Correlation Studies on Ancient Irrigation Tanks in Sri Lanka

O. A. Gunawardena and R. P. de Silva

Abstract: Arumugam (1957) outlined a simple method of determining the spill dimensions of a village irrigation tank. A study was carried out to see if the ancient tank builders have followed this method and the very high correlation coefficients (> 0.91) suggest that these builders may have known the method proposed by Arumugam. Of course the study could be carried out only in the case of 8 tanks where the relevant data are available. The correlations are not that strong when these tanks were restored as now modern methods of designing a spill is available.

Keywords: Irrigation tanks, spill design, ancient Sri Lanka

1. Introduction

Sri Lanka (then Ceylon) is famous for its ancient irrigation systems consisting of many tanks (about 25,000 of them), canals and also for inventions of our own such as the Bisokotuwa (400 -300 BC) or valve pit, which enabled a controlled off take of water from tanks. Figure 1 below shows the distribution of some of these ancient tanks in Sri Lanka.

Out of these 25,000 or so tanks (referred to as *Wewa* and *Kulum* in some instances), many are village tanks, built using a technology known perhaps only to the ancient builders. This paper describes a study where an investigation was carried out to see if the ancient tank builders also have followed the method given by Arumugam (1957) for village tank spill analysis leading to the design of the spill

**Fig. 1 - Location map of some of the ancient tanks in Sri Lanka
(Tanks considered in this study are identified)**

Eng. O A Gunawardena, BSc Eng Hons (Cey), MSc (Lond), DIC., FIE (SL), CEng (SL).
Eng. (Dr.) RP De Silva, BSc: Eng Hons (Moratuwa), MSc (Cranfield), PhD (Cranfield), MIE (SL), CEng (SL) is a Senior Lecturer in Agricultural & Plantation Engineering at The Open University of Sri Lanka.

The method by Arumugam (1957), one of the simplest of methods of a village tank spill analysis, is to assume that the maximum flood inflow is obtained by Dickens' formula at a constant rate for 12 hours and to equate this flood to the tank detention and spillage, whereby the required spill design is obtained. The method is illustrated graphically in Fig. 2.

2. Materials and Methods

The relevant data (such as catchment area of a tank, area of tank at full supply level, length of original bund, width of bund top, full supply level (FSL), bund top level (BTL), length of spill etc) were obtained from various sources (Parker, 1909; Brohier, 1934; Arumugam, 1969 and Dharmasena, 1988).

Fig. 2 - Graphical illustration of Arumugam's Spill Analysis Method (Arumugam, 1957).

Dharmasena (1988) has published an article on "Some Aspect of Ancient Irrigation Works in Sri Lanka" in the Journal "Engineer", September - December 1988. From H Parker's data, he prepared the parameters of 11 tanks. These parameters are given in Table 1 (top row for each tank) along with the present day parameters (bottom row). Only 8 of the tanks have the ancient spill parameters given.

To estimate the inflow flood, Dickens' formula $Q_d = CM^{3/4}$ where Q_d is the flood inflow into the tank in cusecs was used. Here, C is a coefficient taken by us as 800 (for a discussion on the selection of

C, please refer Arumugam, 1957) and M is the catchment area of the tank in square miles. This flood inflow was correlated to $(Q = 3.3LH^{3/2}) + AH$ where Q is the flood discharge over the spill, L is the spill length, H is the head over the spill and A is the water spread area. Here Q is in cusecs, L and H are in feet and A is in acres. The detention term AH is a volume in Acft. but over 12 hours can be considered as cusecs, because 1 cusec for 12 hours is 1 Acft. and the high flood level is attained at 12 hours after the commencement of the flood inflow.

The water spread areas were obtained from Parker's Ancient Ceylon (1909).

Table 1 Comparison of Tank parameters for ancient and restored tanks
(Source: Dharmasena, 1988; Arumugam, 1969)

	Name of tank & approximate construction date	Catch -ment area sq.mls.	Capacity (Ac.ft.)	Original bund length in ft.	Top width in ft.	Full supply level - FSL (ft)	Bund top level - BTL (ft)	Length of spill in ft.	U/S & D/S/ slopes
1	Panda Wewa . 400 B.C	NA NA	2400	8400 NA	8.0 NA	13.0 NA	22.0 NA	250 NA	2.5/2.5 NA
2	Basawakkulama Tank 300 B.C.	3.6 NA	1900	5910 5910	8.0 NA	19.0 19.0	28.0 22.0	22 100	3.0/3.0
3	Tisawewa 300 B.C.	NA 2.0	2900	11000 11000	18 NA	15.3 13.5	25.0 19.5	50 100	2.8/3.0
4	Pavat Kulam 300 B.C.	NA 115	27000	9700 9700	25.0 NA	18.0 19.3	28.0 28.8	250 1060	3.0/2.5
5	Tissa wewa 300 B.C.	NA 15.7	2900	4000 4000	20.00 NA	13.5 15.5	18.5 18.0	100 200	5.0/4.5
6	Vavuni Kulam 200 B.C.	NA 88	35300	13550 13550	12.0 NA	18.0 24.0	26.0 32.0	830 2500	3.0/3.0
7	Yoda wewa	18 NA	7900	3600 3600	15.0 NA	9.0 8.25	14.0 12.7	60.0 163.0	NA
8	Weerawila wewa 100 B.C.	NA 32	10000	11400 11400	20.0 NA	12.5 12.7	17.5 19.3	NA 250	7.5/7.0
9	Batalagoda wewa 100 B.C.	NA 5.0	4400	4000 4000	5.0 NA	17.0 12.7	30.0 19.3	NA 250	3.0/2.5
10	Nuwara wewa	NA 32.5	36000	16000 16000	16.0 NA	17(31) 23	37 33	136 243	3.0/2.5
11	Nachchaduwa wewa	NA 236	45100	5500 5500	20.0 NA	14.0 15.0	36.0 25.0	167 466	2.5/2.5

NA - Not Available, Top row shows parameters for ancient tanks and bottom row shows parameters for restored tanks.

3. Results

The calculation of parameters for $H = BTL - FSL$, $H - BTL - FSL - 2$, $H = BTL - FSL - 4$ are shown in Tables 2(a), 2(b) and 2(c) respectively.

Table 2(a) Spill analysis using Arumugam (1957), $H=BTL-FSL$, Ancient Tanks.

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acre ft)	Detention + Spill (acre ft)
Nachchaduwa wewa	236	48170	167	22	56868	2015	44330	101198
Pavat Kulum	115	28094	250	10	26089	2029	20290	46379
Vavuni Kulum	88	22985	530	8	39575	1975	15800	55375
Nuwara wewa	32.5	10889	136	6	6596	3180	19080	25676
Yoda wewa	18	6991	60	5	2214	1230	6150	8364
Tissa wewa	15.7	6310	100	5	3690	652	3260	6950
Basawakkulama Tank	3.6	2091	22	9	1960	330	2970	4930
Tisa wewa	2	1345	50	9.7	4985	396	3841	8826

Table 2(b) Spill analysis using Arumugam (1957), $H=BTL-FSL-2$, Ancient Tanks.

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acreft)	Detention + Spill (acre ft)
Nachchaduwwewa	236	48170	167	20	49292	2015	40300	89592
Pavat Kulum	115	28094	250	8	18668	2029	16232	34900
Vavuni Kulum	88	22985	530	6	25705	1975	11850	37555
Nuwarn wewa	32.5	10889	136	4	3590	3180	12720	16310
Yoda wewa	18	6991	60	3	1029	1230	3690	4719
Tissa wewa	15.7	6310	100	3	1715	652	1956	3671
Basawakkulama Tank	3.6	2091	22	7	1345	330	2310	3655
Tisa wewa	2	1345	50	7.7	3525	396	3049	6575

Table 2(c) Spill analysis using Arumugam (1957), H=BTL-FSL-4, Ancient Tanks.

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acre ft)	Detention + Spill (acre ft)
Nachchaduwa wewa	236	48170	167	18	42086	2015	36270	78356
Pavat Kulum	115	28094	250	6	12125	2029	12174	24299
Vavuni Kulum	88	22985	530	4	13992	1975	7900	21892
Nuwara wewa	32.5	10889	136	2	1269	3180	6360	7629
Yoda wewa	18	6991	60	1	198	1230	1230	1428
Tissa wewa	15.7	6310	100	1	330	652	652	982
Basawakkulama Tank	3.6	2091	22	5	812	330	1650	2462
Tisa wewa	2	1345	50	5.7	2245	396	2257	4503

Table 2(d) Summary of results for ancient tanks

	Flood inflow $Q=CM^{3/4}$ (Ac ft)	Detention + spill (Acre ft)		
		BTL-FSL	BTL-FSL-2	BTL-FSL-4
Nachchaduwa wewa	48170	101198	89592	78356
Pavat Kulum	28094	46379	34900	24299
Vavuni Kulum	22985	55375	37555	21892
Nuwara wewa	10889	25676	16310	7629
Yoda wewa	6991	8364	4719	1428
Tissa wewa	6310	6950	3671	982
Basawakkulama Tank	2091	4930	3655	2462
Tisa wewa	1345	8826	6575	4503

The calculation of parameters for restored tanks for H = BTL - FSL, H = BTL - FSL -2, H = BTL - FSL - 4 are shown in Tables 3(a), 3(b) and 3(c) respectively.

Table 3(a) Spill analysis using Arumugam (1957), H=BTL-FSL, Ancient Tanks after restoration

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acre ft)	Detention + Spill (acre ft)
Nachchaduwa wewa	236	48170	466	10	48630	4400	44000	92630
Pavat Kulum	115	28094	1060	9.5	102425	3000	28500	130925
Vavuni Kulum	88	22985	2500	8	186676	3150	25200	211876
Nuwara wewa	32.5	10889	243	10	25358	3000	30000	55358
Yoda wewa	18	6991	163	4.45	5049	1200	5340	10389
Tissa wewa	15.7	6310	200	2.5	2609	575	1438	4046
Basawakkulama Tank	3.6	2091	100	5.5	4257	265	1458	5714
Tisa wewa	2	1345	100	6	4850	450	2700	7550

Table 3(b) Spill analysis using Arumugam (1957), H=BTL-FSL-2, Ancient Tanks after restoration

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acre ft)	Detention + Spill (acre ft)
Nachchaduwwewa	236	48170	466	8	34796	4400	35200	69996
Pavat Kulum	115	28094	1060	7.5	71848	3000	22500	94348
Vavuni Kulum	88	22985	2500	6	121250	3150	18900	140150
Nuwara wewa	32.5	10889	243	8	18145	3000	24000	42145
Yoda wewa	18	6991	163	2.45	2063	1200	2940	5003
Tissa wewa	15.7	6310	200	0.5	233	575	288	521
Basawakkulama Tank	3.6	2091	100	3.5	2161	265	928	3088
Tisa wewa	2	1345	100	4	2640	450	1800	4440

Table 3(c) Spill analysis using Arumugam (1957), H=BTL-FSL-4, Ancient Tanks after restoration

	Catchment Area - M - sq miles	Flood inflow $Q=CM^{3/4}$	Spill Length - L - (ft)	H (ft)	Spill = $3.3LH^{3/2}$ (acre ft)	Area - A - (acres)	Detent- ion - AH - (acre ft)	Detention + Spill (acre ft)
Nachchaduwa wewa	236	48170	466	6	22601	4400	26400	49001
Pavat Kulum	115	28094	1060	5.5	45119	3000	16500	61619
Vavuni Kulum	88	22985	2500	4	66000	3150	12600	78600
Nuwara wewa	32.5	10889	243	6	11785	3000	18000	29785
Yoda wewa	18	6991	163	0.45	162	1200	540	702
Tissa wewa	15.7	6310	200	0	0	575	0	0
Basawakkulama Tank	3.6	2091	100	1.5	606	265	398	1004
Tisa wewa	2	1345	100	2	933	450	900	1833

The plots of flood inflow vs (detention + Spill) for all 6 cases in Tables 2(a), 2(b), 2(c), 3(a), 3(b) and 3(c) are as shown in Fig. 3.

Fig. 3 - Plots of flood inflow vs (detention + spill) for ancient tanks (a, b and c) and for ancient tanks after restoration (d, e and f)

4. Concluding Discussion

As seen from the graphs and also from Table 4 below (which gives a summary of correlation coefficients for all 6 cases the correlation between the flood inflow and (detention + Spill) is very good (>0.90) for ancient tanks. Even for restored tanks the coefficients are greater than 0.4.

Table 4 - Correlation co-efficient (when C = 800)

Tank	Head over spill (ft)	Correlation co-efficient (R ²)
Ancient tanks	H=BTL-FSL	0.96
	H= BTL-FSL - 2ft	0.95
	H=BTL-FSL - 4ft	0.91
Ancient Links after restoration	H=BTL-FSL	0.41
	H= BTL-FSL - 2ft	0.47
	H=BTL-FSL - 4ft	0.56

The correlation coefficient is considered strong if for a sample size of 5 the minimum $R^2=0.77$ and for a sample size of 10 the minimum R^2 is 0.40 (Pardoe, 1962). From the above figures, we see that both ancient tanks and present tanks show correlation. The stronger correlation is with the ancient tanks. The difference between the two cases is that in the case of the present tanks, the design was done by present day engineers using advanced hydrological studies using unit graphs and flood routing through spills.

A summary of the results of flood inflow (for C = 800) and the (detention + spill) is given in Table 2(d). This Table shows that 5 of the ancient tanks lie within the range BTL-FSL and BTL - FSL - 4ft. The 3 tanks Nachchaduwa, Basawakkulama and Tisawewahave highBTL - FSL. Freeboards higher than 4ft may have been used in their design. This is probably why they lie outside the range BTL - FSL and BTL - FSL - 4ft.

In view of the very strong correlation for ancient tanks and with 5 out of 8 tanks falling within the range of $H = BTL - FSL$ and $H = BTL - FSL - 4ft$, can we say that the ancient builders very likely used the simple Arumugam method for designing their tanks? The spill discharge and detention formula must have been known to them as they are simple in concept. However, the ancient builders would not have had information about the catchment areas. They would have estimated the flood inflow by gauging of the river during flood.

Mr DGL Ranatunga states that "the Egyptians took levels on the Nile as far back as 3000 BC. They subsequently developed techniques for flood warning, hydraulics etc. Hence it may not be farfetched to imagine this to be a clue to the origin of irrigation in Sri Lanka.

In the gauging of flood inflow, during floods, the high flood level has to be estimated by observation of twigs and other telltale marks left by the floods. The area of flow has to be measured. The velocity of flow has to be obtained by the distance covered by floods over a period of time or a velocity of 12 ft/s may have been used. Area velocity will give the flood inflow very approximately.

As regards Dickens C=800 used, we give a Table (Table 5) - for Mahakanadarawa floods. Mahakanadarawa tank is near Mihintale in the dry zone. It has a catchment are of 133 sq miles.

Table 5 - Dickens C for Mahakanadarawa Tank

Flood magnitude	Flood inflow	Dickens C
100 year	60,000	1500
50 year	45,000	1200
25 year	31,000	800

Thus C =800 corresponds approximately to a flood of 25 years only.

So the ancient builders around 300 BC may have used the Arumugam method for the earliest irrigation tanks. The other possibility is that during the restoration of the many tanks by Parakrama Bahu the great 1153-1186 AD this method may have been used. The spill lengths and bund heights were adjusted to suit. The flood inflows would have been obtained by studying the spill discharge heights during the operation of the tanks over 1400 years, except when breached.

This analysis was carried out for the 8 tanks shown in Fig. 1 as the required data could be obtained only for these 8 tanks. However, it will be interesting to see if the hypothesis holds true for other ancient tanks as well.

References

1. Arumugam S (1957), "Development of Village Irrigation Works" Transactions IESL 1957.
2. Arumugam, S (1969). "Water Resources of Ceylon". Water Resources Board, Sri Lanka.
3. Dharmasena GT (1988). "Some Aspects of Ancient Irrigation Works in Sri Lanka", *Engineer*, Sep/Dec 1998.
4. Pardoe Kevin (1962). "Quantitative Methods", Butterworth-Heinemann, New-York.
5. Parker H (1909) Ancient Ceylon, Reprint Asian Educational Services, New Delhi., 1992.
6. Ranatunga DGL (1973). "Contributions of the ancient civilizations of Sri Lanka to the Historical Development of Hydrology", *Engineer*, December 1973.