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Over 35 years of age - Second Place

Ecosensitive Watershed Management as a Solution to the Power Crisis

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Abstract: Sri Lanka is rich in water resources. Therefore the economic well being of the country is closely associated with the water resources development. Most of the technically feasible and economically viable hydropower sources have already been tapped. On the other hand, hydroelectric power development needs comparatively high capital cost and long construction periods. However, electricity demand is rapidly increasing while alternative power sources such as liquid fuel and coal power sources are not acceptable due to high operational cost and negative environmental effects.

1. Introduction

"A single drop of water that falls from the sky should not be allowed to flow into the sea without serving man." - King Parakramabahu the Great

The concept of water management has been completely described in the above statement. However, water resources cannot be fully utilized for human needs mainly due to the associated environmental problems. Therefore the management of the existing water resources projects is becoming more important.

Even though three fourth of the Earth's surface is covered by water only as little as 2.5% of this is pure and fresh. Much of the water resources [70%] are in the form of icebergs in the arctic and other regions of extreme cold. As such, less than one percent of the total volume is suitable for human consumption.

A thousand cubic metres of water per year is the minimum need of each human being. The United Nations Development Programme [UNDP] says anything less than 1000 Cubic metres indicate an acute shortage of water.

Sri Lanka has a land area of 65,000 sq km. This is only one twothousands of the Earth's ground surface. The world's annual average rainfall is about 800 mm while Sri Lanka receives 2000 mm average rainfall. A minimum of 600mm rainfall is available in the dry zone while the central hill area of the country receives more than 3000 mm per annum. Let us assume only 400 mm of rain can be retained for human needs. Each Sri Lankan

citizen would be entitled to 1300 cubic metres of water, which is well above the minimum requirement.

A huge volume of water is used for irrigation, which requires only a marginal head for conveyance. More than eighty percent of irrigation water cannot be reused. Therefore, per capita irrigation demand is nearly 700 cubic metres per annum. An average man needs 80 cubic metres of potable water for domestic purposes leaving another 280 cubic metres of water for other unclassified applications. Even after harnessing the available energy in the water it can be used for some other purpose such as irrigation. Therefore water used for hydropower generation is non-consumptive. On the other hand Irrigation, Domestic water supply and hydropower development can be integrated with each other. The socio economic development of the country can be mainly attributed to the multipurpose water development that has taken place in the country.

The earth is surface receives massive energy in the form of solar radiation. Fifteen percent of the solar energy is consumed by the Hydraulic cycle. Finally, less than five percent of the energy in the hydraulic cycle can be extracted in the form of hydroelectric power. The total hydropower development potential of the country is more than 2500 MW while only 1270 is exploited so far with an annual energy output of 4756 GWh. The

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remaining Hydropower sources cannot be exploited mainly due to environmental reasons, bureaucratic and political reasons and not being economically viable.

The present hydropower system is capable of generating 1 kWh per person per day. This can be further increased by 20% , if proper watershed management is adopted.

1.1 Hydropower Development in Sri Lanka

The geographical formation of the country has favorable effects on hydropower development. The central hill area of the country receives a comparatively high rainfall. Approximately 5000 sq km area is above the 300 m contour and these areas enclose another 2000 sq km above 500 M.S.L. The most productive Kelani and upper Mahaweli catchments consist of 500 sq km over the 1000-metre M.S.L. The total annual Evapo-transpiration in this area is less than 750 mm. More than 75% of the rain water can be harvested in this area. [This can be verified from available records]

Late Eng. D.J. Wimalasurendra, the father of Hydropower development in Sri Lanka, dreamt about the Kehelgamu and Maskeli oya system sixty years ago. His dream became a reality in 1960 after completion of the Wimalasurendra and old Lakshapana with an installed capacity of 100 MW and annual energy output of 370 GWh. Since then, the installed capacity of the national hydropower systems increased up to the present level with an annual energy output of 4700 GWh worth 47 billion Rupees.

The massive Mahaweli project contributes nearly fifty percent of the national demand while the Kelani system contributes nearly thirty percent of the demand. Samanalawewa and Kukule Ganga are the other major projects, which contribute significant amounts of energy to the National grid.

Upper Kothmale, Moragahakanda, Uma oya, Broadlands, Belihul oya, Madulu oya and Gin Ganga are the remaining major hydropower projects. A large number of medium and minor hydropower schemes are now being constructed by the private sector. The details of the hydropower projects are given in the annexure.

1.2 Reasons for the present power crisis

During the initial stage of hydropower development, electricity was considered as a luxury or industrial oriented and only 10% of the population enjoyed the benefits of hydroelectric power' On the other hand individual consumption was as low as 0.5 kWh per day.

After completion of the accelerated Mahaweli project, nearly twenty years ago, electricity supply was more than the demand and consumers were requested to go on electricity. However, 200 MW thermal plants were installed in Kelanitissa and Sapugaskanda for peak load operations. During the last two decades, electricity demand has increased at the rate of twelve percent per annum.

Today, peak demand is about 1400 MW while maximum hydropower is limited to 1200 MW. Under normal circumstances only 1000 MW is available in the form of hydropower while another 400 MW has to be generated by the thermal plants. During severe droughts hydropower capacity reduces up to 500 MW causing power cuts. Now, all peak load thermal power plants are being operated even for the base load. The lifetime of the thermal plants will be drastically reduced due to continuous operation.

2. Aim

The aim of the study is to find out a cost effective and environment friendly solution to the energy problem so that we will be able to overcome the present power crisis.

3. Methodology

Hydrologic Behavior of the Mahaweli watershed up to Rantambe reservoir [Some 3000 sq km] is modeled under the virgin forest condition, prevailing condition and after restoration. By comparing outcome of above three conditions necessary recommendations will be drawn.

Under the second part of the analysis, the effects of the proposed upper Kothmale reservoir on entire Mahaweli project will be considered. Mahaweli system will be compared with the most effective Kehelgamu oya and Maskeli oya combined system and the conclusion will be made by considering theoretical, practical, and socio-economical aspects.

4. Mathematical model to represent the Hydrological behavior of upper Mahaweli catchment.

It is very difficult to model the natural things while man-made things can be modeled very easily. Therefore modeling of a watershed may not give hundred percent accurate results. Results from the mathematical model will be calibrated by means of available data.

Hydrological behavior of a catchment is a function of so many variables. The slope of the terrain, soil type, nature of the forest cover and the rainfall intensities are the governing factors. It can be shown that any catchment produces it's maximum efficiency under the virgin forest condition. However, considerable deforestation has taken place, especially during the last two centuries, thus reducing the watershed performance drastically.

River flow consists of rapid component surface run off and slow ground water flow through a long period. Flood flow is causing certain difficulties to man while the Ground water flow makes our living more comfortable. Natural watersheds are capable of retaining more ground water, which could be released slowly during the dry period.

There are several methods to assess the ground water recharge and surface run off. Curve Number method was selected for this analysis.

Technical data pertaining to the Upper Mahaweli Catchment is given below.

Table 1

Catchment area	3000 sq km
Average annual rainfall	3000 mm [previous]
Average rain fall [now]	2800 mm
Average rain fall [after restoration]	2900 mm

Curve Number CN = 25400/(254+Total abstraction S) ----- (1)

Example :Calculate the total abstraction S if CN=80

$$\text{Total Abstraction} = [25400/\text{CN}]-254 \\ = 63.5 \text{ mm}$$

$$\text{Initial Abstraction Ia} = 0.2 \times \text{Total abstraction S} \text{ -(2)}$$

$$\text{Surface Run off Q} = [R-0.2 \times S]^2 / \{R+0.8S\} \text{ --- (3)}$$

If Rainfall R < Initial Abstraction Ia-No surface run off

Values of curve numbers are given below

Table 2

	Average	After Rain	Dry
Virgin Forest	67%	70%	65%
Prevailing	77%	81%	75%
After restoration	71%	72%	69%

Relevant Total and Initial abstraction Values

Table 3

	Average		After rain		Dry	
	S (mm)	Ia (mm)	S (mm)	Ia (mm)	S (mm)	Ia (mm)
Virgin Forest	120	20	109	22	136	27
Prevailing	76	15	60	12	84	17
After restoration	103	21	100	20	115	23

Specimen calculation

Calculate the surface run off after 100 mm rain under the virgin forest condition.

$$\begin{aligned} \text{Curve Number} &= 75 \Rightarrow S=85\text{mm and Ia}=17 \text{ mm} \\ \text{Run off Q} &= (100-17)^2/(100+68) \\ &= 41 \text{ mm} \end{aligned}$$

Normal Ground Water flow equation

$$\text{Discharge after t days (Qt) = Initial discharge(Qo) x [exp] ----- (4)}$$

$$\text{Ground Water storage after t days (St) = Qt x [Exp] ----- (5)}$$

Table 4

	K	Alpha ()
Virgin Forest	0.970	.030
Prevailing	0.942	.0596
After restoration	0.961	.040

Ground Water simulation Equations are given below

Virgin Forest

So =413 MCM After the 52 th Week So
Remains same

$Q_o = S_o \times 0.347$ ----- (6)

$S_t = Q(t-1) \times 2.334 + \text{Recharge} \times 3$ ----- (7)

$Q_t = S_t \times 0.347$ ----- (8)

Prevailing

So =134 MCM After the 52 th Week So Remains
Same

$Q_o = 0.689 \times S_o$ ----- (9)

$S_t = Q(t-1) \times 0.955 + \text{Recharge} \times 3$ ----- (10)

$Q_t = S_t \times 0.689$ ----- (11)

Similarly After Proposed Restoration

So=257 MCM

$Q_i = 0.463 \times S_i$ ----- (12)

$S_t = Q(t-1) \times 1.632 + \text{Recharge} \times 3$ ----- (13)

Following Assumptions were made

- Actual Evapo-transpiration is equal to eighty percent of Potential Evapo-transpiration when there is sufficient soil moisture
- Actual Evapo-transpiration is only ten percent of the potential evaporation two weeks after the rain
- Intensive rains were considered to obtain most unfavorable results
- Rain falls with 75% of probability of exceedance was considered
- Hypothetical rain fall patterns were assumed
- Effects of the reservoirs were initially neglected and finally introduced.

6. Results

Tables 5, 6 & 7 and the graphs in the annexure shows the distribution of the ground water flow and flood flow through out one year period. Capacity of the virtual ground water reservoir can be increased by 200 MCM by proper Watershed Management.

Table 8 shows the hydropower generated by each power station after the proposed restoration.

6.1 Sedimentation of Existing tanks

Large reservoirs are normally designed for a hundred year lifetime. In most of the cases an annual sediment yield of 0.25% was assumed in initial designs. [Even after the active lifetime 75% of the capacity should be available for storing water. However, actual rate of sedimentation of tanks seems to be very much higher than predicted values.

Table 5

Reservoir	Sediment Yield (Actual)	Based on analysis
Victoria	0.08%	0.5% Flat Rate
Pollgolla	2.80%	-do-
Randenigala	1.0%	-do-
Rantambe	4.30%	-do-
Kothmale	1.20%	-do-
Other Large Reservoirs	0.08% to 1.5%	-do-

If the rainfall intensity is more than twenty five millimetres per hour those rains are called erosive rains. However, thick forest cover over a watershed area can provide a high resistance for soil erosion. Sedimentation of large reservoirs can be reduced by more than fifty percent by proper watershed management.

7. Comparison of Kelani and Mahaweli Systems

The Kehelgamu Oya and Maskelioya system is capable of generating 1600 GWh per annum with a combined catchment area of just 320 sqkm while the highest output of 2400 GWh is obtained from the Mahaweli system with a catchment area of 3200 sqkm.

As far as the Kelani system is concerned, the Hydropower benefits from one hectare of watershed land is nearly worth four hundred thousand Rupees.[Net income of a properly managed one hectare of tea land in this area is about two hundred thousand Rupees]. Higher productivity of the Kelani system can be attributed to the higher rainfall received, low Evapo-Transpiration and mainly due to construction of two reservoirs at the maximum possible elevation of 1100 metres above Mean Sea Level. These reservoirs are capable of supplying a regulated flow for the rest of the system. The

other important feature of the Kelani system is Utilization of nearly 1000 metres effective head starting from major reservoirs and ending at Samanala pond.

However, the same efficiency is not available in the Mahaweli system. The entire Mahaweli system utilizes an effective head of 500 metres. [The Kothmale reservoir is at the highest elevation of 702 m above M.S.L) Water level fluctuations in the Mahaweli reservoirs are very significant and considerable energy is lost especially during the dry periods, because of low heads.The proposed Upper Kothmale reservoir at an elevation of 1200 metres M.S.L would definitely increase the performance of the Mahaweli system by providing a regulated flow to enhance the effective heads of the scheme, downstream in addition to the energy generated by the scheme itself. But, unfortunately, the Upper Kothmale project is temporarily suspended and it's future is yet unknown due to political reasons

8. Recommendations

- Reforestation of 50 sqkm upstream of the proposed Upper Kothmale reservoir and conservation of the existing forest in the area.
- Construction of the proposed Upper Kothmale reservoir paying due attention to the beauty of the environment.
- Construction of silt traps just upstream of the Polgolla and Rantambe reservoirs.
- Construction of small ponds, similar to the Kelani system, just upstream of the

Kothmale and Victoria reservoirs and extending the tunnels up to the ponds to make use of the full potential of the base flow.[The height of the Kothmale dam was reduced by thirty metres deviating from the original plan and therefore this is quite possible]

Table 6

	Ground water (MCM)	Flood Water (MCM)	G.W Sediment coefficient	F.W Sediment coefficient	Sediment Yield (MCM)
Virgin Forest	4020	2500	0.0005	0.001	4.51
Prevailing	2940	3408	0.0005	0.004	15.10
After Restoration	3500	2920	0.0005	0.002	7.59

Table 7
Performanance of Mahaweli System After the Proposed Restoration

	Catchment Area [sqkm]	Ground Water	Flood water (MCM)	Increased Head (m)	Rated Head (m)	Annual Energy GWh
Upper Kothmale	250	292	218	425	410	558
Lower Kothmale	544	633	476	210	201.5	537
Ukuwela	517	604	452	78	78	203
Bowatenna	1034	1208	906	57	55.2	267
Victoria	1374	1605	1204	198	190	1165
Randenigala	1713	2001	1752	78	78	700
Rantambe	2940	3435	2575	33	33	454
Total						3884

General recommendations to overcome the power crisis [These are not based on the analysis]

- Convert the pumped water supply schemes into gravity flow type schemes
- Rain water harvesting to cut down the power requirement for pumping water
- Use compact Florescent bulbs for illumination purposes
- Rehabilitation of the power transmission system to minimize losses

9. Conclusion

Any infrastructure development project causes certain damage to the environment. The environmental degradation caused by the Mahaweli project has been very high compared to the Kelani project. On the other hand, the Environmental damage caused by deforestation, especially during the colonial time, cannot be lightly treated. So-called developed countries are now concerned about the mitigatory plan after completion of development projects. In Sri Lanka very little attention was paid to mitigatory works.

Therefore, new hydropower projects should not be encouraged, unless the existing projects are properly managed or the new project has significant favorable effects on the existing system. Perhaps effective hydropower system management requires certain modifications to the old system. However, this involves little capital investment, compared to the initial project cost, which could be recovered during a short period.

The productivity of the Kelani Hydropower system is six times than that of the Mahaweli. Theoretically, it should be possible to extract 7,000 GWh from the Mahaweli system,

The analysis shows that it is possible to obtain 3850 GWh from the Mahaweli network, with the combined effect of watershed management and construction of the proposed Upper Kothmale powerhouse. However, construction of Upper Kothmale project will be a multi-dimensional optimization problem subjected to so many constraints.

Global warming has become an environmental hazard especially for the tropical countries. Scientists have correctly pointed out that the emission of carbon dioxide is the main reason for

global warming. In 1990, at Koyoto, Japan, a set of emission reduction targets were determined for the 39 worst carbon dioxide emitting countries. It was also decided that most of the developing countries are not required to reduce the GHG emission as they were well below the emission levels of industrialized nations. There are several flexibility mechanisms that allow the countries to trade their obligations with others. Clean Development Mechanisms allow developed nations to trade their obligations with a country like Sri Lanka, which is not under any obligation to reduce emissions.

Under the prevailing conditions 1- Ha of forest land in the upper watershed area can provide hydropower benefits worth 200,000 to 400,000 Sri Lankan Rupees.

When the Koyoto Protocol becomes law, reforestation of one Ha of bare land or leaving a forest land as it is will be able to absorb 100 tons of Carbon dioxide worth 20,000 US\$ annually. Now, it is the right time to give up harmful activities in the central hill areas. Nature will reward us for living with nature. Otherwise, we will have to spend billions of Rupees for importing oil while leaving the poor people of the country for ever in darkness.

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Appendix

Table 8
Kelani system

Project	Catchment area [sqkm]	Reservoir Capacity [MCM]	Rated Head	Installed Capacity [MW]	Annual Energy [GWh]	Price of Energy Rs Million
Old lakshapana	134.7	0.39	449.3	50	265	2120
Wimalasurendra	115.3	55.3	227.4	50	105	840
Samanala	315.3	0.2	259.0	75	427	3316
New Lakshapana	152.6	0.93	575.5	100	558	4464
Canyon	129.5	114.7	204.2	60	175	1400
Total		171.52		335	1530	12140

Table 9
Mahaweli system

Project	Catchment area [sqkm]	Reservoir Capacity [MCM]	Rated Head	Installed Capacity [MW]	Annual Energy [GWh]	Price of Energy Rs Million
Ukuwela	40% of 1292	4.42	78	40	200	1600
Bowatenna	518+1292*.4	49.8	55.2	40	108	864
Victoria	% of 1891	722	189.9	210	984	7872
Kothmale	544	174	201.5	201	478	3824
Randenigala	2330	565	77.8	126	428	3424
Rantambe	3118	16.5	32.7	52	180	1440
Total		1531.72		669	2378	19024

Table 10
Other

Project	Catchment area [sqkm]	Reservoir Capacity [MCM]	Rated Head	Installed Capacity [MW]	Annual Energy GWh]	Price of Energy Rs Million
Samanalawewa	444	120	320	120	462	3696
Kukule	300	2	180	72	256	2048
Gal Oya	2000	950	25	12	31.0	248
Uda Walawe	1200	250	10	6	15.5	124
Nilambe	25	3.2	90	3.2	14.8	118
Total		1325.2		213.2	779.3	6234

Table 11
Yet to be Developed

Project	Catchment area [sqkm]	Reservoir Capacity [MCM]	Rated Head	Installed Capacity [MW]	Annual Energy GWh]	Price of Energy Rs Million
Upper Kothmale	200	43.7	450	248	840	6920
Broadlands	400	0.2	70	40	170	1360
Moragahakanda	1000	100	50	27	111	888
Uma oya 2,3 & 4		48.2		96	405	3240
Madulu oya		4.1		72	296	2368
Belihul Oya	75	5.8	100	17	73	584
Total		202		500	1895	15360





