Sri Lanka J. Aquat. Sci. **5** (2000):75-86

Hydraulic changes of three reservoirs (Minneriya, Udawalawe and Victoria) in Sri Lanka

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Abstract

Hydrological characteristics of three Sri Lankan FISHSTRAT reservoirs namely Minneriya, Udawalawe and Victoria were examined. Victoria reservoir, which is located about 438 m amsl, has the steepest gradient and the largest volume. The gradient of Minneriya and Udawalawe reservoirs which are located in the lowland is more or less similar but the capacity of Minneriya is 50 % that of Udawalawe. The seasonal water level fluctuation in the three reservoirs is influenced by seasonal rainfall and release pattern but shows moderate changes during different years. When compared to the annual draw-down from 1994 to 1999 it was lowest in Minneriya (4.22 m) in 1996 and highest (7.05 m) in 1994 with a six year average of 5.91 m and the draw-down in 1999 was 6.62 m. The Udawalawe reservoir had the lowest annual draw-down of 7.71 m in 1995 compared to its highest (11.9 m) in 1994. The six years average in Udawalawe was 8.20 m and the water level dropped by 7.05 m in 1999. In Victoria, which had an average annual draw-down of 35.3 m for a period of six years had the lowest draw-down (13.3 m) in 1995 and the highest was 47.4 m in 1996 and the draw-down in 1999 was 28.8 m. The littoral exposure resulting from draw-down was highest in Minneriya (82 %) and it was 60.3 % and 52.6 % in Victoria and Udawalawe respectively in 1999. The flushing rate in 1999 was 5.5 times per year in Udawalwe and it was 4.9 and 3.8 time per year in Minneriya and Victoria reservoirs respectively. The magnitude and seasonal pattern of dam site rainfall was different among the three reservoirs in 1999 and it has no relationship to seasonal fluctuation of water level

Introduction

Arresting rivers and streams by dams and weirs for creation of reservoirs are among the most unprecedented land based human activity common on a global scale. The off-cited rationales for building dams for creating reservoirs, impoundment, barrages etc., throughout the world are mainly for human benefits (e.g. irrigation, hydropower generation, flood control, storage, drinking water supply, recreation and transport). The utilization of these artificial inland water bodies for capture and culture-based fisheries especially in developing countries is one of the gratifying aspects of reservoir building. Sri Lanka produced about twenty percent of her national fish production exclusively from man-made inland water bodies until the recent past.

Nevertheless, manifold impacts resulting from reservoir building have changed ecosystem continuum at various levels especially in the tropics (Baxter 1977, Petr 1977, Davies 1980, Obeng 1981, Rudd *et al.* 1993, Milliman 1997).

It was assumed that the ecological processes and dynamics of reservoir ecosystems are less similar to those of natural lakes but the differences are still less obvious. In general, these intermittent lotic-lentic ecosystems are more riverine when they are built by arresting mountain rivers. A lacustrine nature is predominant when reservoirs are built inundating shallow basins in the lowland channeling diverted water. Duncan *et al.* (1993) identified two types of limnologically distinct man-made water bodies in Sri Lanka based on their morphology and release patterns. Apparently, hydraulic balance, a salient feature, distinguishes man-made water bodies and natural lakes. The hydraulic balance, which is partly controlled by man, may significantly vary among morphologically and operationally different man-made water bodies. The water budget and residence time essentially describes the hydrology of lakes and reservoirs. The relative importance of the components of the water budget (i.e., inflow, outflow and draw-down) mostly determines the nature of the processes involved in material fluxes and ecological regulation of the water body. In lakes and reservoirs the magnitude and impact of resulting environmental variations are directly linked with the residence time of water storage and its inverse, the flushing rate. Silva and Gamlath (2000) describe the catchment characteristics and water quality of three reservoirs studied under the European Union funded FISHSTRAT program. The hydraulic changes of the three reservoirs are compared in this paper as a prerequisite for further limnological analysis.

Materials and Methods

INCO-DC-FISHSTRAT project examined the limnology, fish ecology and biology, and the capture fishery together with socio-economic aspects of the riparian community of Victoria, Minneriya and Udawalawe reservoirs in Sri Lanka over a two-year period (1998 - 2000). Hydrographic characteristics such as water level, inflow and volume release recorded on a daily basis from 1994 to 1999 were obtained from the Irrigation Department for Minneriya reservoir and from the Mahaweli Authority of Sri Lanka for Udawalawe and Victoria reservoirs. In addition, bathymetric dimensions such as elevation above mean sea level and corresponding area and volume were also obtained from respective government agencies and prepared hypsographic curves (depth : area and depth : volume). Hydrographic data were used to compute monthly average water level fluctuation for six years (1994 – 1999) and it was compared with the water level fluctuation in 1999. Monthly water level fluctuation in 1999 was also compared with monthly release and seasonal rainfall recorded at the dam site. In addition, draw-down, flushing rate and littoral exposure were also computed for each reservoir.

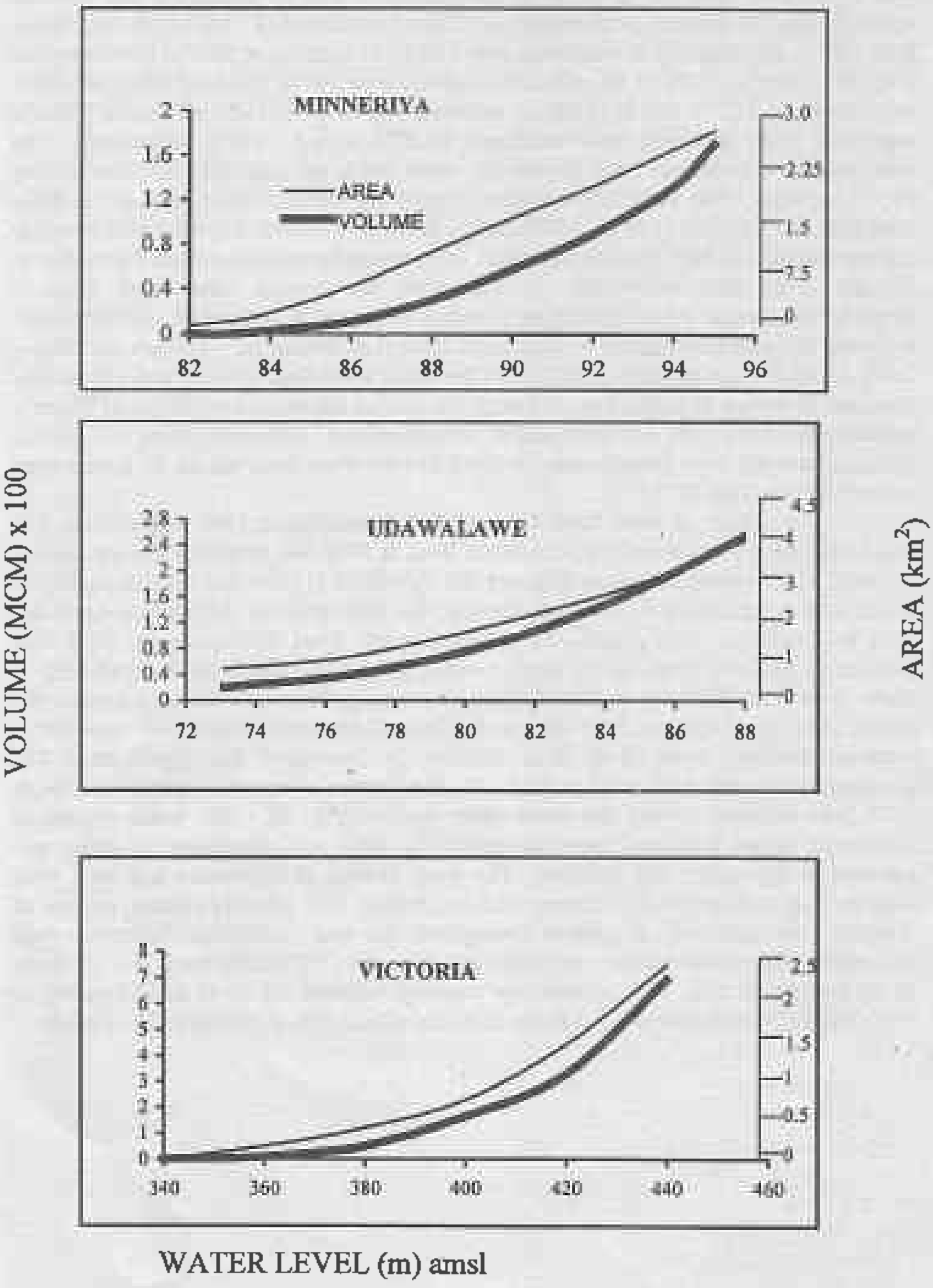

Figure 1. Hypsographic curves of three reservoirs.

Results

Figure 1 depicts the hypsographic curves of the three reservoirs. Although the area of Victoria reservoir is more or less similar to that of Minneriya, the Victoria reservoir has the steepest gradient and the largest capacity (783 MCM) at full supply level (FSL). The capacity of Minneriya was 17.2 % of Victoria or 50% of Udawalawe at FSL. In Minneriya, 50% of the effective reservoir area will be dried off when the water level drops by 7.25 m and 50% littoral exposure will occur in Udawalawe and Victoria reservoirs when the water level decreased by 8.25 m and 72.0 m respectively. The changes in water volume with decreasing water levels are markedly different among three reservoirs. The seasonal fluctuation of monthly average water level of the three reservoirs for six years (1994 – 1999) and in 1999 are shown in Figure 2 with monthly release volume in 1999. The average water level is apparently higher from November to January in all three reservoirs. In Minneriya, the average water level shows a progressive decrease from February and reaches its lowest in September. In Udawalwe, there are two prominent peaks of high water level (i.e. November – January and May – June) in the six year monthly average and the water level decreases gradually from July reaching its lowest in September. Although the second inter-monsoon filling of Victoria reservoir is more or less similar to that of Minneriya and Udawalawe, there is a marked decrease in water level from January to April and the water level retains its lowest from June to August (Fig. 2).

The pattern of water level fluctuation in Minneriya in 1999 was more or less similar to its six years average but the water level in 1999 was relatively low throughout the year. The situation was quite different in Udawalawe in 1999 and a relatively higher water level compared to its six years average was retained from February to April and July to October. In Victoria, the seasonal water level fluctuation in 1999 was completely different from its six years average (Fig. 2). There was a rapid drop of water level from February to May followed by a progressive increase and a relatively higher water level retained form May to August and the lowest water level occurred in October. Further, water level from October to December was significantly low compared to its six years average (Fig. 2). The pattern of monthly release volume in 1999 was different among the three water bodies (Fig. 2). The water release in Minneriya shows a marked seasonal pattern in 1999 and absolutely no water was released in September and October. The water release in Udawalwe was high from May to July and lowest in February and September. The monthly release volume of Victoria was relatively consistent throughout the year except in November and December. The annual release was lowest in Minneriya (298 MCM) but it was 2.2 times of its capacity at FSL. The Udawalawe reservoir released 3.3 times of its capacity at FSL (268 MCM) while it was 2.3 times of its capacity at FSL in Victoria (783 MCM).

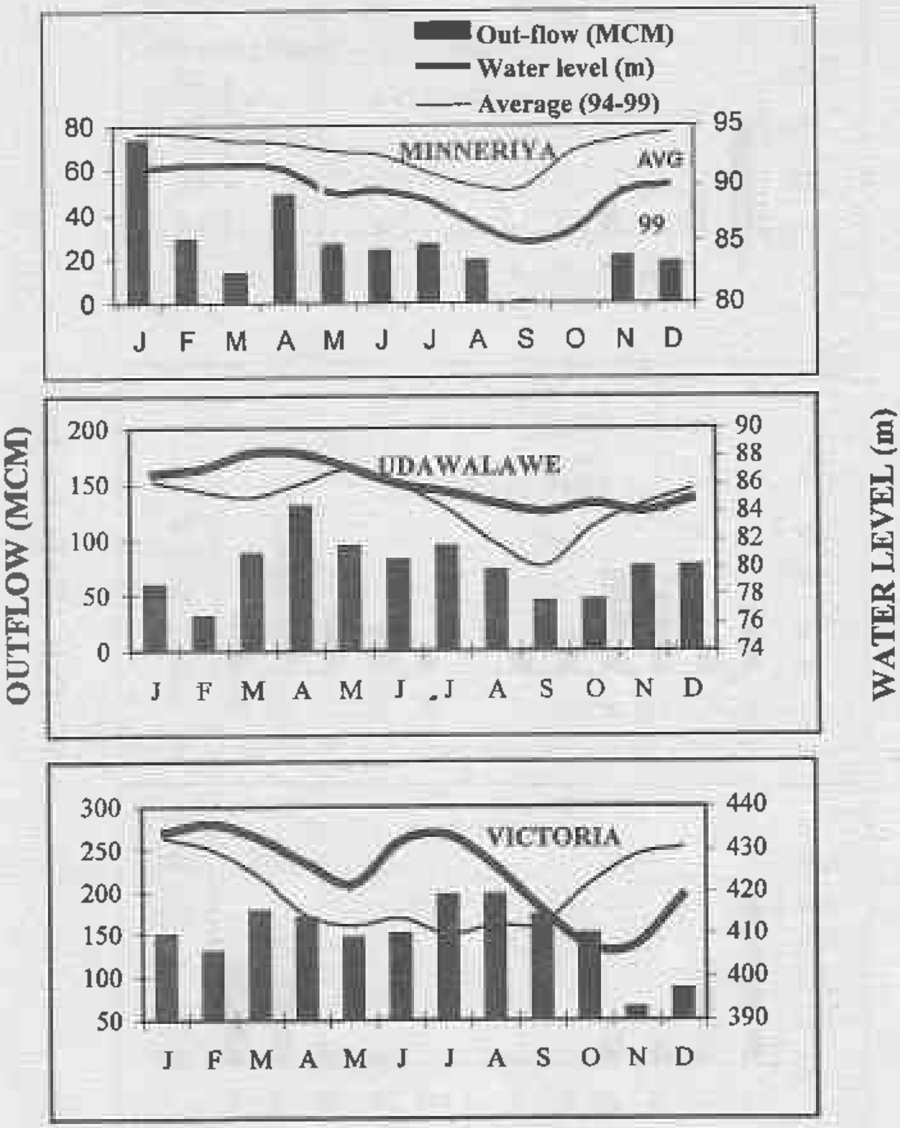

Figure 2. Seasonal fluctuation of water level (six years average and in 1999) and monthly release volume in 1999 of three reservoirs.

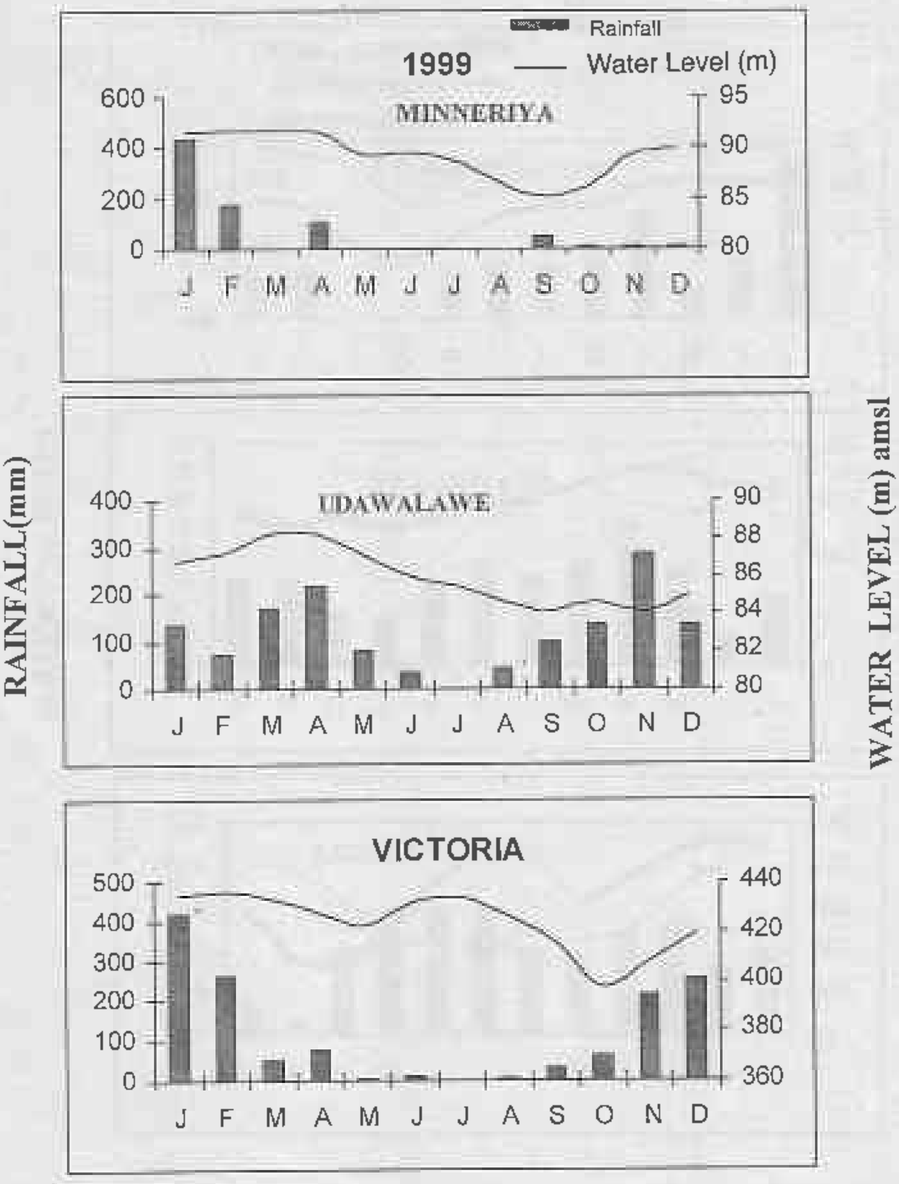

Figure 3. Monthly water level and rainfall recorded at the dam site of each reservoir in 1999

Monthly water level fluctuation and rainfall recorded at the dam site of each reservoir in 1999 are shown in Figure 3. The annual rainfall at Udawalawe (1445 mm) and Victoria (1385 mm) dam sites were relatively high compared to that of Minneriya (782 mm) in 1999. It was more or less dry in 1999 in Minneriya and rain occurred only in January and February. In Victoria also no rain was recorded from May to August in

1999. Irrespective of the rainfall the water level was high in Victoria from May to August indicating that there is no relationship between dam site rainfall and reservoir water level. A similar observation was made in Minneriya where the reservoir started filling up when the dam site rainfall was lowest in 1999. Figure 4 depicts variation of annual draw-down over six year period (1994 - 1999) in the three reservoirs. The Victoria reservoir shows the highest annual draw-down (47. 4 m) in 1996 which is more or less half of the maximum depth at FSL and the lowest was 13.3 m in 1995. The water level of the Victoria reservoir dropped by 28.8 m in 1999 compared to its six years average of 35.3 m. The annual draw-down in Minneriya was lowest (4.22 m) in 1996 and the highest was 7.05 m in 1994 and it has an average of 5.90 m for six years. In Udawalawe, which had an average annual draw-down of 8.20 m for a period of six years had the lowest (5.71 m) in 1995 and the highest was 11.9 m 1994. This indicates that 1995 was a relatively wet year compared to the other years. Figure 4 also shows a gradual decrease in annual draw-down in Victoria reservoir from 1996 towards 1999 but such a trend is not apparent in the other two water bodies.

Figure 5 shows the littoral exposure or land-water ecotone of the three reservoirs resulting from the annual draw-down in 1999 as a percentage of reservoir area at FSL and corresponding flushing rates. The maximum littoral exposure in Minneriya reservoir was 82 % of the reservoir area with its corresponding draw-down of 6.62 m. In Udawalawe and Victoria reservoirs in 1999 the littoral area exposed by 52.6 % and 60.3 % with corresponding draw-down of 7.05 m and 28.8 m respectively (Fig. 5). The flushing rate computed for Minneriya was 4.19 times per year compared to 5.5 and 3.8 times per year in Udawalawe and Victoria respectively (Fig. 5).

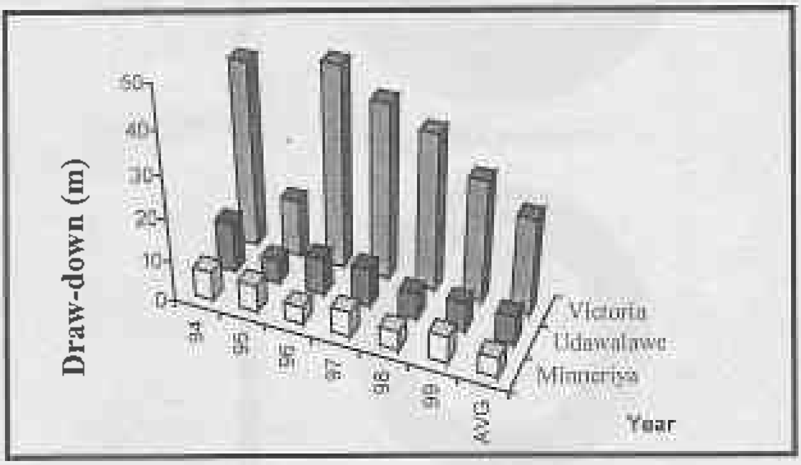

Figure 4. Annual draw down from 1994 to 1999 and the six years average of three reservoirs

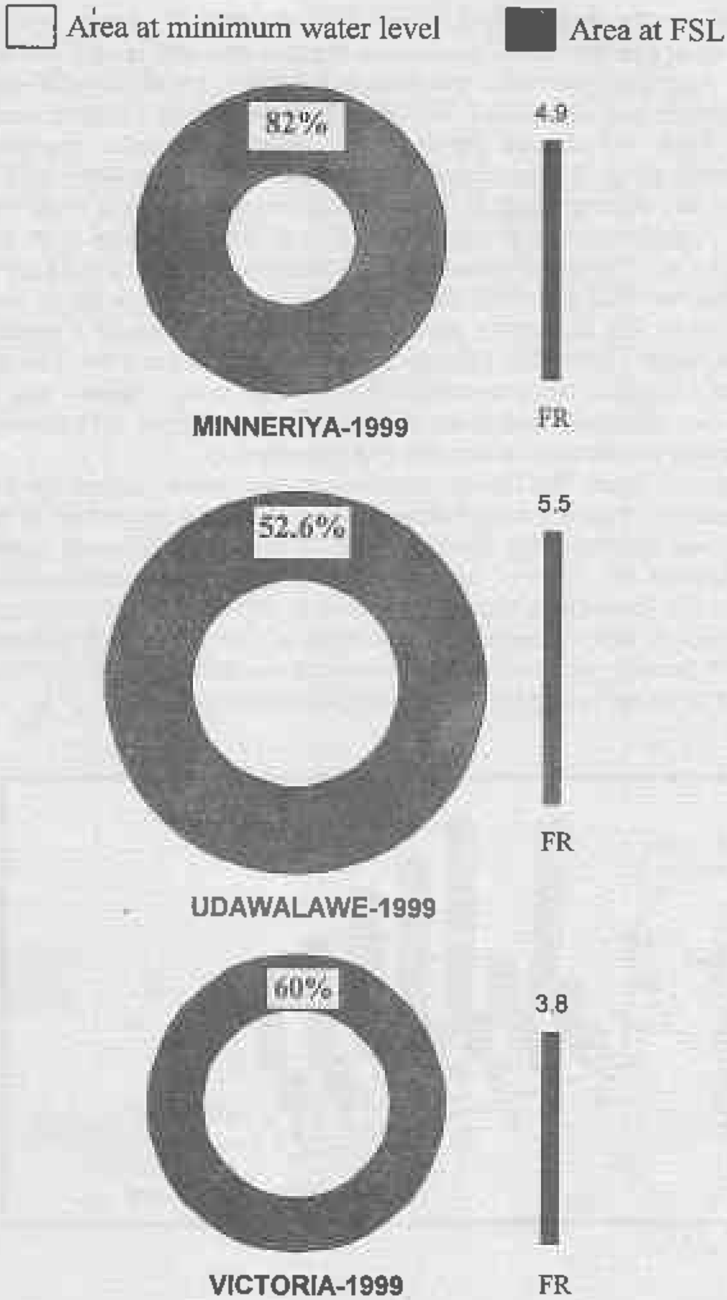

Figure 5. Littoral exposure as a percentage of reservoir area at FSL and flushing rate (FR) of three reservoirs in 1999

Discussion

The steepest gradient and the corresponding largest capacity of Victoria reservoir can be attributed to basin morphology and landscape. Being located in the lowlands, both Minneriya and Udawalawe reservoirs have tapering gradients and relatively low basin capacities. However the mean depth of Udawalawe reservoir (7.9 m) is relatively higher than Minneriya (5.8 m). The hydrological regimes of dry zone irrigation reservoirs in Sri Lanka are characterized by high water levels from December to April due to the second inter-monsoonal rain (October - December) and low water level from June to September resulting from water release for irrigation of rice fields. As a consequence of the seasonality inflow, outflow and water storage the water renewal rates exhibits strong seasonal differences with highest relative rates in July and lower ones from December to May (Schiemer & Duncan 1983). Further, multiple use of tropical reservoirs for irrigation, generation of hydropower, storage, and supply of potable water and natural processes such as evapotranspiration and seepage result in marked draw-down in reservoir water level. The hydraulic balance, which is partly controlled by man, is significantly different among morphologically and operationally distinct man-made water bodies. The water budget and residence time are key factors, which describe the hydrology of lakes and reservoirs. The relative importance of the components of the water budget mostly determine the nature of the processes involved in chemical dynamics and ecosystem balance of the water body. In lakes and reservoirs the magnitude and impact of resulting environmental variation are directly linked with the residence time of water storage and flow fluxes (the inverse of the flushing rate or alternative on the quotient of water storage/total input flux (its inverse of the water renewal rate).

A relatively a large volume of water passes through the Victoria reservoir since it has the largest basin capacity and drains a vast catchment area, which is exclusively confined to the wet zone. A major portion of the Udawalawe catchment is also confined to the central highland and experiences both southwest and the second inter-monsoon rains. This rainfall pattern has resulted in the occurrence of two prominent peaks in the seasonal variation of water level in the Udawalawe reservoir. The Minneriya reservoir is characteristic with a low flow-through since it has no drainage area in the wet zone. However, Minneriya receives partially diverted water from the trunk stream of the Mahaweli River via Polgolla barrage but, inter-monsoon rains (October - December) is more prominent than the inflow of the diverted water with respect to filling of the reservoir. The distinct seasonal pattern of water level fluctuation and outflow among the three reservoirs may be attributed to operational practices. The Victoria reservoir releases water throughout the year for the generation of electricity while the Udawalawe reservoir also releases water throughout the year for irrigation of two paddy crops (*Yala*, May- September and *Maha*, October - April), other cash crops and for generation of electricity. In the case of Minneriya reservoir, water is released mainly for two crops of paddy.

The variation in littoral exposure resulting from draw-down is primarily determined by basin morphology. Studies on biological consequences of fluctuations in water level indicate the importance of draw-down area for reservoir productivity (McLachalan 1971, 1981). It has been reported that fluctuation in water level in tropical reservoirs has a significant impact on its nutrient status through fluxes and mobilization from submerged vegetation during littoral inundation (McLachalan 1971). Further, long term water level fluctuation in reservoirs have effects on fish population structure

(Beam 1983, De Silva 1985) and the estimates of fish yields and management (Amarasinghe *et. al.* 2000). Duncan and Kubeka (1995) who termed the draw-down area of reservoirs as land-water ecotone have indicated that there is a positive effect of the draw-down area of a reservoir on fish populations. Schiemer *et al.* (2000) discussed the significant changes in trophic characteristics in Asian reservoirs in relation to hydraulic balance. The extent of draw-down area and mean reservoir area both of which are dependent on the bathymetry of the reservoir have positive and negative effects on fish yield (Nissanka *et. al.* 2000). Further, the extent of littoral exposure has significant effects on under water optics, plankton distribution and nutrient status or in other words trophic characteristics in the following high water level (Silva *et al.* in prep.). Apparently, shallow and moderate size irrigation reservoirs with high draw-down some times become hypereutrophic leading to a heterotrophic condition and the extreme scenario is that a water body becomes slush with high turbidity and low phytoplankton biomass.

Annual changes in draw-down and flushing rate (inverse of residence time) are apparent in the three FISHSTRAT reservoirs. These changes are primarily influenced by natural factors such as distribution and magnitude of annual rainfall in respective watersheds and demand in the command area of irrigation reservoirs and power supply in the case of hydropower reservoirs. Relatively low flushing rates in the Victoria reservoir may be attributed to its deep basin and large capacity. However, relatively high flushing rate in Udawalawe compared to Minneriya may be attributed to its large volume of inflow water and resulting release for both hydropower generation and irrigation. The effects of hydrological flushing and dilution on the limnetic biomass have been observed during periods of low water level and times of strong changes in water throughout rates in P' Samudra (Schiemer & Duncan 1983). Further, it has been reported that periods of decline in plankton densities were associated with high water inflow from resulting in dilution effects and high biomass losses due to outflow while the density of plankton increases with decreasing flushing rates (Duncan & Gulati 1983). Therefore, the human factor, which is the fourth dimension of limnology plays an important role in sustainable management of reservoir ecosystems in the tropics (Silva & Schiemer 2000). Furthermore, incorporation of draw-down has been neglected during derivation of a majority of yield predictive models for these biologically productive water bodies (Oglesby 1977, De Silva 1988, Sugunan 1993, Welcome & Bartly 1998). This has lead to a question of validity of such models in predicting yields and their use as management tools. Apparent variations in hydraulic balance of the three FISHSTRAT reservoirs may play an important role with respect to biological production and material fluxes.

Acknowledgements

This publication is a product of the European Union funded INCO-DC FISHSTRAT program (Grant No. IC18-CT97-0190). We are thankful to Prof. U.S. Amarasinghe, Sri Lankan coordinator of FISHSTRAT and his field brigade for various assistance. Iranganie Thumpela typed the manuscript and Viraj Rajaguru prepared computer graphics. Shirani Nathaneal read the manuscript in draft. We never forget the dedication and hard work of Dr. Annie Duncan who was instrumental in launching the FISHSTRAT project in the three Asian countries.

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