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SUSTAINABLE DEVELOPMENT OF WATER RESOURCES, WATER SUPPLY AND ENVIRONMENTAL SANITATION

Enhancing of Drinking Water Source for the City of Tangalle

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The Tangalle town is located on the Southern coastal belt of Sri Lanka and the source of drinking water to the Tangalle town is the Kirama Oya. Due to rapid expansion of the town the project operates at 25 % of its capacity. In addition the projected demand of 15,000 cu.m.per day is required in 2025. Due to competitive use of water for irrigation during the dry weather periods, it is conceptualized to store back water of Kirama Oya during floods in a lake. The floods which normally occur with the monsoonal rains are expected to fill up the lake. Apart from the empirical knowledge available regarding the flooding of the Kirama Oya , there was no detailed hydrological study. This paper describes the application of NAM hydrological model and HEC_RAS hydrodynamic model to understand the process of flooding, its frequency of occurrence and any implication of impounding water in Nawayalawila on the existing environment.

Introduction

Competition among the many uses for limited fresh water resources is a common situation faced in many countries, and the problem is likely to aggravate with time, as population increases and fresh water resources are decreasing and being degraded. In order to resolve the conflicts among the different authorities responsible for providing water for the different purposes optimum use of the limited water resources has to be achieved by understanding the temporal and spatial variations of the availability of water.

The present water supply scheme for Tangalle town was originally constructed about 50 years back and upgraded to a capacity of 2500 cum per day. Since then the Tangalle city has expanded and due to the shortage of water in the Kirama Oya, the project operates at 25 % of its capacity during the months of July to September in most of the years. In addition to that the proposed plant has to meet the demand of 10,000 cu.m. per day for the projected demand in 2015 Figure.1 shows the catchment of Kirama Oya which intercepts 223.0 sq.kms.

Due to the shortage of water in the Oya during the dry weather periods, it is conceptualized to store water in a lake, called Nawayalawila, which is located on the right bank of the Kirama Oya above the Nalagama intake. The floods which normally occur with the onset of the inter monsoonal rains during the months of November to December and May to June are expected to fill up the lake to full capacity. The water impounded in the lake will be retained until a water shortage occurs at the Nalagama intake. The impounded water has to be preserved until July before releasing gradually to the Nalagama intake during the dry months of July to September.

Apart from the empirical knowledge available regarding the flooding of the Kirama Oya in the vicinity of Nalagama and Nawayalawila, there was no detailed study available to ensure this process, its frequency of occurrence and any implication of impounding water in Nawayalawila on the existing environment.

The determination of the long-term water availability in the Kirama Oya is complex due to man-made interventions to divert water for irrigation through a number of diversion weirs (anicuts) and irrigations tanks and ponds. The Kirama

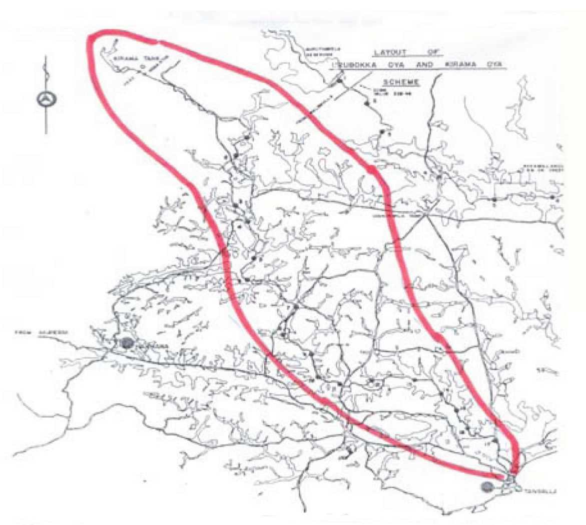

Figure 1. Catchment of Kirama Oya

Oya water had been primarily developed for the last 100 years or more for irrigated agriculture. The available water in the Kirama Oya is not sufficient to meet the water demand even for irrigation, especially during the South West monsoon (Yala season).

Source of water

The principal source of water for the Tangalle town is the Kirama Oya and it has 223 sq.kms of drainage area. The flow in the Oya is diverted for irrigation by 18 anicuts directly across the Oya and about 1500 ha of paddy lands are available for cultivation. These lands are being cultivated successfully during the North East monsoon (Maha season) and only a part of the land is cultivated during the South West(Yala season) due to the water shortage The average annual rainfall in the basin varies from 2000 mm at the head catchment at Kirama to 1140 mm in the lower basin close to the sea coast near Tangalle. There is an inadequate regulation capacity in the basin and therefore the Oya depletes completely during dry weather. The Kirama tank is the largest working tank in the catchment with a capacity of 1215 ac.ft (1.5 mcm). The Nalagama water intake is located just above the last anicut in the series and therefore it receives water left over by 17 anicuts upstream.

There are a few rain gauges in the Kirama Oya basin, but no river gauging stations in the Kirama Oya and the only hydrological data available are the tank water replenishment data at the Kirama tank in the head catchment. Therefore in the absence of any direct stream flow measuring stations in the area, there is no way to obtain any direct information regarding the flow characteristics. Hence tank replenishment data at the Kirama tank available with the Irrigation Department is the only basis to estimate flow characteristics. The monthly inflow data from 1976 to 1979 were obtained from the Irrigation Department (ID) and used for the calibration of the NAM rainfall runoff model.

Methodology

The following elements of hydrological and hydraulic modeling were undertaken during this study. The sequence of modeling carried out is given below.

a. Generation of stream flow data for four years from 1976 to 1979 on daily basis for the Kirama tank catchment (13.3 sq.kms) from a hydrological model and calibration of the model parameters by comparing the estimated flow volumes obtained from water balance study.
b. Generation of the daily inflow series for Kirama Oya for 30 years from 1970 to 2000 from daily rainfall records at Kirama and Tangalle rain gauges using the calibrated model.
c. Frequency analysis of maximum flood peaks from annual and partial series from April to August for 30 years of generated flow series.
d. Estimation of average flow regime for Kirama Oya from the 30 years of generated flows.
e. Setting up of a numerical hydraulic model for the Kirama Oya near the confluence of Nawayalawila with the Kirama Oya. The hydraulic model covered about 4 kms of the Kirama Oya (2 kms upstream of Nawayalawila, Kirama confluence and 2 kms downstream of the confluence). This includes the Kirama Oya in between Wile Amuna and Waladora anicut including Nawayalawila and the stream connecting Nawayalawila to Kirama Oya.
f. Calibration of the hydraulic model
g. Simulation of medium and flood discharges of the Kirama Oya during the months of May to August to understand the replenishment of Nawayalawila.

Reservoir water balance

The reservoir water balance study plays a key role in modeling the river flow regime of the Kirama Oya in the absence of any direct flow measurements. The water balance principle was applied to the Kirama tank and its catchment .Then the stream flows were estimated from balancing the components of the water balance equation. This was done on monthly basis from 1976 to 1979.

Rainfall runoff model for Kirama Oya

Due to the non availability of observed stream flow records as explained previously, the NAM rainfall runoff hydrological model has to be used to generate a synthetic stream flow series. Among the hydrological models, the conceptual models are superior to Black Box models and therefore in this study a conceptual model was used to generate stream flows. The NAM rainfall-runoff model developed by the Danish Hydraulic Institute (DHI) in Denmark was used in this study. The NAM model is a well-proven engineering tool that had been applied to a number of catchments in different climatic regions of the world including Sri Lanka.

Brief description of some of the important parameters of the NAM model is given below.

In general it was our experience that for the calibration of a model, direct accurate stream flow measurements are needed. Therefore in the absence of such direct measurements higher accuracy in model fitting cannot be achieved. The parameters obtained from the model calibration are given below

Umax	=	25 mm-Upper zone soil moisture
Lmax	=	100 mm-Lower zone soil moisture
Cqof	=	0.60 - Overland runoff coefficient
CK1	=	10-Time constants for overland flow routing
CK2	=	10- do -
Ckbfu	=	1000- Base flow parameters for routing (Upper zone)
CKbfl	=	5000 - (Lower zone)
Carea	=	1.0-Correction for catchment area
Cevp	=	0.60 Pan Coefficient

The comparison of the monthly flow volumes derived from the water balance study and the flows generated by the NAM model from 1976 to 1979 are shown in Figure 2.

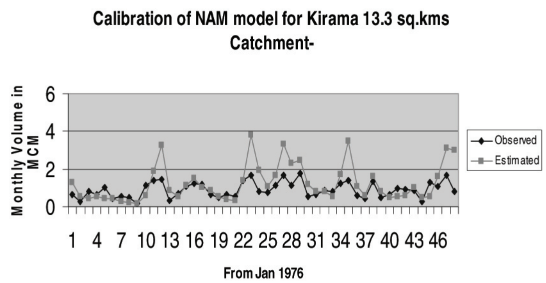

Figure 2. Calibration of NAM Model

It should be noted that flood peaks are generally underestimated in water balance studies. This is due to the underestimation of spillage. Therefore estimated flood flows by the NAM model are higher than the flow estimated from the water balance study.

Generation of stream flows

After calibration of the rainfall runoff hydrological model, long term runoff data were generated for 30 years from the daily rainfall of Kirama and Tangalle for the whole catchment of Kirama Oya (223.0 sq.kms)using the estimated model parameters.

The generated stream flow from the NAM model has to be corrected by making an allowance for irrigation diversions. During the initial modeling process, the diversion of water for irrigation was ignored with the idea of making a subsequent correction. During heavy and moderate rainfalls, diversions for irrigation will not take place as there is sufficient water in paddy fields. Water diversion takes place during the dry weather flow and therefore the correction for the irrigation demand will be required only during the low flow periods. However this correction will not have any influence in this particular study as we do not intend to take the low flow period for the simulation of the model. The hydraulic model will be used for simulation of high and moderate flows of the Kirama Oya.

This annual average flow series was derived by estimating the statistical parameters of monthly flow volumes and selecting the matching months for 50 % probable volumes for 30 years. Then this series was corrected for the irrigation demand by considering 1500 ha of paddy cultivation during both seasons. The corrected flow regime is shown in Figure 3. From this series the period from 1 st May to the end of August was considered as the model input for the simulation of the hydraulic model.

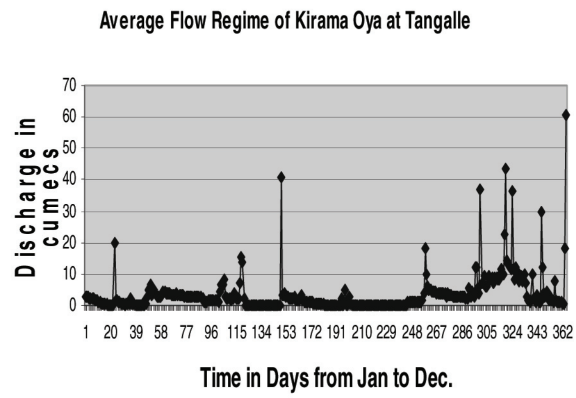

Figure 3. Average flow regime

Frequency analyses of flood peaks

Frequency analysis of flood peaks is important in two ways. The intake structure and treatment plant for the water supply project have to be designed for a safe flood level and therefore flood frequency analyses have to be done to determine flood levels of different frequencies. The other aspect is to determine the threshold value of the flood frequency which is capable of filling Nawayalawila. For this analysis generated stream flows for 30 years were used.

From the generated flow series the annual maximum flood peaks and the flood peaks during the period from April to August (partial series) were screened and these flood peaks were analyzed by fitting the Extreme value Type I distribution (Gumble). Table 1 shows the results of the frequency analysis. Then these food peaks were simulated in the hydraulic model to obtain the required corresponding flood levels at the Nalagama intake and Nawayalawila.

Table 1. Frequency analysis of floods

Return Period in Years	Annual Maximum floods cumecs	Water levels at Nalagama in m msl	Water Levels at Nwaya-lawila in m msl	Maximum floods from the Partial Series-cumecs
2	70	2.19	2.8	37
5	102	3.5	3.8	60
10	128	3.9	4.7	78
25	149	4.1	4.9	94
50	168	4.22	4.96	108
100	187	4.4	5.1	123

Nawayalawila

Nawayalawila has an independent net catchment of 2.0 sq.kms and the surface runoff from this 2.0 sq.kms reaches Nawayalawila directly. According to the Iso Yield curves developed by the Irrigation Department specific yield for the South West monsoon for Tangalle area is 300 ac.ft/sq.mile. This is equivalent to 234 ac.ft of inflow during the SW monsoon to Nawayalawila from 2.0 sq.kms of net catchment. According to the model studies done during this study the specific yield for the Tangalle area has been estimated as 340 ac.ft per sq.mile. By adopting the lower value given by the Irrigation Department guidelines an average 234 ac.ft of water to Nawayalawila can be expected during the SW monsoon. As the SW monsoon rain occurs during the months of May to July this quantity of water will be in addition to the flood water intended to be trapped at Nawayalawila.

The bed level of Nawayalawila is approximately at 1.5 m MSL. The inflow to Nawayalawila consists of flow from 2.0 sq.kms of its own catchment apart from the occasional spillage from two upstream cascades during the NE monsoon and the return flow from the command areas of upstream tanks. Nawayalawila has its full supply level at 3.13 m MSL and at this level it will have a capacity of 670,000 cu.m. and a surface area of 80 ha.

During the inter monsoons, the Kirama Oya gets flooded and the entire area will be under water for a few days. According to the information available major floods occur once in 4 to 5 years. By rehabilitating Nawayalawila it is envisaged to trap flood water during the monsoons and to release water gradually to the Nalagama intake during droughts. The Kirama Oya goes dry during the months of July to September. Therefore during this period the Nalagama water intake becomes ineffective and therefore it is planned to provide the supplementary water from Nawayalawila to Nalagama during this period.

In an event of a flood when Nawayalawila reaches its full supply level, the quantity of water available for drinking would be 670,000 cu.m. However there will be losses due to evaporation and seepage when water is kept in storage for a long period. Assuming that water has to be retained in the reservoir for the period from May to September, the approximate volume of evaporation would be 299,000 cu. m. An evaporation loss rate of 4.0 mm per day based on the average pan evaporation rates at Angunukolapepessa was assumed in this study. There will be a certain amount of return flow from the Sitinamaluwa and Aluthwewa paddy fields and it is assumed that this would compensate for the seepage and other transmission losses.

The shortage of water in the Kirama Oya to meet the present and the projected demand is only during the period of three months from July to September .There is sufficient water during the rest of the period to meet even the projected demand of 15,000 cu.m per day in 2025 . After implementing the Nawayalawila project, the quantity of water available for drinking from Nawayalawila would be 371,000 cu.m and this will be sufficient for 75 days at the present demand of 5000 cu.m. per day. Therefore the present water shortage at the Nalagama intake can be resolved to a satisfactory level. Then the Tangalle water supply scheme can be operated at 100 % efficiency to meet the present demand. The Nawayalawila water at full capacity will be sufficient only for 40 days and therefore a water shortage will exist for 50 days. Therefore both water and storage have to be found for the balance 50 days. This aspect of possible enhancement of both storage and water is under further investigation.

Hydraulic modeling of Kirama Oya

In order to understand the process of replenishment of Nawayalawila from the Kirama Oya, a numerical model was set up to simulate 4.0 kms of the Kirama Oya, Nawayalawila and the stream connecting Nawayalawila to Kirama Oya. All the important structures were incorporated to the model.

Boundary conditions

The model requires hydraulic boundary conditions at the open ends of the river system. In this particular modeling there are three locations where boundary conditions have to be defined. These are at Wile Amuna, Nawayalawila and the Waladora anicut. For the simulation of the average flow regime of Kirama Oya during the South West monsoon, the time series from 1 st May to 1 st August was taken as the upstream boundary for Kirama Oya at Wile Amuna. The second upstream boundary is at Nawayalawila and it was kept at almost zero level assuming that there is no significant contribution from the catchment of Nawayalawila during the South West monsoon to simplify the problem. The actual contribution from the Nawayalawila catchment was added subsequently to the water balance. The third boundary is the down stream boundary at the end of the model at Waladora Bridge This was kept as a constant during simulation, but it was varied from 1.0 m to 2.5 m msl during the study.

Calibration of the Hydraulic Model

Normally the calibration of a model is done for known observed historical input hydrographs with measured water levels at strategic locations in the model area. In this particular study even though the observed flood levels during the May 2002 flood were obtained by making inquiries, no measured hydrographs were available at the upstream boundary. Therefore observed flood levels during the May 2002 flood was used to understand the possible flood gradient during a major flood and to adjust the friction in the model accordingly.

In general the accuracy of model results depends on the accuracy of data inputs and not so much on the model structures of well proven models. In this study it was not possible to carryout the conventional model calibration due to the absence of measured inflows and therefore the model outputs will be marginally accurate.

Model Simulation

The model simulation consisted of two steps. First it was necessary to find out a threshold value of the magnitude of the flood which is capable of filling Nawayalawila to the full supply level. The bed level of Kirama Oya at the confluence of Nawayalawila is at 0.69 m msl and the Nawayalawila regulator sill is at 1.50 m msl. Therefore for the intrusion of water into Nawayalawila, the flood level at the confluence has to be above a particular level. For this purpose steady flow analysis of the model was done for different flood profiles until the required magnitude of the flood wave was established. It was found that a flood peak of the magnitude of 48.0 cumecs was required to fill up the lake to the design full supply level. During this simulation the water level of the lake reached 3.13 m msl and the downstream water level at Waladora was kept at 2.0 m msl. According to the frequency analysis of the partial series a flood peak of 48.0 cumecs has a return period of 2.75 years. Flood profile of the Nawayalawila is shown in Fig. 4 .It can be seen from Fig. 4 that when the flood peak reaches 48.0 cumecs, flood bunds on either side of Nawayalawila stream go under water.

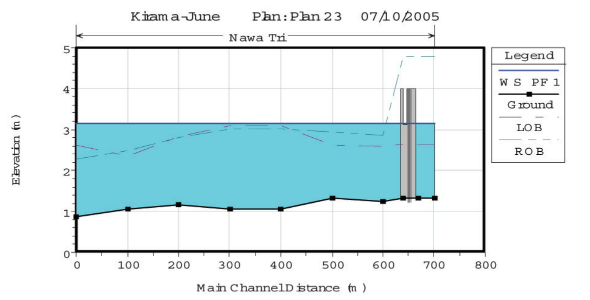

Figure 4. Flood profile of Nawayalawila when Q=48 m3/s

Shortage of water occurs at the Nalagama intake after the month of July. Nawayalawila is expected to fill up from the floods during the South West monsoon, which generally occur from April to July. The replenishment of Nawayalawila due to the North East monsoon has no advantage as impounded water has to be kept at the lake for at least 6 to 7 months before actual use. In the event of preserving the Nawayalawila water from the North East monsoonal rains, the loss of water due to evaporation and seepage would be of the order 300,000 cum. This is nearly 50% of the capacity of Nawayalawila. Therefore the possibility of getting the lake filled up during the South West monsoon has to be closely studied. The generated daily flow series for 30 years was examined to identify the occurrence of floods having a magnitude of more than 48 m3/s during the period from April to August. It was found that from the frequency analysis in Para 9.0 that, the occurrence of such floods capable of filling Nawayalawila has a return period of nearly 2.75 years. Therefore during the 30 years under consideration the annual maximum flow rates exceeded 48 m3/s during the period from April to August only 11 times . However from the annual series it can be seen that the lake gets filled up 25 years during the 30 years , from flood water from the Kirama Oya.

The second step of flow simulation was to understand how Nawayalawila is going to behave during a normal year with average climatic conditions. In order to understand this, the average flow regime from May to August has to be used as the input to the model during the simulation. During this simulation the variation of water levels in the Nawayalawila Lake can be studied. The input to the model during this simulation was the average flow regime and the downstream boundary level of Kirama Oya at Waladora anicut was varied from 1.0 m to 2.5 m. The downstream boundary condition was kept at a constant level during a particular simulation, but varied from simulation to simulation. During this simulation contribution from the Nawayalawila catchment was ignored and therefore an empty lake was assumed at the beginning of the simulation. In other words the initial lake elevation was assumed at 1.50 m msl.

Table 2 provides the information derived from simulations.

Table 2. Information derived from simulations

	Down-stream-Level in m msl	Peak Inflowto Naway-alaM3/s	Peak stage In m msl	Storage in Nawayala cum
Trial 1	1.5	8.40	2.87	463,000
Trial 2	2.0	7.67	2.93	536,000
Trial 3	2.5	8.71	3.04	588,000

Note: F.S.L. of Nawayalawila is at 3.13 m msl and corresponding storage is 670,000 cum

From the above simulation it can be seen that a maximum pool level of 2.93 m. can be achieved during a normal year by keeping the downstream boundary level at 2.0 m. This is also a possible practical solution as the sill level of the Waladora anicut is at 0.0 m level and the gate height is 2.0 m. Therefore it is possible to keep the downstream level at 2.0 m by keeping the gates closed during floods. When the gates are closed at the Waladora anicut the water level can be raised to the 2.0 m level. In order to do this the present flood bunds have to be raised to 3.0 to 3.5 m msl between the Waladora anicut and the confluence of Nawayalawila and Kirama Oya to a distance of 2000 m.

The storage of water in Nawayalawila at the level of 2.93 m is 530,000 cu.m and anticipated water from the catchment of Nawayalawila due to surface runoff during the SW monsoon is 288,000 cu.m (234 ac.ft).Therefore as the capacity of Nawayalawila at Full Supply Level (FSL) is 670,000 cu.m a spillage of 148,000 cu.m is estimated during a normal year. This spillage can be arrested if the capacity of Nawayalawila can be enhanced. This aspect of increasing the capacity was examined due to insufficiency of the Nawayalawila storage capacity to meet the water requirement during the full period of water shortage that is 3 months. However if this spillage is arrested, drinking water can be extracted for a further period of 15 days making a total of 65 days extraction period. Therefore the possibility of enhancing the Nawayalawila will be under consideration.

The arrangement to keep the Waladora anicut gates closed will be required only for medium floods. During major floods the Kirama Oya flow will exceed 50.0 cumecs and therefore Nawayalawila will get filled up to the full supply level. Therefore this arrangement is not required during major floods.

During the simulation of the average flow regime the water level in Nawayalawila reached the maximum level of 2.93 m msl. With the surface runoff from the catchment, the lake will reach the full supply level indicating no water shortage during a normal year. The control gates of Nawayalawila have to be operated first by closing the gates to store water during the NE monsoon. Until the on-set of the SW monsoon this water has to be retained to observe the response of the SW monsoon. The operation of gates during the SW monsoon will be very sensitive to catch the surface runoff from the Nawayalawila catchment and backwater from Kirama Oya floods. The total quantity of water trapped will be 617,000 cu.m and this quantity will be sufficient for 55 days making an allowance for evaporation losses from the actual date of water release to Nalagama from Nawayalawila. In this estimate the evaporation losses are ignored between the time of water release and the time of peak water level at Nawayalawila. The estimate of 55 days also assumed the highest extraction rate of 10,000 cum per day from the lake.

Adequacy of flood control gates at Nawayalawila

There are three lifting gates provided in the design to regulate flood water in Nawayalawila. The adequacy of the gates was checked up by altering the gate closure. It was found during simulation that three gates for the regulator gave the optimum results for extracting water during floods

Augmentation of Kirama Oya flow

After implementing the Nawayalawila project, the present 90 days water shortage at the Nalagama intake can be resolved. Then the Tangalle water supply scheme can be operated at 100 % efficiency to meet the present demand. However in order to meet the 10,000 cu.m per day demand in 2015, Nawayalawila water at full capacity will be sufficient only for 40 days and therefore a water shortage exists for 50 days and we are confronted with the inadequacy of water in Kirama Oya during the South West monsoon.

Estimated flow regime shows the possibility of extracting a daily rate of 1.0 m3/s (86, 4000 cu.m. per day) for a period of 30 days to fill up Nawayalawila from the Kirama Oya. In order to enhance the irrigation and drinking water supply the Kekiri Obada reservoir in the head catchment of Kirama Oya with 5.0 mcm capacity is under construction .The completion of this work is expected by the Irrigation Department during the year 2007. The degree of reliability of the water availability for diversion will be further enhanced with the completion of this reservoir. It has been agreed to release 1.0 mcm of water annually from this reservoir for drinking. However any further increase in the water demand beyond 2015 needs consideration to augment the Kirama Oya with trans basin diversions from either Nilwala Ganga or Kalu Ganga. Diversion of water from Nilwala Ganga had been investigated and a project has been formulated to augment the adjoing Urubokka Oya basin. If this is implemented the Kirama Oya too can be augmented. Diversion of Kalu Ganga is also a multi purpose mega project under investigation to supply water for Hambantota and Monaragala districts for multiple uses.

Therefore it is recommended to rehabilitate and improve this existing 2.5 km canal from the Daranda anicut to Nawayalawila once and for all to the optimum capacity in order to extract the total volume of Nawayalawila in case of any unforeseen reason. In order to extract the required quantity of water within 30 days through an open unlined canal with 50 % losses, a canal capacity of 1.0 cumecs (86,400 cu.m per day) will be required

Conclusions

With the restoration of Nawayalawila lake the present demand of drinking water supply (5000 cum per day) to Tangalle city can be successfully met from the back water of Kirama Oya during floods. After improving the Daranda feeder canal to a capacity of 1.0 cumecs and by diverting Kirama Oya water during the off cultivation seasons the demand of water in 2015 (10,000 cu.m per day) can be met. The degree of reliability of the water availability for diversion will be further enhanced with the completion of Kekiri Obada reservoir in the head catchment of Kirama Oya and obtaining the assured 1.0 mcm of annual water for drinking from the irrigation Authority. Any further increase in the water demand beyond 2015 needs consideration to augment the Kirama Oya with trans basin diversion from either Nilwala Ganga or Kalu Ganga.

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