Figure 33. Precipitation and estimated runoff (first year, 5-day average).

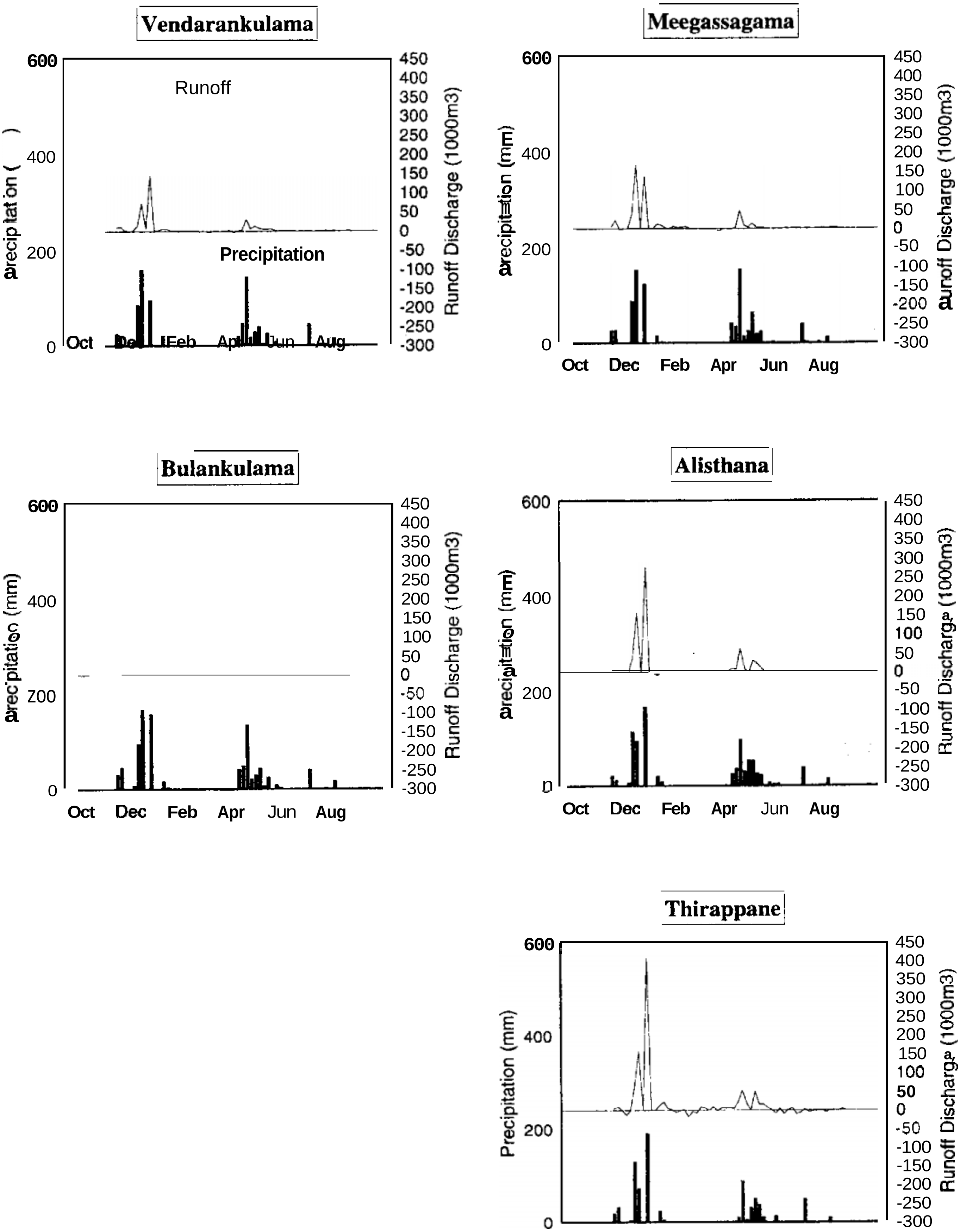


Figure 34. Precipitation and estimated runoff(second year, 5-day average).

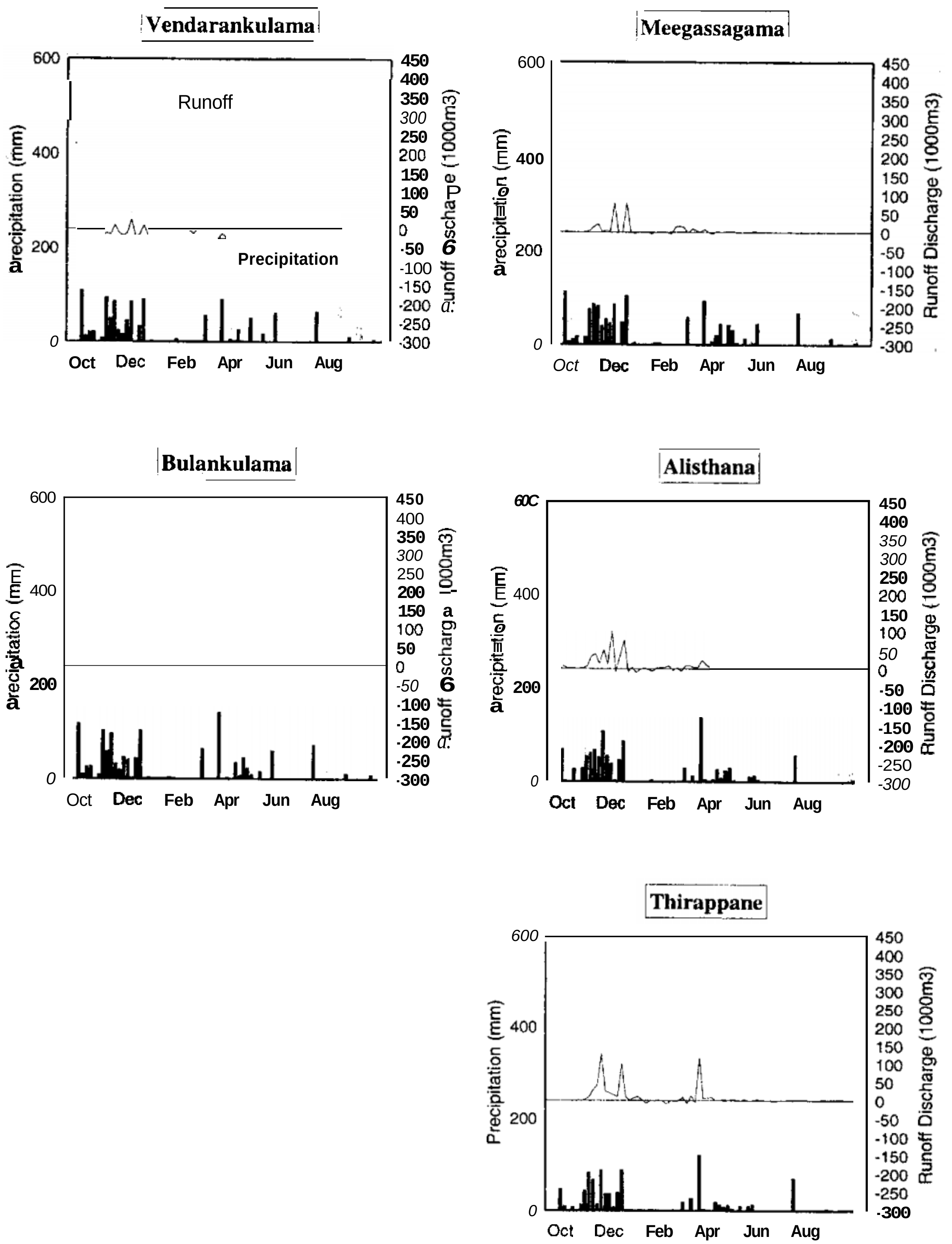


Figure 35. Fluctuation of composition of inflow (firstyear, QC excludes the spill water coming from upstream tank).

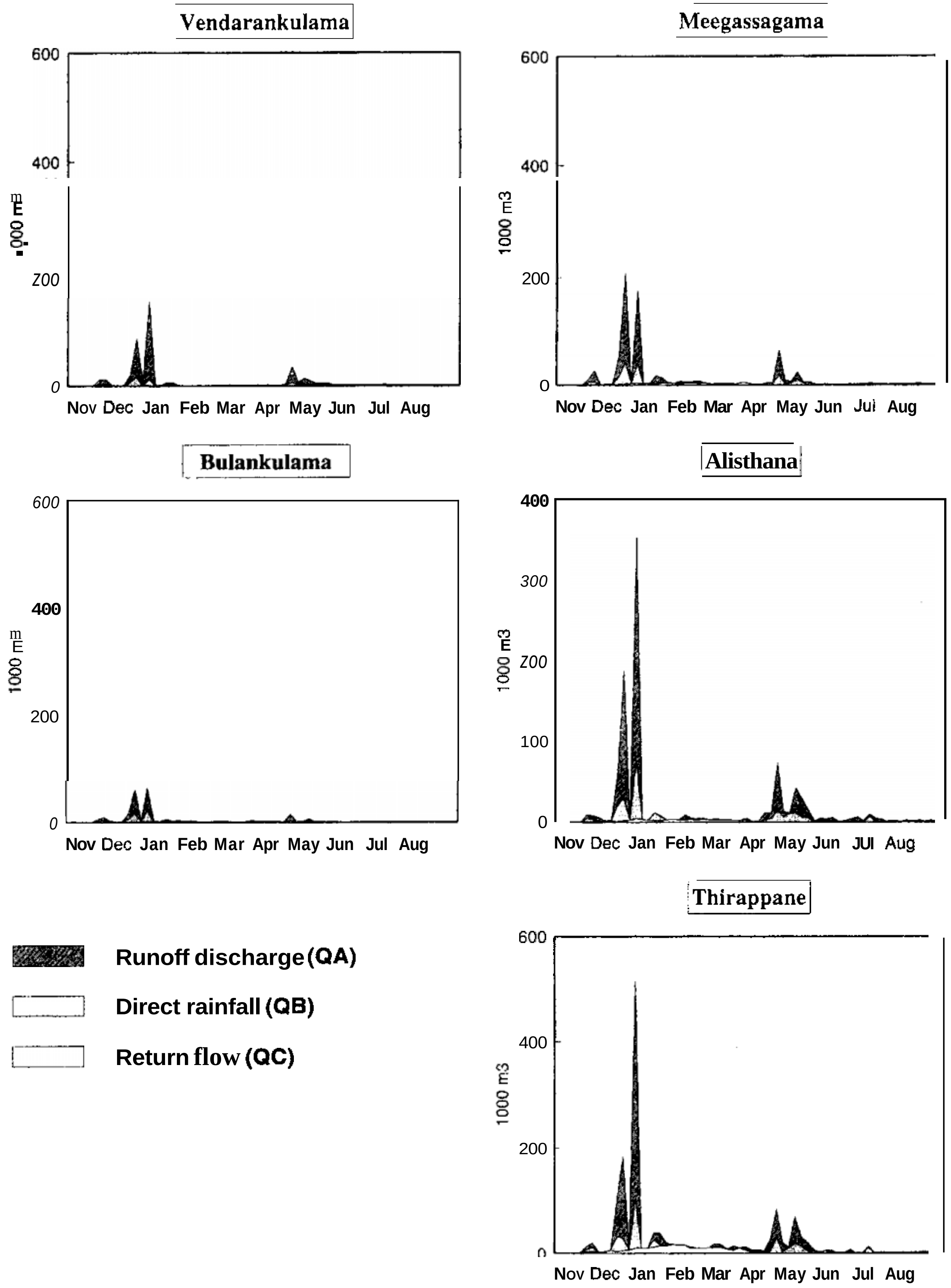


Figure 36. Fluctuation of composition of inflow (second year).

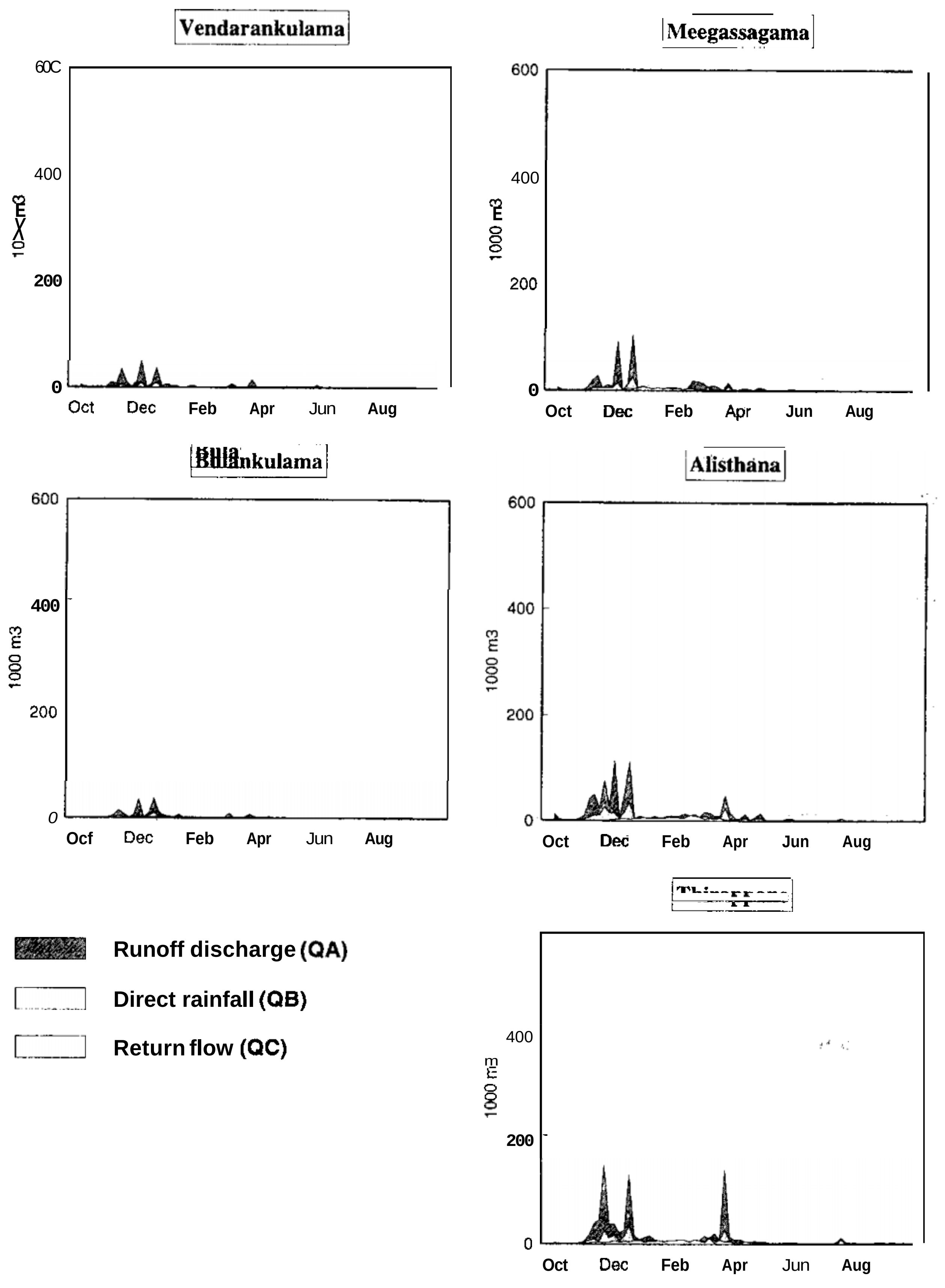


Figure 37. Composition of total inflow (first maha, 16 November - 31 March, QC includes spill water from upstream tank).

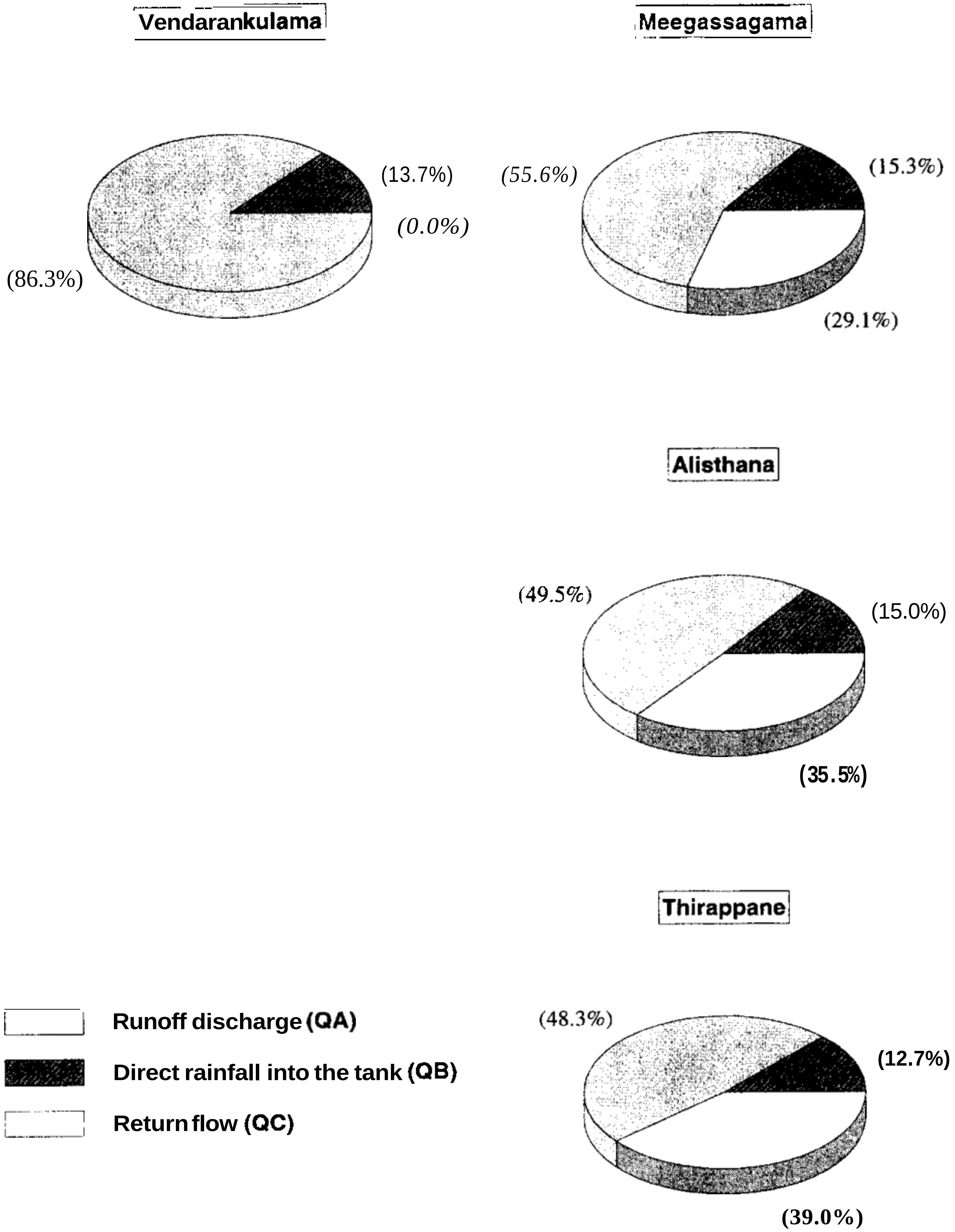
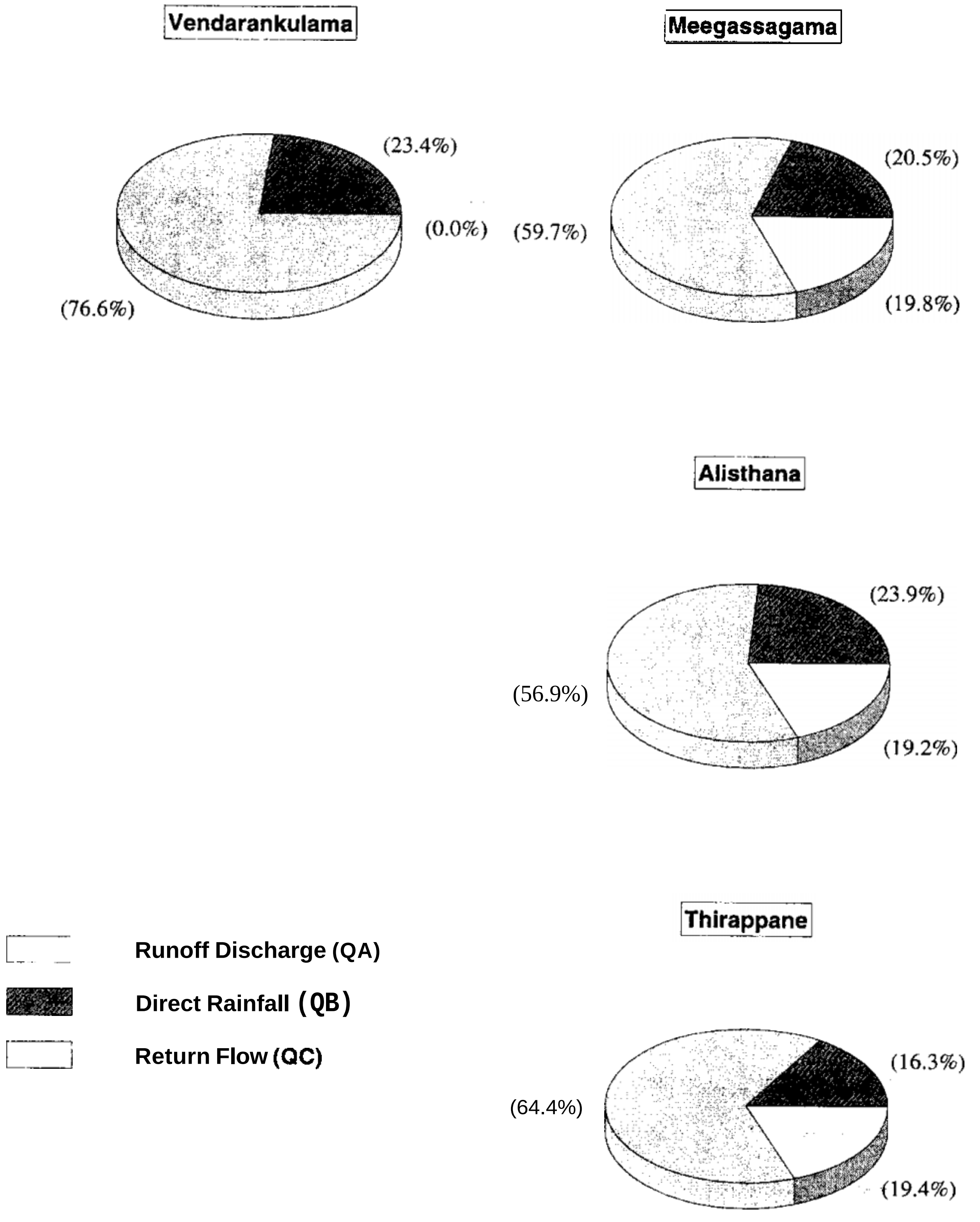


Figure 38. Composition of total inflow (second maha season, 76 November - 31 March).



	Rice	Tea	Rubber	Coconut	Others	Total
Land use(1000 ha) Share (%)	740 39	222 12	199 10	416 22	323 17	1900 100
GDP (100,000 Rs) Share (%)	6378 24.6	3004 11.7	718 2.8	3261 12.7	12366 48.1	25729 100

Source: **Kikuchi, Sano, 1993, Agriculture of Sri Lanka 1993, Association for International Cooperation of Agriculture & Forestty. Japan**

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
Tank Catchment Area (CA) km^2	1.95	0.64	3.56	3.70	4.48
Full Tank Water Surface Area (FWA) km'	0.13	0.10	0.30	0.51	0.60
FWA / CA (%)	6.7	15.6	8.4	13.8	13.4

Table 3. Calculation of QE and fy for first tank (for the uppermost tank, assessing no rain during March)

Month	Period	No. t	QAi,t	QBi,t	QCi-1,t	QDi,t	QEi,t	QFi,t	dSi,t
October	01 -05	1	QA1,1	QB1,1	*0.00*	QD1,1	QE1,1	QF1,1	d51.1
	06 - 10	2	QA1,2	QB1,2	*0.00*	QD1,2	QE1,2	QF1,2	dS1,2
	11 - 15	3	QA1,3	QB1,3	*0.00*	QD1,3	QE1,3	QF1,3	dS1,3
	16 - 20	4	QA1,4	QB1,4	*0.00*	QD1,4	QE1,4	QF1,4	dS1,4
	21 - 25	5	QA1,5	QB1,5	*0.00*	QD1,5	QE1,5	QF1,5	d51.5
	26 - 31	6	QA1,6	QB1,6	*0.00*	QD1,6	QE1,6	QF1,6	dS1,6
:	:	:	:	:	:	:	:	:	:
March	01 - 05	31	*0.00*	*0.00*	0.00	QD1,31	QE1,31	QF1,31	dS1,31
	06 - 10	32	*0.00*	*0.00*	*0.00*	QD1,32	QE1,32	QF1,32	dS1.32
	11 - 15	33	*0.00*	*0.00*	*0.00*	QD1,33	QE1,33	QF1,33	dS1,33
	16 - 20	34	*0.00*	*0.00*	*0.00*	QD1,34	QE1,34	QF1,34	dS1,34
	21 - 25	35	*0.00*	*0.00*	*0.00*	QD1,35	QE1,35	QF1,35	dS1,35
	26 - 31	36	*0.00*	*0.00*	*0.00*	QD1,36	QE1,36	QF1,36	dS1,36
			fx		fz		fy		

***1. Underlined values: unknown values.**

***2. Double underlined values: unknown values. which are calculated in this table**

Table 4. Calculation of QE for the second tank.

Month	Period	No. t	QAi,t	QBi,t	QCi-I,t	QDi,t	QEi,t	QFi,t	dSi,t	
October	01 - 05	1	QA1,1	QB1,1	QC1,1	QD1,1	QE1,1	QF1,1	dS1.I	
	06 - 10	2	QA1,2	QB1,2	QC1,2	QD1.2	QE1,2	QF1.2	dS1,2	
	11 - 15	3	QA1,3	QB1,3	QC1,3	QD1,3	QE1,3	QF1,3	dS1.3	
	16 - 20	4	QA1,4	QB1,4	QC1,4	QD1,4	QE1,4	QFI.4	dS1.4	
	21 - 25	5	QA1,5	QB1.5	QC1,5	QD1.5	QE1,5	QF1,5	dS1.5	
	26 - 31	6	QA1,6	Q81.6	QC1,6	QD1,6	QE1,6	QF1,6	dS1,6	
:	:		:		:	:	:	:		
March	01 - 05	31	*0.00*	*0.00*	QC1,31	QD1.31	QE1,31	QF1,31	dS1.31	
	06 - 10	32	*0.00*	*0.00*	QC1,32	QD1.32	QE1,32	QF1.32	dS1.32	
	11 - 15	33	*0.00*	*0.00*	QC1,33	QD1.33	QE1,33	QF1.33	dS1,33	
	16 - 20	34	*0.00*	*0.00*	QC1,34	QD1.34	QE1,34	QF1,34	dS1,34	
	21 - 25	35	*0.00*	*0.00*	QC1,35	QD1,35	QE1,35	QF1,35	dS1.35	
	26 - 31	36	*0.00*	*0.00*	QC1,36	QD1.36	QE1,36	QF1.36	dS1,36	
			fx		fz		fy			

*1. Underlined values: unknown values,
*2. Double underlined values: unknown values, which are calculated in this table.

Table 5. Calculation of QC and fZ for the second tank.

Month	Period	No. t	QAi,t	QBi,t	QCi-1,t	QDi,t	QEi,t	QFi,t	dSi,t	
October	01 - 05	1	QA1,1	QB1,1	QC1,1	QD1.I	QE1,1	QF1,1	dS1,1	
	06 - 10	2	QA1,2	QB1,2	QC1,2	QD1,2	QE1,2 QE1,2	QF1,2 QF1,2	dS1.2	
	11 - 15	3	QA1,3	QB1,3	QC1,3	QD1.3	QE1,3 QE1,3	QF1,3 QF1,3	dS1.3	
	16 - 20	4	QA1,4	QB1,4	QC1,4	QD1,4	QE1,4	QF1,4	dS1,4	
	21 - 25	5	QA1,5	QB1,5	QC1,5	QD1,5	QE1,5	QF1,5	dS1.5	
	26 - 31	6	QA1,6	QB1,6	QC1,6	QD1,6	QE1,6 :	QF1,6 :	dS1,6	
		:	:		:		QE1,31	QF1,31	:	
March	01 - 05	31	0.00	0.00	QC1,31	QD1.31	QE1.31	QF1.31	dS1,31	
	06 - 10	32	0.00	0.00	QC1,32	QD1.32	QE1,32	QF1,32	dS1,32	
	11 - 15	33	0.00	0.00	QC1,33	QD1,33	QE1,33	QF1,33	dS1,33	
	16 - 20	34	0.00	0.00	QC1,34	QD1.34	QE1,34	QF1,34	dS1,34	
	21 - 25	35	0.00	0.00	QC1,35	QD1,35	QE1,35	QF1.35	dS1.35	
	26 - 31	36	0.00	0.00	QC1,36	QD1,36	QE1,36	QF1,36	dS1.36	
			fx		fz		fy			

*1 Underlined values unknown values
'2 Double underlined values unknown values, which are calculated in this table

Table 6. ***Calculation of QA and fx for the second tank.***

Month	Period	No. t	QAi,t	QBi,t	QCi-l,t	QDi,t	QEi,t	QFl,t	dSi,t	
October	01 - 05	1	QA1,1	QB1,1	QCI.I	QD1.I	QE1,1	QF1.I	dS1,1	
	06 - 10	2	QA1,2	QB1,2	QC1,2	QD1,2	QE1,2	QF1.2	dS1,2	
	11 - 15	3	QA1,3	QB1,3	QC1.3	QD1,3	QE1,3	QF1,3	dS1,3	
	16 - 20	4	QA1,4	QB1.4	QC1,4	QD1,4	QE1.4	QFI,4	dS1.4	
	21 - 25	5	QA1,5	QB1,5	QC1,5	QD1,5	QE1.5	QF1,5	dS1,5	
	26 - 31	*6*	QA1,6	QB1,6	QC1,6	QD1,6	QE1,6	QF1.6	dS1,6	
March	01 - 05	31	*0.00*	*0.00*	QC1,31	QD1,31	QE1,31	QF1.31	dS1,31	
	06 - 10	32	*0.00*	*0.00*	QC1,32	QD1.32	QE1.32	QF1.32	dS1,32	
	11 - 15	33	*0.00*	*0.00*	QC1,33	QD1.33	QE1,33	QF1,33	dS1,33	
	16 - 20	34	*0.00*	*0.00*	QC1,34	QD1.34	QE1.34	QF1,34	dS1,34	
	21 - *25*	35	*0.00*	*0.00*	QC1,35	QD1.35	QE1.35	QF1.35	dS1,35	
	26 - 31	36	*0.00*	*0.00*	QC1,36	QD1,36	QE1,36	QF1,36	dS1,36	
			fx		fz		fy			

*1. Double underlined values: unknown values, which are calculated in this table.

Table 7. Irrigated areas.

Name of tank	Nominal command area ha	Irrigated area 199111992 maha ha	Irrigated area 1992 yala ha	Irrisated area 1992/1993 maha ha	Irrigated area 1993 yala ha	Number of families irrigating	Average sue of family irrigated area ha
Vendarankulama	182	182	00	182	00	17	107
Meegassagama	325	325	61	325	00	34	0.96
Alisthana	39.1	32.4	2.0	25.2	0.0	35	0.93
Thirappane	34.5	26.2	32.3	29.7	0.0	56	0.47
Badugama	2.4	1.1	0.0	1.7	0.0	2	0.55
Bulankulama	17.1	17.1	0.0	13.0	0.0	41	0.42

Table 8. Catchment areas.

Name of Tank	Catchment area (km^2)
Vendarankularna	1.95
Meegassagama	3.56
Alisthana	3.70
Thirappane	4.40
Badugama	0.26
Bulankulama	0.64

Table *9.* Dimensions *of* tanks.

Name of tank	Height (m)	Effective capacity (1,000 m^3)	Full water spread area (km^2)
Vendarankulama	2.9	220	0.13
Meegassagama	3.0	360	0.30
Alisthana	2.8	580	0.51
Thirappane	3.2	790	0.60
Badugarna	2.2	80	0.07
Bulankulama	2.1	100	0.10

	Vendarankulama	Buiankulama	Meegassagama	Alisthana	Thirappane
1991/1992 maha	over 100%	over 100%	over 100%	over 100%	over 100%
199211993 maha	64%	73%	63%	66%	50%

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
199111992 maha	170119	85938	192083	312375	436441
1992/1993 maha	93393	76072	184867	233945	274904

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
1992 yala	325	353	375	348	***237***
1993 yala	201	283	265	**243**	194

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
199111992 maha	0		20	18	45
199211993 maha	0		28	40	36

*

*Table 14. Seasonal runoff percentage **(fx).***

	Vendarankulama	Bulankulama	Meegassagama	Alislhana	Thirappane
1991/1992 maha	**34**	**31**	25	***28***	**32**
1992 yala	10	12	5	12	13
199211993 maha	9	18	7	13	15
1993 yala	3	5	1	5	8

Table 15. Water balance model (for one year simulation, from 01 October to 30 September).

Date	Ri,t	QAi,t	QBi,t	QCi-1,t	Epi,t	QDi,t	QEi,t	QFi,t	dSi,t	Si,t	QEi-1,t + QFi-1,t	WAi,t-1
	A	B	C	D	E	F	G	H	I	J	K	L
		A * CAi * fxi	A * L	K * fzi		E * L	fyi * L		B+C+D-F-G-H	J+I		
October 01												
October 02												
:	:	:	:	:	:	:	:	:	:	:	:	:
:	:	:	:	:	:	:	:	:	:	:	:	:
September 29												
September 30												

(WA tank water surface area, C A catchment area of the lank, Ep pan-evaporatton (daily) in Meegassagama)

Table 16. Total water balance in the first observation year

Top ***value:*** **I99111992 maha** ***(from*** **16** ***November*** **1991 to 31** ***March*** **1992)**
Bottom value: **1992 yala** ***(from*** **01 April 1992 to 30** ***September*** **1992)**

Tank	Ri	QAi	QBi	QCi-1	QDi	QEI	QFi	QGi	dSi
Vendaran kulama	408 398	273026 79511	43425 19797	0 0	47460 36755	64872 37593	170119 40960	81000 0	-47000 -16000
Bulan kulama	520 428	102160 32326	50849 11187	36464 0	36006 19342	52129 20425	85938 8245	43400 0	-28000 -4500
Meegassaga ma	436 438	380122 80794	104842 54241	198670 0	104116 69125	141301 73400	192083 75011	27613 5 0	-30000 -82500
Alis thana	444 419	466761 178441	141583 70292	335100 0	143098 107718	195567 111966	312375 90299	31490 4 0	-22500 -61250
Thirappane	476 311	674998 174779	177340 99580	543934 0	211582 170948	273611 179998	436441 245112	35293 9 0	121700 - 363400

Table 17. Total wafer balance in the second observation year.

Top *value:* 1992/1993 *maha (from* **01** *October* **1992** *to* **31** *March* **1993)**
Bottom *value.* **1993** *yala (from* **01** *April* **1993** *to* **30** *September* **1993)**

Tank	Ri	QAi	QBi	QCi-1	QDi	QEi	QFI	QGi	dSi
Vendaran kulama	867 161	153223 10189	50289 6334	0 0	48130 14471	52988 15052	93393 0	0 0	9000 -13000
Bulan kulama	952 203	109620 6331	31987 1556	7495 0	32421 2570	37108 2680	76072 6137	0 0	3500 -3500
Meegassagama	972 303	255531 13450	86525 14103	73206 0	88357 26959	97324 26634	185830 16460	0 0	43750 -42500
Alis thana	891 192	425013 36227	16491 5 24440	114511 0	170681 82798	185086 79671	248672 6947	0 0	100000 - 108750
Thirappa ne	764 173	525698 61235	13793 5 30384	155412 0	157899 147423	172942 134144	274904 5052	0 0	213300 195000

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
Number of periods spill *of* water occurred	1	1	3	3	3
Total QG (1000 m3)	8	4.3	27.6	31.5	35.3
QG by self-catchment	8	4.3	15.3	3.9	3.8

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
1991/1992 maha	53	61	73	68	66
1992 yala	65	83	66	71	59
1992/1993 maha	48	46	49	58	53
1993 yala	100	100	100	100	100

Table 20. Through-flow ratio of the tank water.

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
Effective tank capacity	(1000 m^3) 220	100	360	580	790
Annual outflow	(1000 m^3)				
the first year (1)	479	265	931	1276	1871
the first year (2)	398	222	655	961	1518
the first year (3)	211	94	267	403	682
the second year (1)	224	157	442	774	892
the second year (2)	93	82	202	256	280
Through now	(times/year)				
the first year (1)	2.2	2.7	2.6	2.2	2.4
the first year (2)	1.8	2.2	1.8	1.7	1.9
the first year (3)	1.0	0.9	0.7	0.7	0.9
the second year (1)	1.0	1.8	1.2	1.3	1.1
the second year (2)	0.4	0.8	0.6	0.4	0.4

Notes;

The first year: from 16 November 1991 to 31 August 1992
The second year: from 01 October 1992 to 30 September 1993
The first year (1) includes QD, QE, QF and QG.
The first year (2) includes QD, QE and QF.
The first year (3) includes only QF.
The second year (1) includes QD, QE and QF.
The second year (2) includes only QF.

Table 21. QF per hectare.

	Vendarankulama	Bulankulama	Meegassagama	Alisthana	Thirappane
QF per hectare	(mm/ha)				
1991/1992 maha	935	503	591	964	1666
1992/1993 maha	513	445	572	987	926
Nominal command area	(ha) 18.2	17.1	32.5	39.1	34.5
Tank capacity	(1,000 m^3) 220	100	360	580	790

Notes:

1991/1992 maha: 16 November 1991- 31 March 1992 (137 days)
1992/1993 maha: 01 October 1992 -31 March 1993 (182 days)
Bulankulama can receive water through the drainage of Vendarankulamain.

Annex 1

Details of Water Balance Analysis

Tables 16 and **17** show the components of the water balance for five tanks for all sample seasons, and Figures **27-1** to **27-3** show the change over time of QD, QE. Ev and WA for the second year data. Although the peak pan evaporation occurred during the last period of September, the calculated peak in evaporation loss from the tank, QD, did not occur until the last period of January, as the latter term is also influenced by the surface area of the tank, WA, which peaks in the fifth period of December. Peak values of seepage and percolation losses, QE, coincided with the peak in WA. As was mentioned earlier, water discharge from all tanks, QF, was lower during maha **1992/93** than in the previous year, due to a shorter irrigation period, reduced tank discharge and hence smaller command areas.

The duration and intensity of spillage are given in Table **18.** As was expected, QG was largest in the downstream tanks because of accumulation as water flows through the cascade.

Figures **29** and **30** show the fluctuation in the composition of outflow without considering spill (QG), and with QG in Figures **31** and **32.** Of all outflow components, only discharge (QF) was used for irrigation. The percentages of outflow, not directly beneficial to irrigation, are presented in Table **19.** The significant difference between the two maha seasons results from the larger amount of return flow, QC, in the first maha season. It is noteworthy that during the main irrigation season nearly 50 percent of the stored water cannot be utilized for irrigation. The typically shallow depth of these tanks accounts for the relatively high evaporation losses.

Rainfall and estimated runoff as calculated from the water balance model are plotted side by side in Figures **33** and **34.** Errors resulting from measurement deficiencies and the bold assumptions made in the water balance model accumulate in the runoff values (QA). as these are the last to be calculated. This also accounts for the few negative QA values that were calculated by the model. The plots of Figures **33** and **34** clearly show the difference in runoff response to rainfall events in maha and yala. which was discussed before. Seasonal QA values of the downstream tanks were larger than those of the upstream tanks, reflecting the differences in size of the catchments.

Figures **35** and **36** show the change over time in the composition of inflow into the tanks. The pie charts of Figures **37** and **38** depict the composition of inflow during the two maha seasons. It is obvious that return flow, QC, including spill, is important in the operation of the tank cascade. The ratio of annual outflow volume to effective tank capacity (the so-called throughflow ratio) is presented in Table **20.** These throughflow ratios are not high, and there is a striking difference between the data of the two years. In the second year, only about one half of the tank volume was available for irrigation, with the exception of Bulankulama where the ratio was higher (second year **2).** Table **21** shows the amount of water available for irrigation in the command areas (QF/ha), together with the size of the command and the capacity of the tank. The water duty in mm/ha varies widely between command areas, but—as was to be expected—it is closely related to the ratio of tank volume to size of command area. The sequence of the tanks in decreasing order of the ratio of storage capacity to size of the command is Thirappane, Alisthana. Vendarankulama, Meegassagama and Bulankulama. which is nearly the same sequence as the QF/ha values for the two years. From the available data, which admittedly is too little for this type of a conclusion, it appears that the ratio of tank volume in thousands of cubic meters to command area in hectares should be at least 12 to have a viable system for tank-based irrigated agriculture under the conditions of this particular catchment area. Further studies that take into account issues such as field sizes, land consolidation, water distribution arrangements and other management and maintenance aspects would be required to substantiate this conclusion.

ANNEX 2

Possible Improvements in the Model

The water balance model was shown to be effective in illustrating mean system response characteristics, which are important for a better intuitive understanding of the cascade system. However, simplification of flow data into discrete coefficients does not give the model adequate flexibility to indicate system responses to varying conditions. Use of static runoff coefficients is probably the greatest deficiency of the model as it is applied to simulate the effect of system modifications or management interventions. It is shown in the paper that the runoff coefficients vary with the season and from year to year, depending mainly on the soil moisture conditions in the catchment areas.

In an effort to deal with these shortcomings, a predictive model was developed that accounted for changes in the soil moisture conditions in the catchment. The coefficients were modeled as linear variables of soil moisture, where the relative level of the water table in the soil between adjacent tanks is used as a proxy for the moisture conditions. Constant head boundaries between two adjacent tanks provide the lower limit of the water table and complete saturation of the soil profile represents its upper limit. Moreover, linear horizontal flow characteristics were assumed to occur with changes in the water table. Change in storage in the soil profile is then related to change in water table level through the specific yield function of the soil. Rates of inflow and outflow from the soil profile are governed by Darcy's Law. Thus the runoff coefficient varied between zero under conditions of prolonged drought to a maximum value effective afler long periods of relatively intense rain.

The coefficient of seepage and percolation was also allowed to vary linearly between zero when the water table is at its highest level, and a maximum value when the gradient between the tank and the water table between the tanks is at its maximum value. The return flow coefficient was split into two separate variables to account for the fact that part of the return flow percolates to the groundwater and is not subject to evaporation whereas some of the surface flow is lost by evaporation along the way.

Preliminary results show a better correlation between simulated and observed values than was obtained with the original model. However, the suggested improvements are not without their limitations and some inconsistencies remain between observed and simulated data that are hard to explain. It is possible that some of the observed data may be suspect, for example, when "observed" storage seems to exceed the stated maximum volumes of the tanks, as was the case in December 1991.

The relative close match between the model and actual values (obtained with the original model as well as the improved model) may be deceptive when simulation is based on the data of only a couple of years. The rainfall runoff coefficients seem to offer the most room for error in the model. After periods of particularly intense rain, especially when occurring after earlier days of rainfall, the observed runoff volumes increased markedly-more than was captured by the improved model. This suggests that the runoff coefficient is not a simple relation of the aggregate wetness of the soil profile as was assumed in the improved model, but may be sensitive to hydraulic conditions at the soil surface.

In conclusion, it is felt that a more accurate modeling would require greater knowledge of the soil physical conditions and hydraulic gradients in the soil than can be easily obtained or can be warranted by the limited scope of this study.

(Note: This comment was prepared by the editor who gratefully acknowledges the assistance received from Daniel Jenkins of Cornell University.)