived on water tolerant grasses and muddy conditions.

The carrying capacity of this newly formed intermediate damana is estimated at 0.6 A. U./hectare, with 65% accessibility to forage. Weight gain is considerably reduced from that found on villu graze and is figured to be about 20 kg. Species composition will approximate a ratio of 35% buffalo and 65% neat cattle.

In summary, the anticipated changes in the villu/damana grazing association are as follows:

- Increase in duration of villu grazing from 7 to 9 months;
- Reduction of villu carrying capacity from 1 to .75 A.U.;
- Reduction of area for villu grazing;
- Extension of the critical grazing period from mid-July to early October to mid-May to early October; and
- Formation of new "intermediate" damana with a carrying capacity of 0.6 A. U./ha.

The net result will be an overall loss in annual grazing benefits of more than one million rupees (See TOPIC REPORT M: ECONOMICS).

Both cattle and water buffalo will decline in numbers due to the loss of area of highly productive grazing land, aggravating a trend that already is affecting the area. The buffalo population in System D has declined by two-thirds and the cattle population by one-fourth in the last several years largely as a result of the loss of grazing land (JICA 1979). Water buffalo may be doubly affected since the high water content grasses which they utilize will be replaced by grasses favored by cattle.

The buffalo is an especially important species in the villu ecology and has special importance in human ecology as well since it provides draft power, fertilizer and food. Pathak (1979) has shown that when buffaloes are used for tillage and threshing the ratio of power output to power input for paddy production is higher than when tractors or human power alone is used. This has obvious significance in a time of dwindling oil resources.

Impacts on Wildlife

The decline in area of the highly productive floodplain habitats will lead to a loss of wildlife from the area in terms of the number of individuals and probably in the number of species as well. The alteration of the wet season-dry season grazing pattern will adversely affect a number of wildlife herbivores in a similar fashion to domesticated stock. Thus carrying capacities for some wildlife species will be reduced.

In addition, the reduction of the villus will seriously reduce favorable nesting and feeding habitats for waterfowl, especially the migratory species. These impacts are discussed more fully in TOPIC REPORT E: WILDLIFE.

Impacts on Fisheries

The reduction in floodplain area will result in a decline in fish yields of about 320 tons annually. Further, there will be a permanent loss of at least 300 kg/ha or a total of 1,920 tons of the standing stock of the floodplains. Additionally, there will be a loss in spawning and nursery grounds which will ultimately result in a decline of some species throughout the Mahaweli Ganga aquatic system. These impacts are discussed in more detail in TOPIC REPORT G: FISHERIES. Also, the economic impacts of the changes which will result in the floodplain villus are evaluated in TOPIC REPORT M: ECONOMICS.

IMPACTS ON MANGROVE SWAMPS

Reduced river flow will also affect mangrove swamp areas. Less river water entering the coastal area will lead to generally higher salinity conditions in the estuarine region especially during periods of low river flow which will become more prolonged. Since the low river flow conditions coincide with the dry period, salinity increases may be large.

Even now the intertidal area is characterized by extensive areas of barren hypersaline tidal flats in the areas that are less frequently flooded by the tides. When salinities increase such barren flats will increase in area and may spread over some of the limited areas now vegetated by mangroves. There may also be a tendency for mangroves to spread into areas where basically fresh water conditions now prevail as salinities increase; but since these areas are for the most part already developed such saline incursions will probably be limited. At any rate, any new mangrove areas that may come into existence through salinity intrusion will do so at the expense of other land uses such as paddy areas or grazing lands. Mangrove vegetation in the Maduru Oya estuary should be little affected by changing river flows since dry season flows will be similar to present levels (TOPIC REPORT A: CLIMATE AND HYDROLOGY).

Another impact on the mangrove swamps will be of a secondary kind. With the influx of greater numbers of people into the area as settlers, there will be a considerable increase in demand for firewood, charcoal and structural timber. This will lead to greater cutting of mangroves unless effective measures of protection and conservation are taken. Such cutting is apparently already going on at an excessive rate in the area with no conservation practices. Heavily cut over areas in mangrove swamps do not readily regenerate naturally. In the higher parts of the intertidal area cut over areas may become barren flats due to increased evaporation and salt accumulation in the soil. In other areas, regeneration will be hindered by the growth of thicket-forming species and predation on seedlings by various organisms.

Economic assessment of the potential resource loss in the project area is hampered in various cases by the fact that many resources that may be lost are as yet underdeveloped or have been overexploited to the point where their continued viability is dubious. The mangroves are a good example of a case of overexploitation with little effort to protect the resource for later generations. Mangrove reforestation is a difficult undertaking even when active conservation programs exist. Where they do not exist, as in Sri Lanka, there is little that can be expected except a continuing decline. This has broader ramifications with respect to fisheries which are linked to these resources.

Turner (1977) has shown an interesting relationship that indicates that the catch of shrimp is correlated with the area of intertidal vegetation (mangrove swamps and salt marshes) and that the yield of shrimp per hectare of intertidal vegetation increases approaching the equator because of the larger amounts of solar energy. Sri Lanka for instance, is shown to have a high yield of shrimp per hectare of intertidal vegetation on the order of 170 kg/hectare, a figure exceeded by only a few places in the world. Thus the loss of a hectare of mangrove would result in the loss of about this amount of annual shrimp production. Since shrimp trawling also results in accompanying fish catches that may be 4-6 times larger, the loss may be far greater for the total fishery. Turner states that mechanized trawling in developing countries "pays for most of the effort expended catching shrimp and fish". Because of this he concludes that, "Even if these same fish were not estuarine-dependent and were present

after removal of intertidal areas, in most instances it would not be economical to harvest them."

IMPACTS OF RETURN FLOWS, DRAINAGE WATERS AND EUTROPHICATION

A number of changes that will result from the proposed project will tend to increase local runoff from upland areas into low-lying areas such as villus, paddy fields and drainage ways. Some of the upland areas will be cleared of forest vegetation to be placed in agriculture. This will have an immediate effect of increasing runoff from the cleared areas. Many of the crops that may becultivated require good drainage for best production. Thus, it is necessary to design plantings so that local heavy rainfalls or prolonged wet periods do not lead to waterlogged soil conditions. This also requires increasing runoff into lower areas. Sediment from eroded soil and nutrients from fertilizer are also discharged by this runoff to the lower lying areas where they may have various adverse impacts primarily in terms of sedimentation and eutrophication.

Human settlements on uplands also have significant impacts on runoff, since they are areas that must have good drainage also and are areas of heavy water use. This runoff includes the waste-water of the human settlements which may lead to eutrophication and to disease transmission to the areas receiving the runoff from the settlements. Treeless settlements with tiled roof housing and extensive paved areas, to give an example, will obviously discharge water faster than the same areas would if they were covered with light forest.

It is apparent that return flows from irrigation and drainage will be a threat to the preservation of the villus in their present state. This is so for various reasons. For example, the fact that the villus are the lowest-lying features in the landscape of the alluvial flood plain (except for the river channel itself) makes them obvious places for discharge of irrigation return flows and drainage waters. Or, as another example, the reduced volume of flow of the lower Mahaweli Ganga will mean that the waters entering the villus from return flows and drainage will become proportionately of much greater importance in the overall water budget of the villus due to less river water entering them.

Eutrophication is a technical term for the process of nutrient accumulation in a biological system. It is chiefly applied to aquatic systems, where critical levels can be reached that may have significant effects on the stability of the system. This is so because aquatic systems have production level maxima that are related to the speed of oxygen circulation through the system. This circulation of oxygen has finite limits which are set by water flow velocities and diffusion rates of oxygen. Since diffusion of oxygen is slow, still-water aquatic habitats may be especially limited in their overall level of production while flowing water habitats are less so.

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In temperate climates one of the first indications of eutrophication of a water body is the appearance of large numbers of phytoplankton. In tropical and subtropical areas this stage may quickly pass to a stage in which floating aquatic vegetation begins to proliferate on the surface. When such growths become dense they shut off light and restrict circulation of the water so that poor oxygen conditions develop very quickly in the water beneath the floating plants. When the production level of an aquatic system progresses through eutrophication to the point at which oxygen circulation is no longer adequate to sustain it, then mortalities of certain elements of the aquatic fauna may result.

The Handapan Villu which is the most upstream of the villus is likely to be one of the most heavily impacted of all. This villu will receive return flow and runoff for a large area of System C via the stream called the Hungamala Ela. The Handapan Villu is not presently connected to the Mahaweli Ganga. Possibly a direct connection once existed, but this may have been severed by the construction of a tank near Yakkure. Currently this villu overflows into the adjacent Bendiya Villu which has had, until recently, rather direct river connections; but these are obstructed now by road crossings which have confined flow to small culverts and reduced flow velocities to such and extent that the channels have become choked with sand. Thus, the Handapan and Bendiya Villus are moreor less isolated from the river except at times of high flooding. Runoff and irrigation return flows, which will be entering them in abundance following implementation of System C agricultural development, will tend to keep these villus flooded. They will also bring about eutrophication, proliferation of aquatic weed species, sendimentation, accumulation of various pesticides and possible salinization around the villu margins.

Around villus in the upermost less frequently flooded margins there is often a zone of relatively little vegetation cover. To some extent this is due to heavy grazing, but it also seems probable that these are zones of occasional high soil salinities especially during the dry season with retardation of plant growth due to salt. It is to be expected that with greater amounts of drainage and irrigation return flow waters entering the villu depressions such salinization is likely to increase and affect a broader zone around the diminished villus. This will further negatively affect the quality of these lands for grazing animals by reducing grass production. The possibility that these soils are already salinized should be checked by field measurements during the next dry season.

FORMATION OF NEW WETLANDS

Creation of new wetlands will result from some features of the project. The canals will cross varied terrain and in many places drainage obstruction may be created by the canal bunds. Such places will collect water for varying periods of time and where this occurs over a sufficient duration, wetland vegetation will appear. In lower lying areas with high seepage rates wetland areas may occur even at some distance from the canals.

Generally, on the side of the canals with higher terrain there is no canal bund; thus, where depressions in the terrain are crossed water may spread outward from the canal into these places at sufficiently frequent times to create wetlands of varying sizes. These conditions can be seen presently along the existing canals such as along the Minneriya-Kantalai Yoda Ela. Travelling along the road down the bund which is situated on the eastern side of this large irrigation canal, it is possible to see areas of impounded drainage where water has been trapped in depressions behind the bund. On the opposite side of the canal, water is more or less confined to the canal itself where slopes are higher, but when areas of lower slope are traversed the water spreads outward over areas that are sometimes rather large.

Many such areas at present are not flooded sufficiently and/or frequently to develop true wetlands characteristics. Along the Minneriya-Kantalai Canal described above, for instance, the low lying areas on the western side, into which water spreads during high flows, remain forested with trees essentially like those areas that are seldom, if ever, flooded. For many areas this will change when flows through the canals become greater and more constant throughout the year, and such areas will become true wetlands with varying kinds of hydrophytic vegetation, while the forest will be diminished. These areas will to some extent replace wetlands losses from other impacts of the project, but the total area is not expected to be great. Also, they may create certain problems including water wastage and become centres for spread of various aquatic weeds which can obstruct the canals.

The older and new large tanks and the proposed reservoirs of the project area will not lead to the formation of any appreciable areas of new wetlands, since these will all be subject to wide fluctuations of water levels and will have drawdown zones that are relatively barren as in the case around existing large tanks. The Minneriya, Parakrama Samudra, Kaudulla, Kantalai and other tanks may be an exception, since it is planned to have a relatively constant water level there over the year. If this condition is actually achieved, it can be expected that wetlands will develop around their margins especially where terrains of low slope intersect the shore zones.

There may be an overall decrease in mean surface areas from some major tanks and an increase for others. The respective gains and losses to fisheries yields and standing stocks are discussed in TOPIC REPORT G: FISHERIES. The net change in fish yields which would occur with the anticipated changes in water levels of the four major tanks would be a loss of about 98 tons/year. Offsetting this to a certain degree will be an increase in the livestock carrying capacity for grazing in the drawdown areas. These impacts are assessed in economic terms in TOPIC REPORT M: ECONOMICS

Certain areas within the command zones of the various irrigation systems will be subject to flooding due to topgraphic conditions. In System B, for instance, ACRES (1979) estimates that there will be 1,480 hectares of such

land. In a few cases, these lands may be of sufficient size to constitute valuable wildlife habitat, but the majority will be small sized plots and so affected by eutrophication that they are far more likely to become areas of chronic water weed infestation. Some areas that are presently used as paddy or which are planned to be used in this way are now, or will be, difficult to drain sufficiently to be kept free of water weeds. Such areas are only marginally productive and are often abandoned to weeds which then spread from these places to other parts of the irrigated areas.

RECOMMENDED ACTIONS

CONTROL OF WATER USE

Perhaps the most effective way to mitigate in any substantial way some impacts of the project on wetlands or the impacts of water weeds on the project is to reduce the total amount of water needed to accomplish the basic goals in agricultural production. The NEDECO (1979, Annex K) report states:

> "Increase of the flow (of the lower Mahaweli Ganga) at the dry period will be beneficial for fish and other animals, as the minimum flow in the river may well be the limiting factor for the number of species. If, however, after the implementation of the complete Mahaweli scheme the waters of the Mahaweli virtually run dry during certain periods, this will have a disastrous effect on the fauna. Moreover, with little flow on the river salt water intrusion is likely to become a problem. The historical low level of the river will be a safe minimum discharge in the planning of the future river regime" (parentheses added for clarity).

As discussed previously, provisions have not been made indicating how this flow maintenance can be accomplished. It is recommended that a dry season conservation flow be maintained for the Mahaweli Ganga which will control salinity intrusion and could at least partially limit dry season drainage of the villus. Conservation flows are discussed in TOPIC REPORT F: WATER QUALITY. These flows can be maintained by release from the proposed storage reservoirs. However, their effectiveness can be enhanced and adverse impacts further mitigated by achieving a high degree of control of water use and high water use efficiency in all aspects of the project. Because of the critical importance of this issue several ways of approaching this problem are discussed below. Because of the frequently expressed opinion that high water use efficiency can probably not be achieved it should now be noted that this is a real problem that the following methods will not necessarily sustantially overcome, and that the negative environmental impacts resulting from heavy water use in the project may not be successfully mitigated in any way.

Water use effectiveness should be given a priority equal to water storage and provision. In this way maximum effectiveness of storage capacities already realized or later added can be made. It is unlikely that high water use effectiveness can be achieved if expansion of agriculture is too rapid into new lands. It is also unlikely that it can be achieved if water is provided to an area before it has an appropriate distribution and drainage system to make effective use of it. Thirdly, providing an excess of water when there are other limitations such as labor or traction power will lead to great water use inefficiency as JICA (1979) has shown for System D. To avoid these pitfalls, efforts to improve drainage or irrigation inadequacies should proceed simultaneously with the construction of new reservoirs and canals and not be delayed until these facilities are ready or considered

as add-ons in a later phase of the project. This should be done initially for land already in cultivation. To attempt to develop more and all at once could lead to delays from resource limitations due to the intensive construction activity that would have to take place simultaniously in all parts of the project area. Such delays would probably result in great water use inefficiency.

A major economy of water use that could be achieved is through proper timing and sequencing of paddy preparation for planting. Appropriate scheduling for water use also facilitates weed control in the paddy. It would probably be best to supply water first to upland fields and allow field preparation to subsequently proceed in lowland areas (JICA 1979). This would require careful attention to effective modes of labor organization.

An interesting question deserves to be asked at this point. When upland crops receive rainfall to the extent that they could provide runoff to lower paddy fields, can this water shomehow be re-routed to paddy fields downslope when necessary and not simply discharged via the drainage way?

This locally conserved quantity of water in some years might not be great, but it should be remembered that it should be evaluated economically on a par with the expensively provided irrigation water. In wetter than usual seasons its value could be significant. Thus, runoff that might otherwise only create flooding, sedimentation and perhaps eutrophication downstream could be reduced appreciably spreading a part of it out over fields. This water re-routing is practiced to some extent in other areas of Sri Lanka and should be emphasized in the Accelerated Program.

The planning of System B (ACRES 1979) will incorporate a feature of this kind in which upland drains will discharge into a countour drain along the base of the upland slope, and the water will at least, in part, be then routed to lower paddy areas. This is good planning and related concepts should be applied wherever possible in the design of the project.

CONTROL OF VILLU DISCHARGES

In order to regulate discharges and to limit dry season drainage, water could be held artificially in most villu areas by the construction of low level weirs in the outflow streams. This would assure a certain amount of water storage after the fall of the river from its high stage and after the end of wet season rains. In this way a certain amount of the reduction of area of the villus following the river diversions could be avoided. Also, the duration inundation could be extended, since drainage from the villus will be more rapid due to the reduced dry season flows.

The streams by which the villus are connected to the river will probably adjust to steeper channel gradients following the reduction of river flow. This will lead to even more rapid escape of water from the villus unless steps are taken to control this by regulation using the weirs. If, however, weirs are placed too close to the river they may be subject to early destruction due to the increased tendency for lateral wandering of the diminished river or from undermining by increased gradients of connecting streams.

Return flow from irrigation and drainage which enters the villus also complicates the problem of using weirs for villu preservation. Low level weirs to hold water in the villus would have at the same time the effects of greater storage of return flow and drainage waters with some predictable consequence, such as eutrophication, water weed infestations, pesticide build-up and possible salinization. This could be avoided if the return flows and drainage waters are routed around the villus or improved in quality through careful control of excessive nutrients and other contaminants. Since weirs will obstruct flow in the channels there will be sedimentation of sand and silt in the channels near the weirs which will require removal probably each year.

A related means of maintaining water levels in the villus would be to construct a barrage in the river just downstream of the villu to inundate the area. Another method is to alter the meander alignment of the river to direct its flow through a villu.

However, the use of any of the above engineering works would be very costly. In addition each method would only maintain the pool area of the villu, essentially controlling it like a tank system. The adjacent floodplain margins cannot be re-inundated and their loss is unavoidable. Maintenance of villu pools would provide a slight benefit for fisheries development, but the loss to grazing carrying capacity for livestock and wildlife would not be recoverable.

WILDLIFE CONSERVATION

It is recommended that the entire floodplain area of the Mahaweli Ganga be included in the wildlife reserve system. This would prevent future development in these areas and maintain existing migration routes and linkages for the continuance of gene flows. The area of particular importance would be the floodplain and associated villus between the Wasgomuma Strict Natural Reserve and the Somawathie Chaitya Sanctuary. This is further discussed in TOPIC REPORT E: WILDLIFE.

MANAGEMENT OF VILLU GRAZING LANDS

Although some of the grazing areas of the villus will be lost and carrying capacities reduced, partial mitigation of these adverse impacts can be achieved with the implementation of proper grazing management procedures. Following project implementation a study of the grazing potential of the remaining floodplain/damana association should be made. The possibility of pasture enrichment in the villus should be investigated, especially for areas which have been invaded by *Xanthium strumarium*.

It may be advisable to spray these areas with herbicides to eliminate this weed and permit suitable forage grasses to reappear.

In addition, proper herd management for the correct carrying capacity needs to be established. Selective grazing practices may also be required. The change in floodplain margin vegetation will provide grass types preferential to cattle over water buffalo. However, the need for draught animals may necessitate the provision of additional grazing areas for water buffaloes at the expense of crops or other usage. Further, some grazing areas which undergo change may in fact become most suitable for the grazing of sheep or goats than cattle and buffaloes.

CONTROL OF VILLU EUTROPHICATION

The extent to which villu eutrophication can be controlled is uncertain, but it is clear that some things can be done. The design of settlement sanitation facilities is an obvious case and one which can offer public health benefits as well.

Drainage water and irrigation runoff entering the villus might be enhanced in quality in other ways. Some of the former villu land around the margins of the diminished villus following project implementation could be set aside to be used in various ways to attempt to do this. One approach would be to apply these waters in a controlled manner such as overland flow for the intensive cultivation of pasture grass to alleviate to some extent the pasture scarcity that the project will create. One or another of the tolerant forage grasses that are abundant in the villus should be rapidly adaptable to these managed conditions. By means of bunds, overland flow could be controlled and directed to achieve a long flow path over an extensive area. Such methods have been applied in various ways in many parts of the world in order to improve water quality and have been successful. The water flowing through these systems is substantially lower in such an undertaking, but since large amounts of water would be available at times to flush out salts it may prove possible to control this problem. Similar systems using some kind of water tolerant trees might also be effective and allow production of wood at the same time.

Although some emphasis is given above on the importance of finding ways of reducing cost or even making profitable the work required for a reduction of eutrophication, it should be pointed out that they may still be worth doing even if at a relatively high cost. The benefits in terms of public health, protection of fisheries and enhancement of grazing lands would justify their being subsidized.

MANGROVE CONSERVATION

Efforts to mitigate the anticipated impacts on mangrove swamps should involve reforestation and protection from excessive cutting. Noakes (1955) gives an excellent description of the kinds of problems that arise in reforestation of mangrove areas. Seedlings must be physically protected and invading thicket forming species kept under control. Cutting should be

reduced to acceptable levels by some means. This is clearly difficult to accomplish, but tactics that might be effective would be to provide other sources of firewood if necessary from outside the area or in new plantings nearby, but outside of the mangrove area.

Substitution of other energy sources for wood should also be explored. Demonstrations of solar cooking techniques and marketing of equipment for using this energy should be arranged. Construction of biogas producing sanitary facilities should be encouraged. Wood conserving stoves should be demonstrated and built in the coastal communities. Stoves capable of using rice husk or other agricultural by-products should be tried. In short, any and all possibilities for substitute energy supplies should be investigated and, where possible, made available to the area. Perhaps electricity from the dams should be allocated preferentially to areas where critical problems related to excessive use of wood for fuel exist, such as the mangrove zone around Koddiyar Bay. In this way impacts partly due to the dams could partly be mitigated by the energy from the dams.

Secondary development resulting from the project should be controlled in various ways. Particularly, all efforts at so-called "reclamation" of mangrove swamp lands for conversion to other uses should be stopped. Any efforts to bridge tidal streams should be done in such a way that tidal exchange is not impeded. Interference with the normal tidal flushing results in an alteration of salinity regimes, usually with a significant increase in salt concentration which is detrimental to fish and shellfish species. No further construction of the concrete, low-level ford bridges with only small culverts for tidal exchange should be allowed. These obstructions to tidal exchange should be replaced by true bridges that do not block flow.

UNPRODUCTIVE NEW WETLANDS

Few unproductive new wetlands are anticipated in the project area. Localized wetlands may be formed in natural depressions where return flows accumulate. Some of these areas could be drained.

Other areas within the irrigated lands that become subject to chronic flooding and water weed growth as a result of irrigation, and paddy fields that are marginally productive or become abandoned due to excessive water weed growth due to poor drainage, should where possible be converted to more suitable uses. Some could be used for water holes to accomodate water needs for draught water buffalo. Others could be utilized for duck raising or as fish ponds.

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ACKNOWLEDGEMENTS

We would like to express our appreciation to the following institutes, agencies and individuals for providing information and assistance in the preparation of this report on WETLANDS:

- B. A. Abeywickrams, MAB Chairman
- ACRES International Limited
- Agriculture Department
- K. D. Arudpragasam, Colombo Campus
- Dr. Balasubramaniam, Peradeniya Campus
- Central Agricultural Research Institute
- C. Felsinger , Kandy
- Hunting Technical Services, Limited
- Japan International Cooperation Agency
- Joint Venture Randenigala
- Land Use Division
- Livestock Development Board
- Mahaweli Authority
- Mahaweli Development Board
- A. M. J. Meijerink, Colombo Campus
- Ministry of Fisheries
- National Science Council
- NEDECO
- USAID

I. AQUATIC VEGETATION

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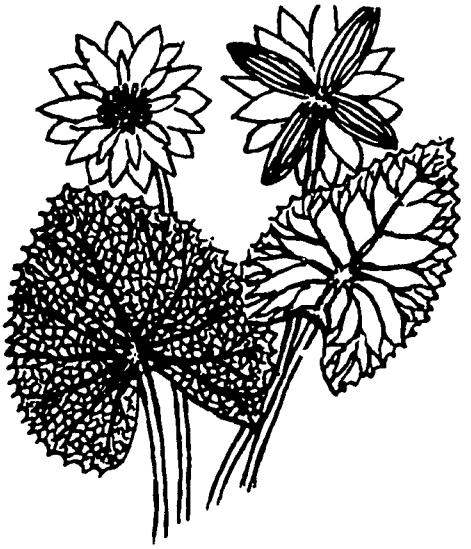
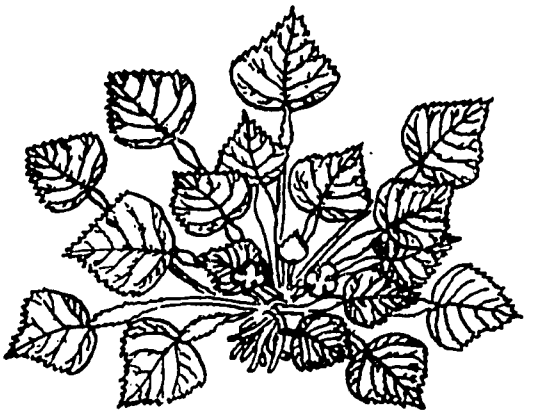
INTRODUCTION

This report on AQUATIC VEGETATION is closely associated with TOPIC REPORT H : WETLANDS, which contains details concerning the various types of plants which occur in aquatic habitats throughout the project area. However, this report focuses upon the aquatic vegetation which has the potential to develop a nuisance condition adversely affecting various aspects of the proposed Accelerated Program projects. This vegetation is usually referred to as aquatic weeds. Potential impacts related to these weeds are identified, and various means of controlling or utilizing them are recommended.

The aquatic vegetation discussed here are generally classified as floating, submerged or emergent. The more well known floating forms include water hyacinths and floating ferns. Common submerged weeds include hydrilla amd milfoil, while the more recognizable emergent species would be the cattails, papyrus and reeds.



NYMPHAEA LOTUS.



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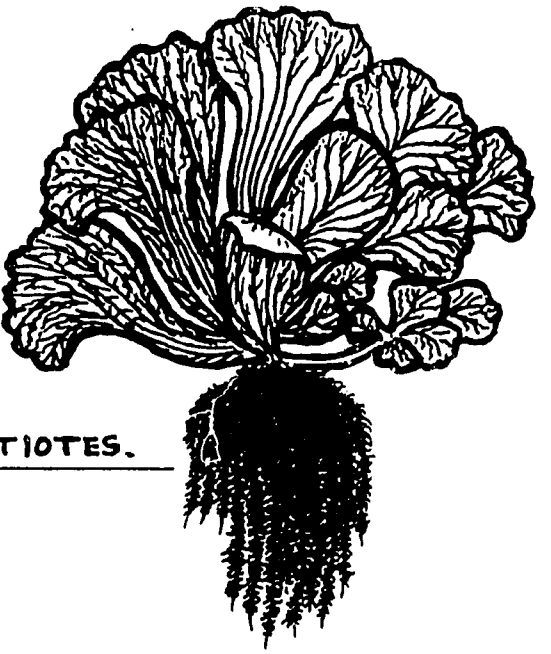
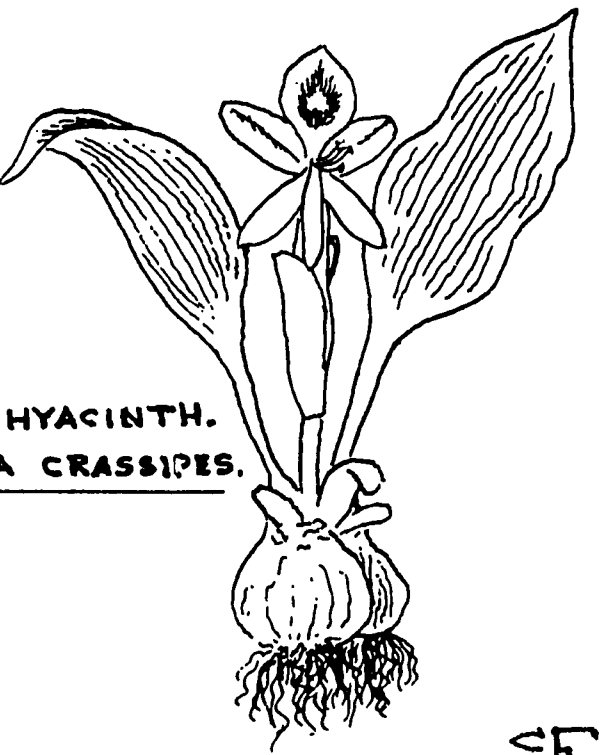


PISTIA STRATIOTES.

SALVINIA NATANS.



WATER HYACINTH.
EICHORNIA CRASSIPES.

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EXISTING CONDITIONS

GENERAL DISTRIBUTION

As in any other form of agriculture numerous unwanted species have proliferated as weeds in the paddy fields, irrigation systems and drainage systems and have caused great hindrance to achieving high production in many parts of Sri Lanka.

In a few areas these are chronic problems, but generally their abundance is limited by the dry season conditions. Only where water is abundant for a large part of the year such as in areas of obstructed drainage, certain smaller tanks, double cropped areas and villus, do the weeds tend to be persistent.

SPECIFIC AREAS OF WATER WEED INFESTATION

Water Hyacinth

Water hyacinths are free floating and prefer quiet water habitats. They are often held in place by shoreline vegetation or various structures. Water hyacinths are annual plants and are very prolific. They reproduce vegetatively and or through seed production. Seeds are capable of survival and are viable for several years.

The occurrence of water hyacinth (Eichhornia crassipes) around the Kaudulla Tank is an informative case to consider as an illustration of how these weeds can be spread and become established in an area. Since other occurrences in the surrounding area are not known, it appears probable that this plant was introduced into the area by human agency probably prior to 1969. That it survived and began to spread owes much to certain conditions found in this area.

The Gal Oya and the Minneriya-Kantalai Yoda Ela which intersect in this vicinity provide water and nutrients to the area year round. Impounded drainage on the western side of the Yoda Ela as a result of bunds and other obstructions to flow created slack water areas favourable to water weed proliferation. Human settlements in this area may have added nutrients to these impounded areas and stimulated growth of water weeds. The blockage of the Gal Oya just below Gal Oya Junction by a road crossing which allows only culvert flow at lower river stages is an example of the kind of obstruction that can favor the establishment of water weeds. This immediate area seems to be the center from which the water hyacinth has spread.

What is already happening in System D is a very good illustration of what the impact of a water hyacinth invasion can be like. In the vicinity of Gal Oya junction water hyacinth has been present for at least nine years, perhaps longer. At the present time, it occupies extensive areas of water surface and grows in a very robust form with leaf petioles up to nearly a meter in length in some specimens.

Water hyacinth extends from Gal Oya Junction along the Minneriya-Kantalai Yoda Ela and is said by irrigation engineers in the this district to enter the Kantalai Tank frequently, although it is not presently known to

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have escaped from the Kantalai Tank into its command areas as it did from the Kaudulla Tank. The Minneriya-Kantalai Yoda Ela is a principal feature of the entire project. The occurrence of water hyacinth in this important artery for transport of irrigation water has very serious implications.

Downstream of the Kaudulla Tank, water hyacinth is extensively spread. In the Kaudulla Oya, the principal drainage way below this tank, water hyacinth roots in the soil of the banks when the water is low and grows as a terrestrial plant only to renew its aquatic habit when the water rises. From this channel and also through the irrigation channels, it has entered the smaller scale irrigation and drainage ways where its effects are most damaging. In these drains it frequently occurs together with dense stands of Scirpus grossus and often with a heavy growth of Ipomea aquatica. Water buffalo observed feeding in these drains were selectively feeding on the Ipomoea ignoring the water hyacinth. The growths may be so thick that they more or less completely block the drainage, and backed-up drainage water overflows into fields carrying the water hyacinth with it.

Several miles downstream of the Kaudulla Tank, local residents say that water hyacinth arrived in their area only about five years ago (1975). It now occurs virtually throughout the command area close to the principal drainage way. It is estimated that its removal at present costs about Rs 6,200 per hectare of water surface covered, but generally funds are inadequate to remove more than a minor part of it. Local residents have been asked to remove it themselves, but such efforts have seldom materialized.

There is no particular reason to believe that what has happened in System D will not also happen in the other systems. When it does, extensive crop losses can be expected. The Kaudulla Oya discharges into the Mahaweli Ganga in which water hyacinth can be expected to spread into all connected water bodies downstream by the river currents.

Floating aquatic plants may provide the substrate to support the growth of other wetlands species with a non-floating habit. A good example of this can be seen at the Gal Oya Junction where the dense stands of robust water hyacinth are heavily outgrown by the trailing vine Mikania scandens which binds together the water hyacinth into stable mats. Panicum repens and even Typha is rooted in this mat. Such aggregations of floating plants with non-floating species rooted in them are referred to as "sudds", a name derived from the large swamp in the Sudan known as the Sudd where such occurrences are common.

Floating Ferns

Tanks in System B which have heavy growths of floating ferns (Salvinia) often show sudd formation. In these, small sedges (Cyperus sp.), Ipomoea aquatica, Polygonum and Panicum species colonize the dense floating growths of Salvinia. Patches of this assemblage of plants can be seen floating about on tank surfaces where they often cover nearly the entire area.

Salvinia molesta is widespread throughout the area. It frequently covers the surface of small tanks and villus. Areas of impounded drainage due to bunds associated with irrigation and flood control works are usually wholly or partly covered. In many areas it occurs in rice fields, especially those of poor drainage or those that have been affected by flooding. It is very abundant along the lower Mahaweli Ganga drifting along in the current and becoming stranded in large masses in the vegetation of the banks.

It should be noted for those not familiar with Sri Lanka, that Salvinia is usually present here in its third phase growth form which is quite different in appearance and far more robust than the second phase growth form usually seen in more temperate latitudes.

Water Lettuce

Water lettuce, Pistia stratiotes, another floating weed recently introduced into Sri Lanka, is already fairly widespread in the area especially along the villus and will probably become more common in the future. This weed deserves special mention because it is known to create breeding conditions favorable for Mansonia mosquitos which are responsible for the spread of filariasis, a disease also known in its later stages as elephantitus. Pistia also provides a breeding habitat for encephalitis-carrying mosquito species.

Other Aquatic Plants

Typha javanica is also widespread throughout the area. It is especially common in rice fields with poorer drainage conditions, and some such areas have been virtually abandoned to this weed. It occurs as well in the minor irrigation and drainage works where its flow blockage effects are severe. Owing to the tough, solidly rooted abundance of rhizomes characteristic of Typha, it is extremely difficult to eradicate.

Rice fields with poor drainage have a large variety of aquatic weeds besides the above. Even Nymphaea stellata is seen in extreme cases. Such places are usually being actively invaded by Typha. Nymphoides indicum, Asteracantha longifolia and Scripus grossus may be common. These fields are often abandoned but remain as centers for spread of aquatic plants to nearby areas.

Rice fields of better drainage may also have large numbers of weeds with an abundance of sedges and grasses among them. These include species of Panicum and Echinocloa, many sedges of the genus Cyperus, Leersia hexandra, and Eragrostis tenella.

Larger and intermediate scale irrigation channels sometimes have weed problems. The banks are usually lined by Panicum and Echinocloa, species which float outward over the water surface. Ipomoea aquatica can also send long streaming shoots out over the water surface.

Potamogeton sp. occurs in some areas as a submergent plant that floats near the water surface. Hydrilla verticillata and Vallisneria spiralis are sometimes extremely abundant. Aponogeton crispus, A. natans, A. monostachyon, Najas minor and Jussiaea repens are sometimes common.

The minor irrigation ditches which feed the rice fields have heavy growths of various water tolerant plants which must regularly be cleared by the farmers. Panicum and Echinocloa species are again very abundant. Typha is common as well, and in many areas Pennisetum typhoides is very abundant in the ditches. Other common forms are Commelina salicifolia, Alternanthera sessilis and Mimosa pudica.

Many of the same species which occur in the better drained paddy and in the minor irrigation works occur as well on the paddy field bunds. These bunds cover a large area of land and when they are not kept trimmed, which is more often than not the case, they represent an abundant source of seed for weeds. This is also true if they are only trimmed after seeds have already matured.

Productivity

Aquatic weeds are often more productive than terrestrial vegetation. Water hyacinth is especially prolific. Stands of 470 tons/hectare of this plant have been reported, with daily weight gains of nearly 5% (USNAS 1976). Grown on sewage effluent, water hyacinths have produced as much as 800 kilograms of dry matter per hectare per day.

However, the dry matter content is very low in aquatic weeds, generally half that of the 10-30% of terrestrial plants. This has been a major deterent in commercial use of aquatic weeds. About 10 tons of most aquatic weeds (20 tons of water hyacinth) must be harvested and processed to obtain one ton of dry matter.

IMPACT ANALYSIS

COMMON IMPACTS RELATED TO AQUATIC WEEDS

Aquatic vegetation constitutes an environmental phenomenon which is somewhat unique in its relation to development projects; the aquatic weeds often have a more adverse effect on the project than the reverse.

The introduction of large amounts of additional water and fertilizer and the creation of large areas of new aquatic habitat will inevitably increase the numbers of aquatic plants in the area. Of these, particular problem species can be expected to vigorously proliferate. The three major problem species, water hyacinth, Salvinia and Typha, can be expected to spread rapidly through the system; in fact, they are already doing so. Other problem species, especially numerous grasses and sedges, will become more of a nuisance. Extensive efforts to control all of these species will be required and will add to the cost of operating the irrigation and production systems.

The general problems associated with dense growths of aquatic vegetation include:

- Blockage of reservoir penstocks or interference with turbine operations;
- Formation of breeding sites for disease vectors;
- Excessive water losses due to increased evapotranspiration;
- Interference with boat transportation or use of fishing gear;
- Production of large amounts of organic matter which increase decomposition rates and deteriorate water quality conditions, often producing obnoxious odors; and
- Blockage of canals, pumps and drainage channels in irrigation systems.

EFFECTS ON PROPOSED RESERVOIRS

Some of the large reservoirs associated with the hydropower and irrigation schemes can be expected to be invaded by water weeds. The occurrence of water hyacinth in Gregory's Lake near Nuwara Eliya is supportive of the view that water hyacinth could possibly occur in these reservoirs. Similar reservoirs in many parts of the world have been invaded by water hyacinth and Salvinia. Salvinia will probably occur also in the lower reservoirs. Outbreaks of water weeds would not occur if catchment areas could be protected from extensive deforestation and settlement. In this project, this may be possible only for the Kotmale catchment, but even here this will require extensive reforestation and may not be attainable.

It may take several years for water weed problems to become severe and chronic in the reservoirs due to a time lag during which nutrients will be accumulating in the system. If the water weed cover becomes extensive, oxygenation of the reservoir water will become poorer and limit their value for fisheries.

Once aquatic weeds invade a reservoir, they may become very prolific and spread over large areas. For example, prior to the filling of Lake Brokopondo in Surinam in early 1964, water hyacinths had been uncommon in the inundation area (Milton 1975). In December, 1964, about 5000 hectares of the lake's surface were covered. The water hyacinths spread further to 17,900 hectares in 1965 and to 41,200 hectares (more than 50% of the total surface area) in 1966.

IMPACTS ON VILLUS AND SMALL TANKS

Where eutrophication is particularly a problem due to return flows, runoff from upland areas, wastewater or other sources, chronically poor water quality and persistently dense growths of water weeds can be expected. Smaller tanks and the diminished villu areas that will remain after the project will be especially vulnerable to these kinds of changes as indeed many are already. Such conditions may sharply reduce potential fisheries resources of these areas.

Water weed infestations such as those already known to occur on smaller tanks in System H and System D can be expected to occur with increasing frequency. Smaller tanks which receive appreciable amounts of runofff and irrigation return flow such as the Vakaneri Tank of System B will be even more seriously and quickly affected.

IMPACT ON THE MAHAWELI GANGA

Main Channel

Reduced flow in the lower Mahaweli Ganga will favour more extensive growths of Salvinia which is already common in the river channel. Diminshed flow velocity will mean that these plants will not be carried downstream and out to sea as rapidly as before while their growth rates will increase from greater quantities of nutrients in the river water.

The possibility exists that Salvinia may spread at times of lower water flow to cover the entire river surface as is the case in certain other Sri Lankan rivers such as the Deduru Oya at the present time. Below the Kandakadu Barrage where water flow in the lower river will at times be most sharply reduced these proliferations can be expected to be most severe.

Kandakadu Barrage

A low level dam on the lower Mahaweli slightly upstream of the settlement of Kandakadu is being considered in the overall plan. The purpose of this structure would be to divert water for irrigation in System A. In plans to date, it is estimated that during times of higher river flows the reservoir beyond this structure would cover about 2900 hectares. On the eastern side several villu areas will be flooded while on the western side a bund is proposed to limit the rise of water over those lands.

Since the depth of flooding produced will be relatively shallow, the affected villu areas may retain certain of their present wetlands characteristics. The typical villu vegetation should spread to higher levels along the margins while in the areas of highest depth of flooding it may be flooded out so that essentially lake habitat will exist. These kinds of changes that might be expected may be profoundly modified however by proliferation of water weeds to such an extent that they exclude the other wetlands species and deteriorate water quality conditions. This must, in fact, be regarded as a rather likely development for several reasons stated below.

The Kandakadu Reservoir will be large and shallow. It will have a high flow through of Mahaweli river water for much of the year. Considerable amounts of irrigation return flow and drainage water will be part of this flow-through at most times of the year. Salvinia is already a problem in the villus that will be flooded. Water hyacinth is spreading in this direction only a short distance away. These very opportunistic weeds are likely to proliferate in the nearby highly suitable habitat that will be created. Salvinia may spread from the very beginning. These developments may reduce the effectiveness of the Kandakadu structure and the conveyance canals leading from it as parts of the overall scheme.

The bund on the western side will impound drainage over a large area, including the area of the Diwulana Villu, one of the larger villus and one of the most heavily utilized for grazing. The obstruction to drainage will create even wider outbreaks of water weeds. Water weeds from these areas and the reservoir itself will spread downstream in the lower Mahaweli and all its distributaries even more effectively than they already do at present.

EFFECTS OF AQUATIC WEEDS ON WATER LOSSES

Water bodies covered by floating water weeds are often said to lose water more rapidly than open water bodies. Published estimates of the magnitude of this effect for water hyacinth vary widely over a range of about 1.4-6 times greater than water loss from open water. This variation in measurement of transpirational effects make it uncertain how much water loss can be due to transpiration. However, even the lower range of the estimates would signify a loss of 40% of water resources in areas heavily infested by water hyacinth.

The reasons for this higher water loss are not certain. The most recent research (Linacre 1976) has indicated that higher water losses are to be expected only in situations where advective energy transfer is especially important. Thus, narrow canals, small wet depressions along canals, small tanks and small areas of paddy where advection is likely to be great would be areas of heaviest water loss due to water weed infestation.

RECOMMENDED ACTIONS

CONTROL OF AQUATIC WEEDS

Effective Water Use

One of the most effective means of preventing the spread of aquatic weeds is through proper water application and drainage in the irrigation systems. This will limit the available habitat which encourages water weed infestation. The control of water use as a mitigative measure is discussed in more detail in TOPIC REPORT H : WETLANDS.

Chemical Control

The application of selected herbicides is one control method which has proved useful in the removal of aquatic weeds in certain localities. Spraying with herbicides is not necessarily harmful in a direct sense to the environment. Herbicides such as 2, 4-D, Amine and Diquat have been used without harmful effects to other aquatic organisms. These herbicides break down rapidly to harmless by-products following application.

There are, however, secondary consequences of herbicide use even if the type used is itself innocuous. The plants killed by the herbicide remain in the drain or water body where they may continue to obstruct flow. The decomposition of large masses of dead vegetation may consume excessive amounts of oxygen in the water and lead to poor water quality for a prolonged period. Also, the nutrients contained in the plants are subsequently released to the water where they add to continued eutrophication and renewed water weed growth. In paddy fields herbicides have definite limitations in usefulness since many common weeds are grasses as is rice, and therefore the weeds cannot be selectively eliminated by spraying. An additional problem may be the cost of the herbicides which are increasing rapidly due to elevated petroleum prices.

Biological Control

One form of biological control is the seeding of competing species which are less harmful or even beneficial in some way. As an example, *Azolla pinnata* is a common member of the floating aquatic plant community in Sri Lanka. *Azolla pinnata* has within it a symbiotic blue-green algae, *Anabaena azollae*, which is nitrogen fixing. Because of this nitrogen fixing ability, the *Azolla pinnata* - *Anabaena azollae* association is deliberately introduced into paddy fields in various parts of Asia, especially in Vietnam, in order to provide nitrogen to the paddy.

It is important to note that although the primary motive of seeding the paddy fields with *Azolla* may be for nitrogen, there is another important role which it may be providing that is also beneficial to the paddy. The deliberate and careful seeding of *Azolla* at the appropriate time makes it an effective competitor with aquatic weed species. By rapidly spreading, the introduced *Azolla* absorbs nutrients and other materials that would foster growth of aquatic weeds. Since it floats on the surface it can retard the

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growth of submerged aquatics and other weeds by shading. This shading also can reduce oxygenation of the paddy field water and further retard weed growth. Oxygenation of the water is also reduced to some extent by the reduced oxygen diffusion through the air-water interface due to the extent of the surface area covered by Azolla. It might be useful to attempt to establish swamp trees whose shade might reduce the water weed growth and abundance.

Shading may be important for bio-control of water weeds in other ways. Shading would be especially appropriate along narrower irrigation and drainage ways. Appropriate planting along the sunnier side of such canals would reduce photosynthesis of the aquatic weed species and reduce their growth rate. Since any such plantings will consume water, those that can be effectively utilized locally should be given precedence. Poles or perhaps firewood could be produced in significant quantities especially if sprouting (coppice-regenerating) species are used. Tall crop species such as maize or sugar cane may be used where appropriate as well.

Another means of biological control is through the introduction of various herbivorous animals which will naturally graze on aquatic vegetation. Three fish species which have been notable for their control of aquatic weeds are the grass carp (Ctenpharyngodon idella) and two tilapia species (Tilapia zilli and Tilapia rendalli). All of these are excellent food source fishes as well. These fish are particularly effective in removing nearly all forms of submerged vegetation; however, they do not normally feed on emergent or floating plants.

Ducks and geese could also be introduced in some areas to control the spread of chiefly submergent or emergent weeds. In addition, they would provide a protein source through eggs and meat. Ducks and geese, however, do not graze upon broad-leaved plants.

Water buffaloes are known to naturally graze on submergent plants, the shoots of cattails and even leaves of the water hyacinth. However, the buffalo prefers the marshy, terrestrial grass species and thus in reality does not usually control aquatic weed growth. The use of aquatic vegetation for animal fodder is discussed in a following section.

Physical Removal

Physical removal of water weeds from infested areas is a method that has much to recommend it, since it eliminates the problem of physical obstruction of irrigation works, high oxygen demand of decaying plant debris and also reduces eutrophication since nutrients are removed from the aquatic system. Removal of water weeds requires much labor so it is best applied in areas that are chronically infested. It also becomes less expensive if some way of utilization is found.

UTILIZING AQUATIC VEGETATION

The following are various suggestions which could be implemented to make effective use of nuisance aquatic weeds (USNAS 1976).

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Animal Feed

As mentioned above, ducks, geese and water buffalo often feed on aquatic vegetation directly. In the dry season of Bangladesh, water hyacinth is hand harvested and fed directly to cattle, sheep and goats. However, the animals do not grow well on it, but it is the only vegetation available. Water hyacinth, Salvinia and Hydrilla have all been used as pig feed.

Processing of aquatic weeds is often necessary, particularly to de-water them by chopping and pressing, in order to make the vegetation amenable as feed. Partially de-watered aquatic plants have been used to make a palatable, digestible and nutritious silage readily acceptable by cattle and sheep.

Careful attention should be given to problems resulting from large concentrations of animals such as with dairy farms, livestock feed-lots or chicken farms. In some areas of the world nutrients lost from large animal concentrations are partially recycled through the cultivating and harvesting of water weeds grown in controlled enclosures, or tanks or simply gathered from nearby infested places. In China, there is a notable example of this form of control. The weeds are used as pig fodder, green manure or made into compost. A better forage plant such as Ipomoea aquatica can also be cultivated in this way.

Fertilizer

Aquatic weeds can be used as green manure through direct application as a surface mulch or plowed under in shallow troughs. As a mulch, they suppress weeds and reduce evaporation, runoff and erosion.

Aquatic vegetation has also been shown to be useful as a component of compost which when applied increases soil fertility, improves yields and enhances soil quality.

Successful composting of water hyacinth has been accomplished in Sri Lanka by the Home Garden Unit of the Department of Agriculture. The compost was made in about 2 weeks from chopped water hyacinth mixed with kitchen refuse, ash, earth and cow manure. This compost has been successfully used in the rearing of nursery plants and also was sold for a slight profit under the brand name "Garbage Gems". Since their costs of production were rather high because of the necessity of trucking the plants from the point of harvest to the composting site, it is clear that costs could be further reduced by deliberate cultivation in controlled enclosures with composting adjacent to the enclosure. Biswas (1976) provides information that indicates that composted water hyacinth has twice as much nitrogen and phosphorous as composted cow manure.

Energy Production

Aquatic vegetation can be used solely, or in combination with other organic matter, in the production of biogas. Methane-producing bacteria cultured on water hyacinth in a sealed tank (for anaerobic conditions) will yield a biogas of about 70% methane and 30% carbon dioxide. Each kilogram of water hyacinth (dry weight) can produce 370 litres of this biogas which

has a heating value of around 22,000 kj/m^3 (580 Btu/ft^3). The biogas burns readily and can be used for cooking, heating and as a power source. The high moisture content of aquatic weeds is an advantage in this process, since it is needed for fermentation. Small biogas plants are presently being experimented with by Sarvodaya and other local community development organizations.

Food and Other Uses

The aquatic plant Ipomoea aquatica, often called water spinach, is presently consumed on a fairly wide basis as a vegetable by the people of Sri Lanka. This plant is also widely consumed as a vegetable by people in many other parts of the world. Alternanthera sessilis, another plant used very much as food in Sri Lanka could grow well in controlled enclosures in which nutrient rich waters can be applied to achieve water treatment and food production simultaneously. Numerous other aquatic plants could be cultivated for food in Sri Lanka including Neptunia oleracea and Limnocharis flava. Another species, common in Sri Lanka, which can be exploited as a food source is Typha or cattails. The rootlike rhizomes contain a firm core with an edible starch. Cattails are also a source of pulp-paper and fiber.

It is apparent from the above discussion that aquatic vegetation can be put to a number of useful purposes which would simultaneoulsy serve as control measures. The more feasible uses would appear to be the low level technology approaches for the production of supplemental animal feeds and mulch or compost. It is recommended that training in the processes for aquatic weed utilization be implemented as an integral part of the agricultural extension services.

Furthermore, research and demonstration projects need to be implemented to promote the control, harvest and cultivation of aquatic vegetation.

Obviously, the success of methods of delibrate cultivation of aquatic plants depends critically upon the question of effective usage of the plants so produced. Design of culture systems should take this closely into account. In one situation green manure usage might be most effective, while in another methane production would have most benefit, and in still another, composting may be most effective.

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ACKNOWLEDGEMENTS

We would like to express our appreciation to the following institutions, agencies and individuals for providing information and assistance in the preparation of this report on AQUATIC VEGETATION:

- B.A. Abeywickrama, MAB Chairman
- ACRES International Limited
- Dr. Balasubramaniam, Peradeniya Campus
- C. Felsinger, Illustrator, Kandy
- Home Gardens Unit, Department of Agriculture
- Mahaweli Authority
- Mahaweli Development Board
- Ministry of Fisheries
- National Science Foundation
- NEDECO
- World Health Organization