Assessments of Irrigation Water Requirement from Deduru Oya Left Bank Canal to Supplement Deduru Oya Left Bank Irrigation Demand

D. S. Sampath, S. B. Weerakoon, B. K. Mishra and S. Herath

Abstract: Rainfall in Deduru Oya basin has a significant temporal variation and thus the Deduru Oya carry flash floods during rainy season and very low flows during dry season. The Deduru Oya reservoir under construction at the upstream of the existing RidiBediEla anicut will be useful to regulate discharge of the Deduru Oya for better utilizing the basin water resources especially for irrigation. The multi-purpose Deduru Oya reservoir project with a reservoir of a capacity of 75 Million Cubic Meters (MCM), augments water resources in 136 existing tank based irrigation systems in the Deduru Oya Left Bank through a Left Bank (LB) canal and also diverts water to the Iginimitiya tanking the Mee Oya basin through a Right Bank (RB)transbasin canal. This study develops a model for water management in LB canal development area and for the assessment of diversion requirement from the Deduru Oya reservoir through the LB Canal to supplement LB irrigation demand. Hydrological Engineering Center-Hydrological Modeling System (HEC-HMS) is used for runoff estimations and CROPWAT model is used to estimate crop water requirements. Water Evaluation And Planning (WEAP) model is used for water balance simulations in Deduru Oya LB canal development area and to calculate water requirements from LB canal for the period of recent 10 years. The study reveals that the annual water requirement from the LB canal for 100% cropping intensity in the proposed 3000 ha irrigable area in LB canal development area varies from 26 MCM to 41 MCM.

Keywords: Irrigation Water Requirement, Deduru Oya Project, Hydrological Modeling, WEAP

1.   Introduction

With the increase of population, demand for food increases and areas under irrigated agriculture continue to increase all over the world [4]. As the supply of water for all needs is only through the dynamics of hydrologic cycle, careful management of the limited water resources under increasing demand of water for irrigation and other multiple uses is utmost important. Extreme climate changes that are evident in the world seriously affect water sources and hydrologic cycle [17].

Area of cultivation has been increased to the maximum in modern irrigation systems in order to maximize the agricultural production under given water source. However, changes in climatic patterns frequently have caused a reduction in seasonal water availability and hence affect the cultivation [8]. Seasonal water shortages in drought years seriously affect the cultivations under modern major irrigation schemes [17]. Failure to manage the water sources in an effective manner which leads to the reduction of irrigated agriculture will affect the society and the economy of the country [8].

Main impacts of the climate change on water resources in Sri Lanka are the unusual variation of rainfall with time, high intensity rainfalls and increase of ambient temperature[12, 19]. Out of these, the changes of rainfall and temperature affect the irrigated agriculture. Irrigated agricultural systems need to be resilient to such effects in order to avoid crop failures.

In the case of ancient irrigation systems, there are number of resilience features such as distributed storages in small reservoirs (tanks). So they are more resilient to climate change compared with modern systems. It is important

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to incorporate the resilient features of the ancient systems to modern irrigation systems to improve their resilience under changing climate [21, 22].

With the recognition of importance of resilient irrigation systems, the mosaic irrigation systems inherited from the ancient times augmented by diversions from perennialrivers is being paid attention now. The Deduru Oya LB canal of the Deduru Oya reservoir project is one example of such development [22]. The assessment of availability of water resources in the existing irrigation systems and the diversion requirement from the river is important for optimal water management in the basin.

1.1.   Deduru Oya Basin

Deduru Oya basin which has an area of 2620 km² ranging from 0m to 1280m MSL is the sixth largest river basin in Sri Lanka extending from Chilaw in the west coast to the central hills. The Deduru Oya has a length of 115 km and flows

them are inherited from ancient time. Major tributaries of Deduru Oya are RatwilaEla, Kospothu Oya and Dik Oya in the upper basin and Maguru Oya, Hakwatuna Oya and Kimbulwana Oya in the middle basin and Kolamuna Oya, ThalagalaEla in the lower basin (Figure 2).

Rainfall is the only source of water and there are no transbasin diversions into or out of the basin at present. The rainfall in the basin has a significant temporal and spatial variation. Annual rainfall ranges from 2600mm in the upper basin to 1100mm in the lower basin. From the annual rainfall about 50% is received during inter monsoon months (March, April, October& November), about 35% during Southwest monsoon months (May to September), while remaining 15% during Northeast monsoon months (December to February) [18].

The Deduru Oya carries flash floods during rainy season and very low flow during dry season and it releases about 1600 MCM of
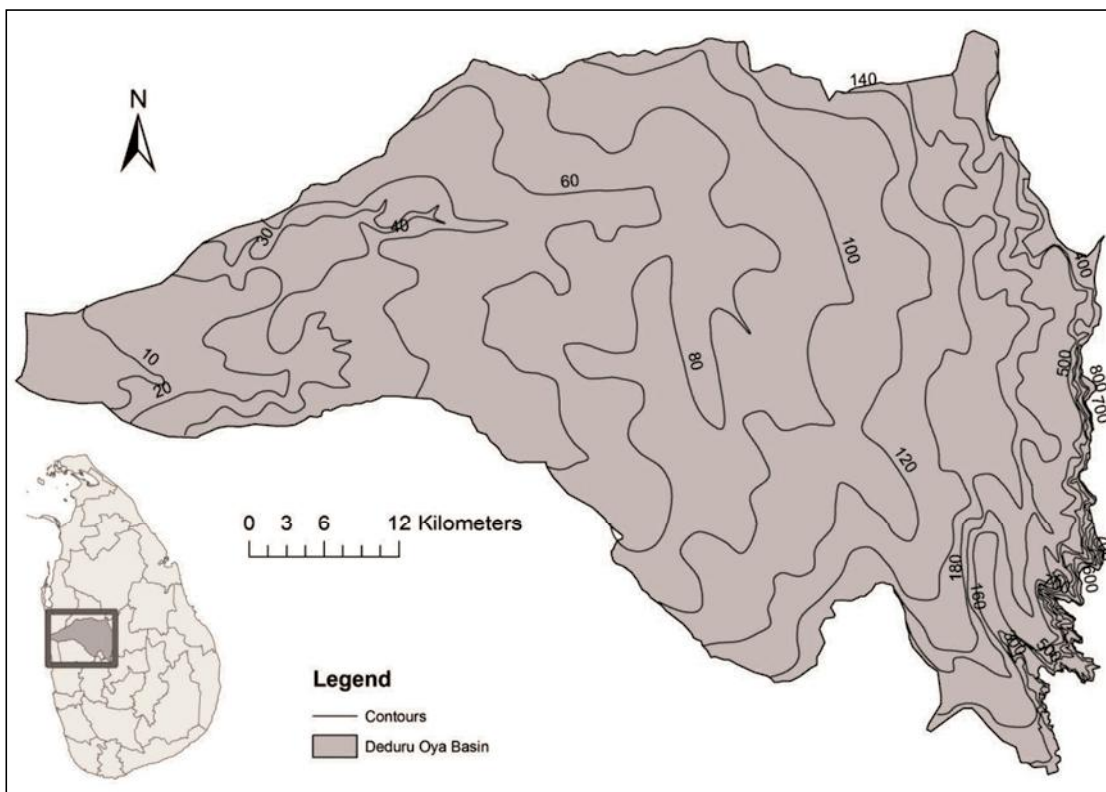

Figure 1-Location and Topography of the Deduru Oya Basin

through Matale, Kurunegala and Puttalam districts. Location of the basin and topography is shown in Figure 1.

The basin contains a large number of small and large tanks used for irrigation, and most of

water to the sea annually [7]. There are several anicuts across it to divertwater for irrigation but there is no single reservoir intercepting the Deduru Oya except the reservoir at Thunmodara being constructed under Deduru Oya project (Figure 2). There is strong need to

regulate Deduru Oya flow for its optimum use especially for irrigation during lean season.

1.2.   Deduru Oya Reservoir Project

Deduru Oya Reservoir Project which is a multi-purpose water resource development project under construction by the Irrigation Department aims primarily to improve the livelihood of farmers in part of the North Western province by increasing the productivity of land through irrigated agriculture. Other purposes of the project include enhancement of reliable sources for domestic and industrial water supply schemes and regulation of the flow to enhance diversion to RidiBendiEla and to control downstream floods[18]. The project includes construction of a dam across Deduru Oya to impound a reservoir of a capacity of 75 MCM, two canals at the RB and LB and instalment of a hydropower plant at the downstream of the dam. RB canal is a transbasin canal to augment water supply to Iginimitiya reservoir which is located in Mee Oya basin. It is proposed to develop 1000 ha along the transbasin canal and 4115ha at the Mee Oya basin. An area of 3000 ha under RidiBendiEla scheme will be benefited by regulated water supply from the Deduru Oya reservoir (Table 1) [18].

Table 1- Details of Existing and Proposed Irrigable Areas by Deduru Oya Reservoir

Canal	LB canal	RB canal	RidiBendiEla	Total
Existing irrigable area (ha)	2400	4715	2400	9515
Proposed irrigable area (ha)	600	400	600	1600

Hydro energy will be supplied to the national grid by using a 1.5MW plant installed at the downstream of the dam [18]. The downstream release of the reservoir is necessary for RidiBendiEla diversion and downstream environmental flows.

The Deduru Oya LB canal which flows through three District Secretariat (DS) divisions namely, Wariyapola, Kobeygane and Hettipola, will supply water to augment 136 existing storage-based ancient irrigation systems in the LB of the Deduru Oya (Figure 2). The 44.1 km long LB main canal has a discharge capacity of about 7.1 m^3/s at beginning. There are four branch canals from the LB canal. These canals pass through number of small tanks(Figure 2). There are about 17Level Crossings along the LB main canal formed by small tanks. There are 'Control Point Outlet (CPO)' points along LB main canal and branch canals to release water for agricultural purposes. Distribution of minor tanks located under main canal and branch canals are shown in Table 2. Most of these irrigation tanks are under cascade systems and inherited from ancient time.

Table 2- Number of Tanks in Main Canal and Branch Canal

Canal Name	Number of tanks
Main Canal	77
Branch Canal 1	15
Branch Canal 2	16
Branch Canal 3	27
Branch Canal 4	1
Total	136

This paper describes the water balance study of the irrigation tanks augmented by the LB canal. Irrigation water requirements from the LB canal for LB irrigation development area to achieve 100% cropping intensity were estimated under different scenarios.
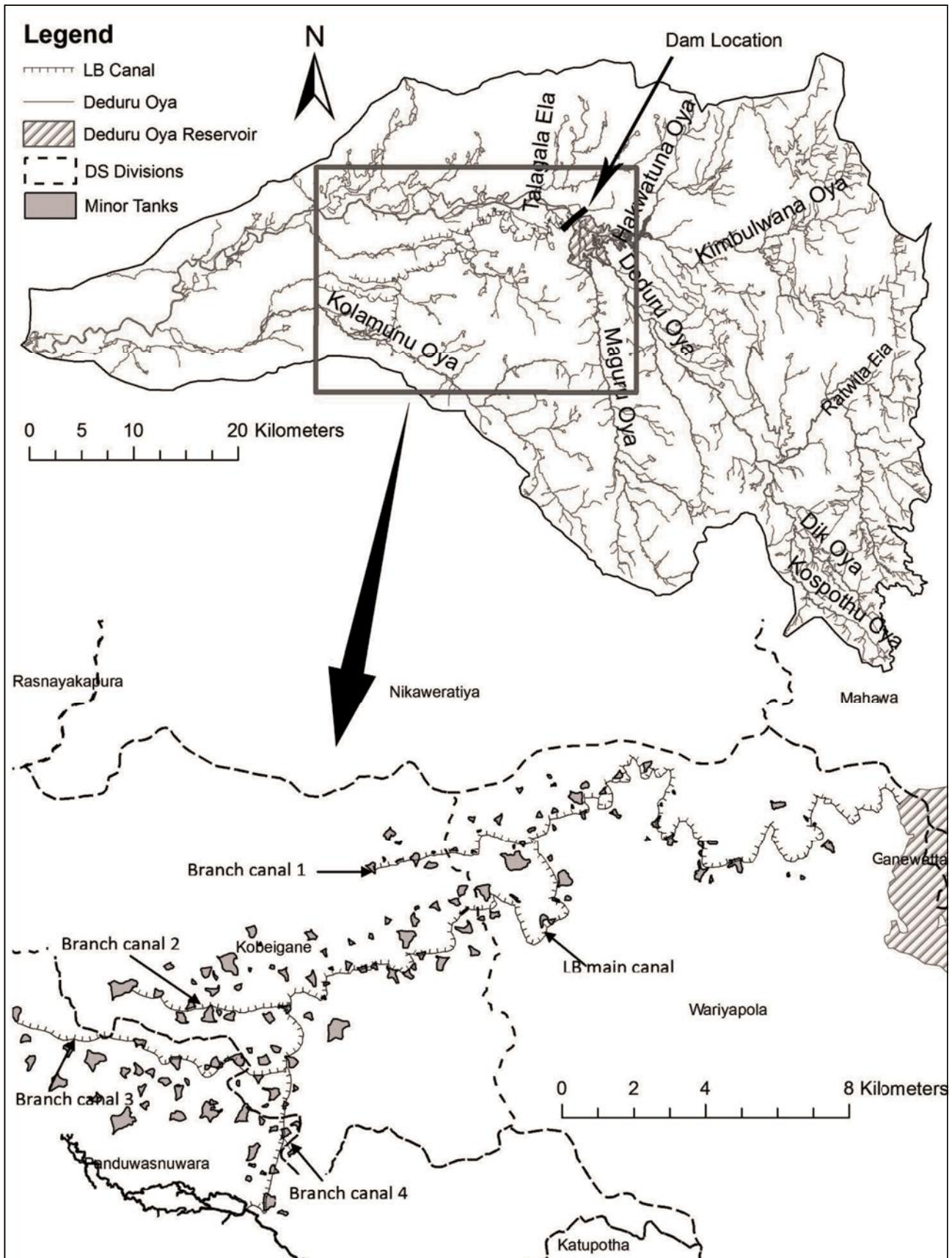
Figure 2-Deduru Oya Reservoir and LB Canal

2.   Methodology

The methodology followed is summarized in a flow chart as shown (Figure 3). For all minor tanks augmented by the LB canal, catchment areas, land use patterns storage capacities, command areas, natural streams, geological features and cascades were identified by using relevant GIS data and digitizing techniques.

Topographic, geologic and land use data were collected from the digital data of the Survey Department of Sri Lanka. ArcGIS 9.3 was used for spatial analysis of the Deduru Oya LB development area consisting of rain-fed tank irrigation systems.

2.1. Rainfall Runoff Modeling

Hydrologic Engineering Center – Hydrologic Modeling System (HEC-HMS) version 3.0.1 developed by US Army Corps of Engineers in USA was used as the rainfall runoff model [24]. The HEC–HMS supports both lumped parameter based modeling as well as distributed parameter based modeling and has been tested for tropical catchments[1].
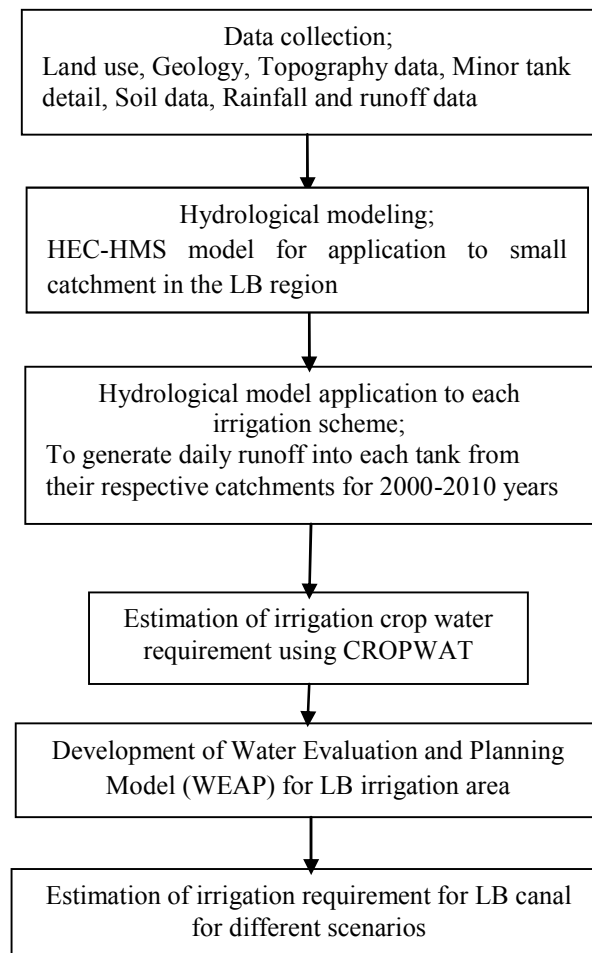
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┌─────────────────────────────────────────┐
│ Data collection;                          │
│ Land use, Geology, Topography data,       │
│ Minor tank detail, Soil data, Rainfall    │
│ and runoff data                           │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Hydrological modeling;                    │
│ HEC-HMS model for application to small    │
│ catchment in the LB region                │
└─────────────────────────────────────────┘
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                    ▼
┌─────────────────────────────────────────┐
│ Hydrological model application to each    │
│ irrigation scheme;                        │
│ To generate daily runoff into each tank   │
│ from their respective catchments for      │
│ 2000-2010 years                           │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Estimation of irrigation crop water       │
│ requirement using CROPWAT                 │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Development of Water Evaluation and       │
│ Planning Model (WEAP) for LB irrigation   │
│ area                                      │
└─────────────────────────────────────────┘
                    │
                    ▼
┌─────────────────────────────────────────┐
│ Estimation of irrigation requirement for  │
│ LB canal for different scenarios          │
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Figure 3-Methodology

region. Major soil type in Deduru Oya basin is reddish brown earth[9, 14].

Inflows to the irrigation tanks in LB development area are not available and therefore a rainfall - runoff model was developed to estimate the direct inflows to the tanks from their own catchments. Irrigation water requirements for the command area of each tank were calculated by using CROPWAT model. WEAP model was applied to compute water requirement from LB canal for the LB

HEC-HMS model is calibrated and verified for the Tittawella tank in Kurunegala District which has rainfall and runoff data [23]. Daily observed rainfall, runoff and evaporation data are available for the period of May 1995 to March 1997[11]. This catchment is in the same ago-climatic region and hydrologically similar to the catchments of the tanks in Deduru Oya LB canal development area. The catchment area of Tittawella tank is 2.95 km². The longest water course is 1800 m long and catchment slope is 0.82%. The tank has a capacity of 0.31MCM.

Major soil group is reddish brown earth and soil depth is more than 120 cm.

Normalized Objective Function *(NOF)*, Nash Sutcliffe efficiency (R^2_{NS}), and percentage bias (δ_b) values were used as quantitative measures for the skill of simulations. These parameters are used to analyze goodness of fit [5, 6, 10, 15,16].

$$NOF = \frac{1}{\bar{O}} \sqrt{\frac{1}{n} \sum_{i=1}^{n} (O_i - S_i)^2} \qquad \text{Eq 1}$$

$$R^2_{NS} = 1 - \frac{\sum_{i=1}^{n} (S_i - O_i)^2}{\sum_{i=1}^{n} (O_i - \bar{O})^2} \qquad \text{Eq 2}$$

$$\delta_b = \left| \frac{\sum_{i=1}^{n} (S_i - O_i)}{\sum_{i-1}^{n} O_i} \right| * 100\% \qquad \text{Eq 3}$$

Where, $O_i, S_i, n, \bar{O}$ are observed discharge, simulated discharge, number of the observed or simulated data points, and mean of the observed discharge respectively.

HEC–HMS model was calibrated for isolated rainfall events and also for continuous rainfall. Observed daily rainfall and discharge during Oct-Nov 1995 was used for event based model calibration. Skill metrics for simulated river discharge with observed were computed and the best fit was obtained by adjusting model parameter values for moisture loss, runoff transform method and base flow processes of the HEC-HMS model. The rainfall and discharge in Oct 1996 and May 1995 were used to validate the calibrated event based model. Rainfall and discharge data during Sept to Nov 1995 period was used to calibrate the continuous simulation of the model while 3 months, 1 year and 23 months time series during Sept to Nov 1996, Sept 1995 to Aug 1996 and May 1995 to Mar 1997 were used to validate the continuous model simulations.

The event based simulations employed the initial and constant loss method to compute infiltration loss while continuous simulations used the 5–layer soil moisture accounting loss method. The initial and constant loss method assumes that the maximum potential rate of precipitation loss is constant throughout an event. The initial and constant loss rate model requires the constant loss rate and initial loss to be specified. These represent physical properties of the watershed and land use and the antecedent condition. The soil moisture accounting loss method uses five layers to represent the dynamics of water movement in and above the soil. The layers include canopy interception, surface depression storage, soil, upper groundwater and lower groundwater. The soil layer is subdivided into tension storage and gravity storage [24, 27]. Implementation of both loss methods requires the soil properties of the sub basin. According to soil type and catchment properties in the basin, an initial loss of 30 mm, and a constant loss rate of 1.0 mm/hr and catchment imperviousness of 10% were used in initial and constant loss method. Above parameters were able to produce the best fit against observations. Parameters used for soil moisture accounting loss method are shown in Table 3.

Table 3- Summary of Parameters Used in Soil Moisture Accounting Loss Method

Parameter	Value
Canopy (%)	0
Surface (%)	0
Soil (%)	70
Groundwater 1 (%)	31
Groundwater 2 (%)	82
Canopy storage (mm)	23
Surface storage (mm)	5
Max infiltration (mm/hr)	15
Imperviousness	22
Soil storage (mm)	124
Tension storage (mm)	25
Soil percolation (mm/hr)	31
Groundwater 1 storage (mm)	44
Groundwater 1 percolation (mm/hr)	0.05
Groundwater 1 coefficient (hr)	66
Groundwater 2 storage (mm)	201
Groundwater 2 percolation (mm/hr)	0.42
Groundwater 2 coefficient (hr)	30

Clark unit hydrograph was selected as transformation method where Time of Concentration and Storage Coefficient are the parameters to be defined in Clark unit hydrograph transformation. The storage coefficient is used in the linear reservoir that accounts for storage effects [24]. In this case, time of concentration and storage coefficient were selected as 3hr and 2hr respectively for the Clark unit hydrograph.

Recession base flow method was employed for both event based and continuous simulations. The recession constant was set to 0.76 and ratio to peak was set to 0.5 while the initial discharge was set to 0.05 m^3/s after simulating several trials. These base flow modeling parameters were used as calibration parameters.

2.2. Crop Water Requirements

CROPWAT 8.0 software developed based on the FAO guidelines, is used for calculation of Crop Water Requirements (CWR) and irrigation requirements from climatic and crop data. The program also allows the development of irrigation schedules for different management conditions and the calculation of scheme water supply for varying crop patterns[3, 20].

For the calculation of CWRs, CROPWAT needs data on evapotranspiration(ETo), rainfall, crop data and soil data. CROPWAT allows the user to either enter measured ETo values, or to input data on temperature, humidity, wind speed and sunshine, which allows CROPWAT to calculate ETo using the Penman- Monteith formulae[2, 3].

Rainfall data are used with CROPWAT to compute effective rainfall data as input for the CWR and scheduling calculations. Crop data are needed for the CWR calculations and soil data to calculate irrigation schedules. Whereas CROPWAT normally calculates CWR and schedules for 1 crop, it can also calculate a scheme supply, which is basically the combined CWR of multiple crops, each with its individual planting date[2, 3].

CWR was calculated assuming that 105 day low land paddy is cultivated. It was calculated using CROPWAT for paddy crop on monthly basis. Rainfall data at Nikaweratiya, Wariyapola and RidiBendiEla station in year 2000 to 2010, Mahailuppallama reference crop evapotranspiration rates and crop factors for

each growth stages were used for the CROPWAT model to calculate CWR. Hydro meteorological data are available at the Department of Meteorology [13]. Rainfall data were selected according to Thiessen polygon method. Computations of irrigation water requirements were made using 60% application efficiency and 75% conveyance efficiency. Land soaking and tiling requirement were also taken into account [18].

2.3. Water Evaluation and Planning Model(WEAP)

The WEAP model developed by the Stockholm Environment Institute (SEI)operates at a monthly step on the basic principle of water balance accounting. The WEAP model represents the system in terms of its various sources of supply (e.g. rivers, groundwater, and reservoirs), withdrawals, water demands, transmission, waste water treatments and ecosystem requirements [26].

The model comprises two distinct systems [25];

- Simulation of natural hydrological processes(e.g., evapotranspiration, runoff and infiltration) to enable assessment of the availability of water within a basin.

- Simulation of anthropogenic activities superimposed on the natural system to influence water resources and their allocation (i.e., consumptive and non-consumptive water demands) to unable evaluation of the impact of human water use.

WEAP is a practical tool for water resources planning and it can address a wide range of issues, e.g., sectoral demand analyses, water conservation, water rights and allocation priorities, groundwater and stream flow simulations, Reservoir operations, hydropower generation, pollution tracking, ecosystem requirements, vulnerability assessment, and project benefit-cost analyses [26].

All system information including irrigation demand, water releases data are input into the current accounts. The current accounts are the data set from which scenarios are built. Scenarios explore possible changes to the system in future years after the current account year. A default scenario, the 'Reference Scenario' carries forward the current accounts data into the entire project period and serves as

a point of comparison for other scenarios in which changes may be made to the system data.

WEAP consists of five main views which are called Schematic, Data, Results, Scenario Explorer and Notes. Schematic is spatial layout and this graphical interface used to describe and visualize the physical features of the water supply and demand system.

WEAP model was setup to Deduru Oya LB development area consisting of 136 rain-fed minor tanks. 150 demand sites, 189 transmission links, 106 diversions and 13 directly feeding demand sites were used in the model.

LB main canal and its branch canals were modeled by 'diversion links'. Waterways between paddy fields and minor tanks were modeled by 'transmission links'. Direct feeding

Figure 4- Schematic Diagram

2.4. Setting up of the WEAP Model

A WEAP project is used to investigate water balance in the LB canal irrigation area of Deduru Oya basin for the period from 2000 to 2010. The year 2000 was selected as the current accounts year or base year for this analysis. Using ArcView 9.2, digital data was analyzed and GIS vector file was prepared for LB canal. Vector file was added as a map layer in schematic view. LB development area was modeled by using required elements such as reservoirs, diversions, demand sites and transmission links. Figure 4 shows the part of the schematic diagram.

ways between LB canal and paddy fields were modeled by 'transmission links'. Diversion of water from LB canal to a tank or from tank to a tank is modeled by 'diversion link'. Different 'Supply preference' and 'Priorities' were used to model the diversion link and transmission links.

Demand sites along LB main canal are numbered as D1 to D57. Demand sites along branch canal 1 are numbered as D1_1 to D1_11. Likewise all the demand sites were numbered. If there are two demand sites up and down it was numbered as D1_up and D1_down. When there is a cascade with number of tanks it was numbered as D3_4a, D3_4b. Demand site which are locate left side of LB canal name as OFC.

Areas name as OFC are located in higher elevation than LB canal. Therefore water diversion to OFC from LB canal under the gravity is not possible. Proposed irrigable area under LB main canal was named as 'D expansion' and irrigable area is 600 ha. Figure 5 shows above numbering system.

Water balance and reservoir operations are embedded in WEAP model, was carried out in monthly basis for each for individual basic for each tank by considering reservoir capacities, monthly inflows and irrigation demand. Withmonthly inflow to all the tanks, each irrigable area was modeled as a demand site. For each demand site 'Annual activity level', 'Annual water use rate', 'Monthly variation' and 'Consumption' are required. Annual activity level is area cultivated annually under a particular tank. Annual water use rate is amount of water used for a unit irrigable area. Monthly variation is monthly share of annual demand. Annual water use rate and monthly variation are calculated from CROPWAT results model. Percentage of inflow consumed is the consumption.
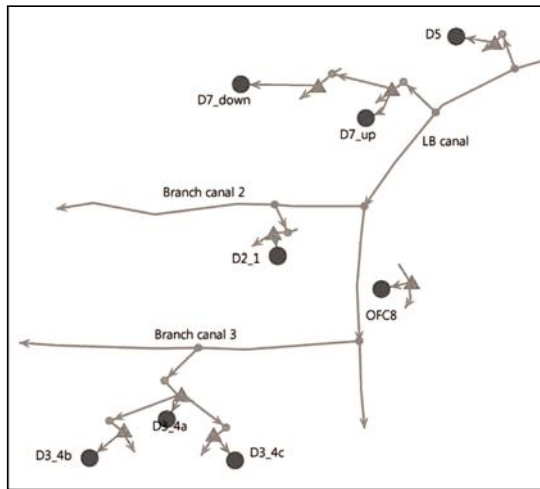
Figure 5- Demand Site Numbering System

3. Results and Discussions
3.1. HEC-HMS Application

HEC-HMS model calibration and validation for Tittawella tank using observed data of selected peak events during Oct-Nov 1995 and Oct 96 and also using observed data of the continuous period of Sept-Nov 95 and Sept-Nov 96 are shown in Figures 6 to 9 respectively. Figure 8 and Figure 9 depict graphical comparisons of the calibration and validation results respectively for continuous simulation. The study used the computed skill metrics of simulated stream flow against observation as a criterion to calibrate model parameters. Table 4 shows that the skill of simulations of calibrated model NOF, R^2_{NS} and $\delta_{b,}$agree reasonably well against observed discharges during both calibration and validation periods in event based and continuous simulation.

Table 4- Computed Skill Metrics for Event Based and Continuous Simulation

	Period	NOF	R^2_{NS}	$\delta_{b,}$
Event based simulation	Oct-Nov 95	0.20	0.95	0.20
	Oct-96	0.26	0.86	1.64
	May-95	0.28	0.92	12.0
Continuous simulation	Sept-Nov 95	0.83	0.85	3.00
	Sept–Nov 96	0.77	0.84	18.0
	Sept 95-Aug 96	1.69	0.73	33.0
	May 95-Mar 97	1.60	0.72	20.0

Calibrated HEC-HMS model applied to generate daily inflows of respective sub catchment of 136 minor tanks in LB development area. Figure 11 shows the calculated monthly inflow values for Mellapoththa tank. Mellapoththa tank is the very first tank which is proposed to augment with the use of LB canal. Monthly basis Gross Water Requirement (GWR) and respective rainfall are shown in Figure 10.
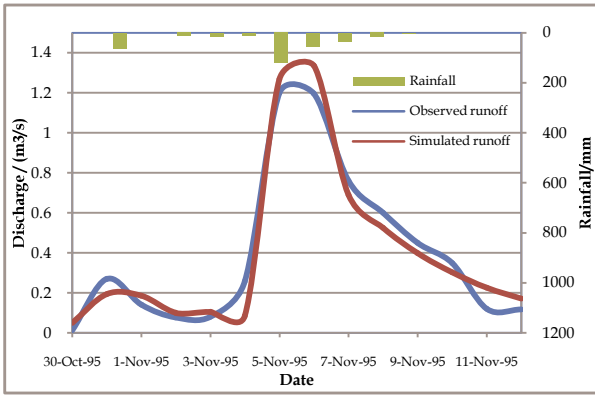
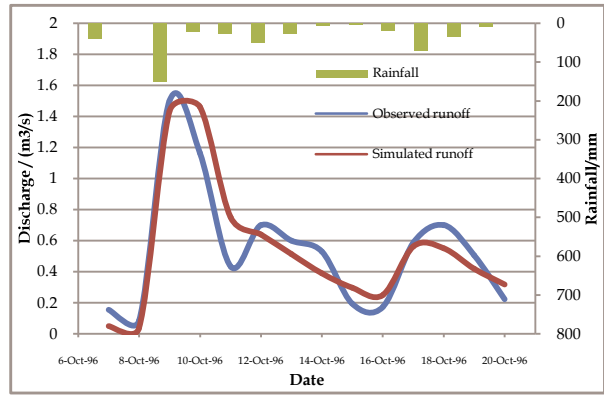**Figure 6 - Calibration of Event Based Simulation**
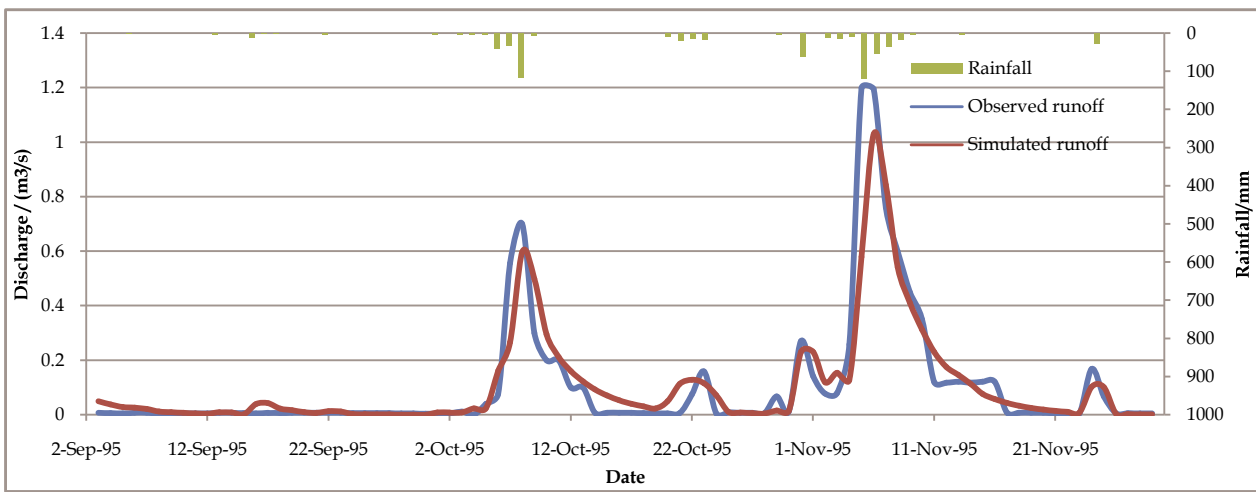

Figure 7- Validation of Event Based Simulation

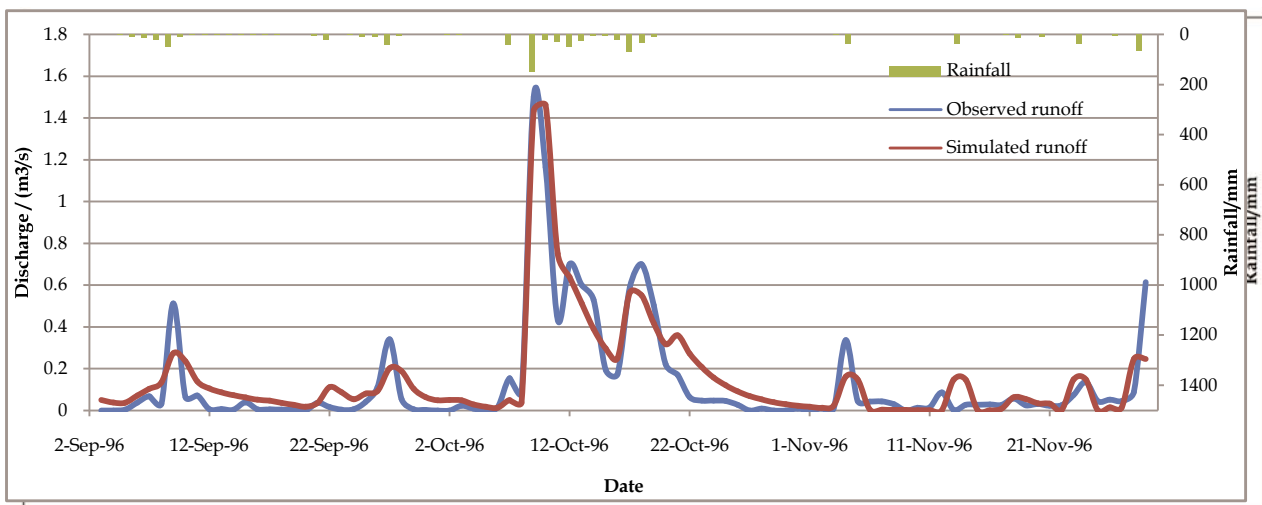**Figure 8 - Calibration of Continuous Simulation**
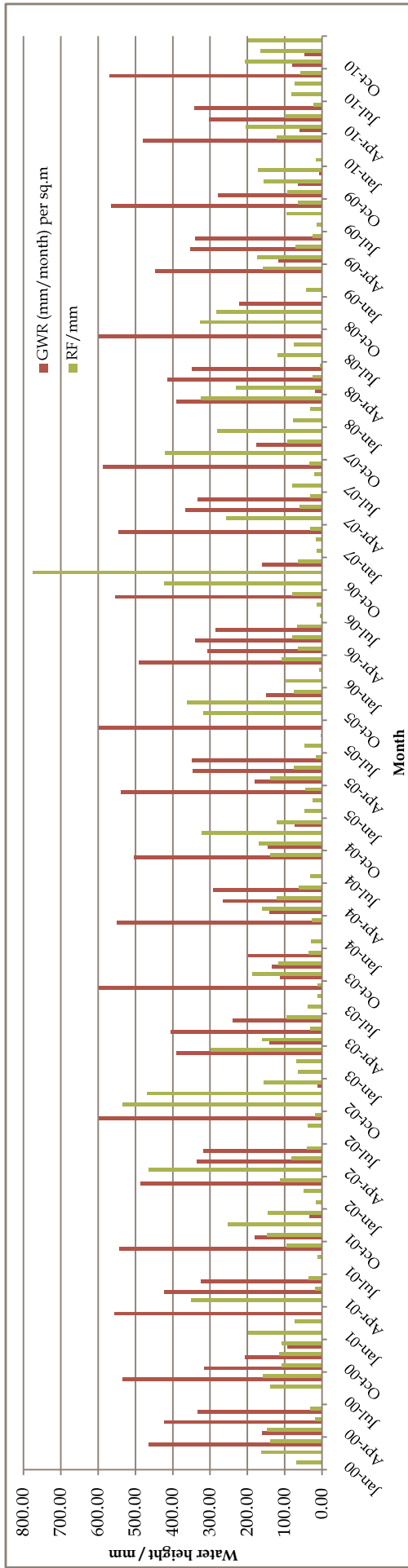

Figure 9 - Validation of Continuous Simulation

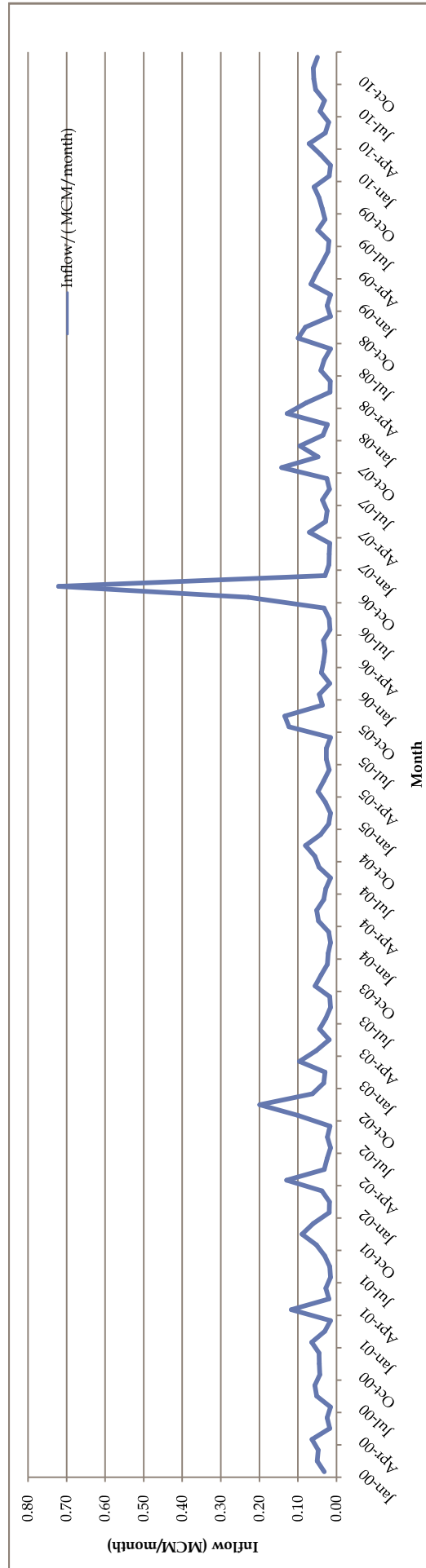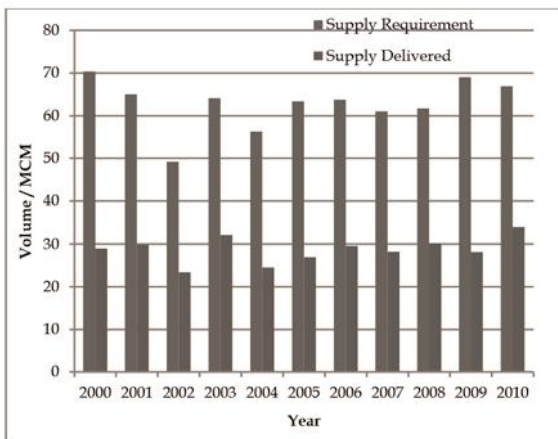**Figure 10 - Monthly Irrigation Water Requirement and Rainfall for Mellapoththa Tank**

Figure 11 - Monthly Inflows to Mellapoththa Tank

3.2. WEAP Model Results

With detailed irrigation demands analyses in LB region, total water requirement and unmet demand in LB have been investigated. Proposed LB canal development area is 3000ha including 2400ha existing irrigable areas. CROPWAT and WEAP simulation results for 10 years on monthly basis from 2000 to 2010 for 100% cropping intensity under existing tank based irrigation provides the monthly irrigation requirement and monthly unmet demands. Unmet demand is water deficiency. Figure 12 shows the variation of total annual water requirement (supply requirement) and total annual available volumes from existing irrigation systems (supply delivered) during 2000-2010 for the LB development area. This results are based on analysis under 'Without proposed reservoir' scenario.

Figure 12 -Comparison of Supply Requirement and Supply Delivered in LB Area

According to Figure 12 there are unmet demands in all the years and Figure 14 shows the annual unmet demand during 2000-2010 periods distributed to demand sites.

Annual unmet demand from 2000 -2010 varies 26 MCM to 41 MCM for 100% cropping intensity in the proposed 3000 ha irrigable area under LB canal development (Figure 14). When annual values of requirements and delivered are compared it is revealed that supply is less than the requirement in all years from year 2000 to 2010 (Figure 12). Accordingly it is not possible to achieve 100% cropping intensity under present condition.

2009 is the one of driest year during the period from 2000 to 2010 resulting an unmet demand of 41MCM. Monthly unmet demands

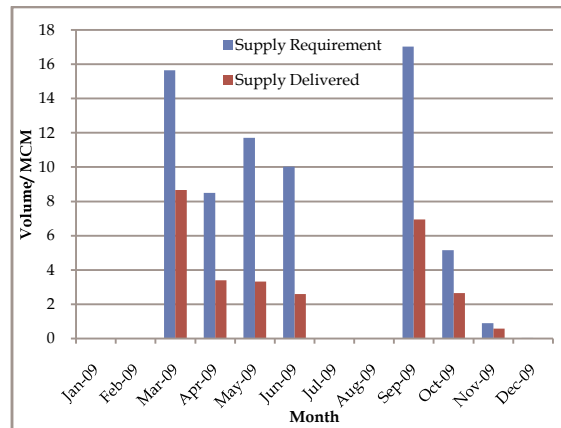distributed to demand sites for year 2009 are shown in Figure 15.

Figure 13- Comparison of Supply Requirement and Supply Delivered in 2009

The difference between irrigation requirement and delivered for 100% cropping intensity in Figure 13 needs to be supplied by the LB canal for year 2009.

When the LB development area is taken as 2600ha without proposed extension of 600ha of irrigable area it is revealed that separate runs of WEAP application annual unmet demand varies from 15 MCM to 28 MCM in the period of 2000 – 2010. This shows that water scarcity even at present condition and the importance of LB diversion.

The present study uses only 10 years for investigating water diversion demand from 2000 to 2010 due to changing climate conditions and to demonstrate the model capability. If we have long term forecast rainfall data, the model with the calibrated parameters can be used for long-term projections of LB diversion demand of the Deduru Oya reservoir project. The model predictions will be useful for water management and to plan water resources development in the Deduru Oya reservoir project.
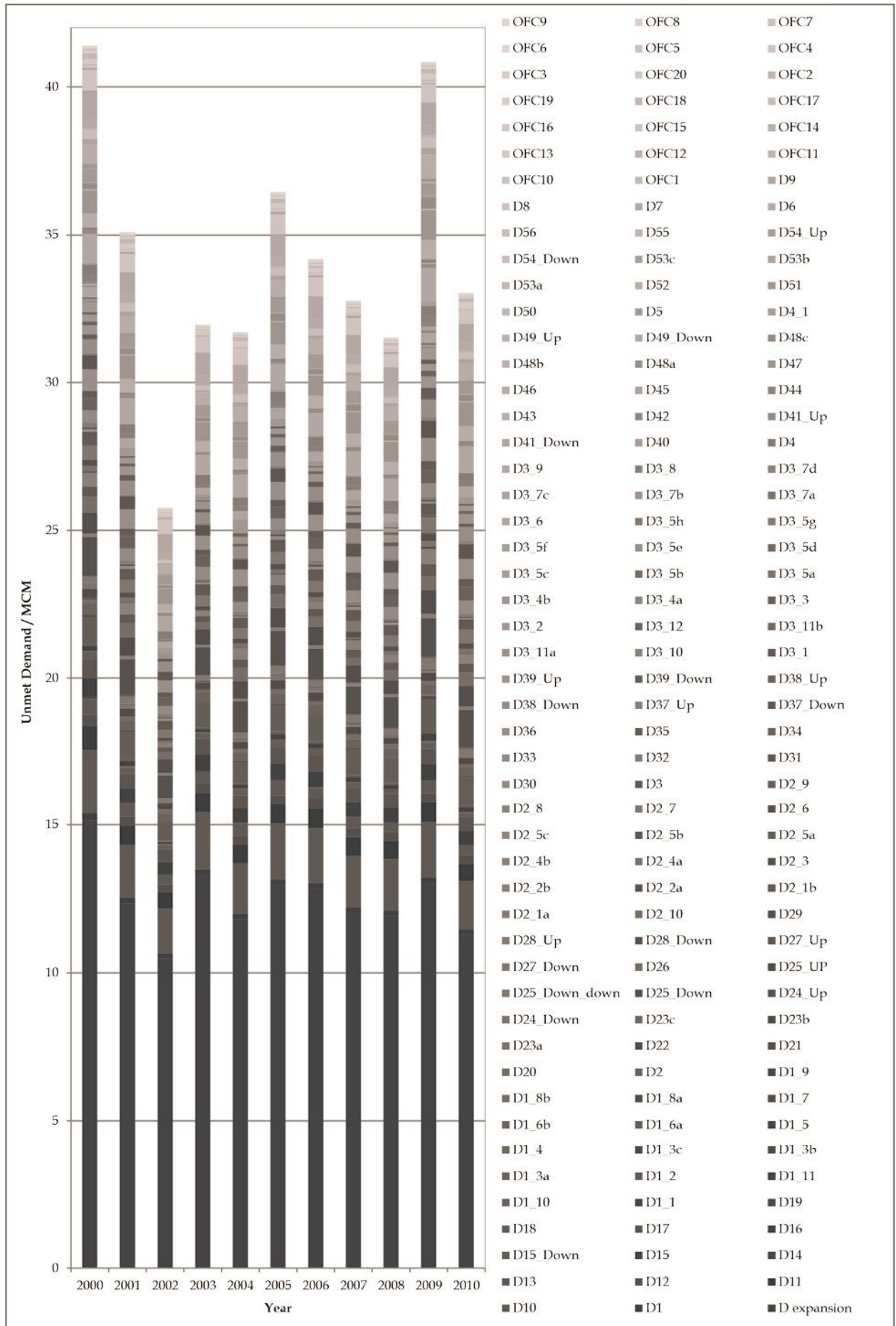
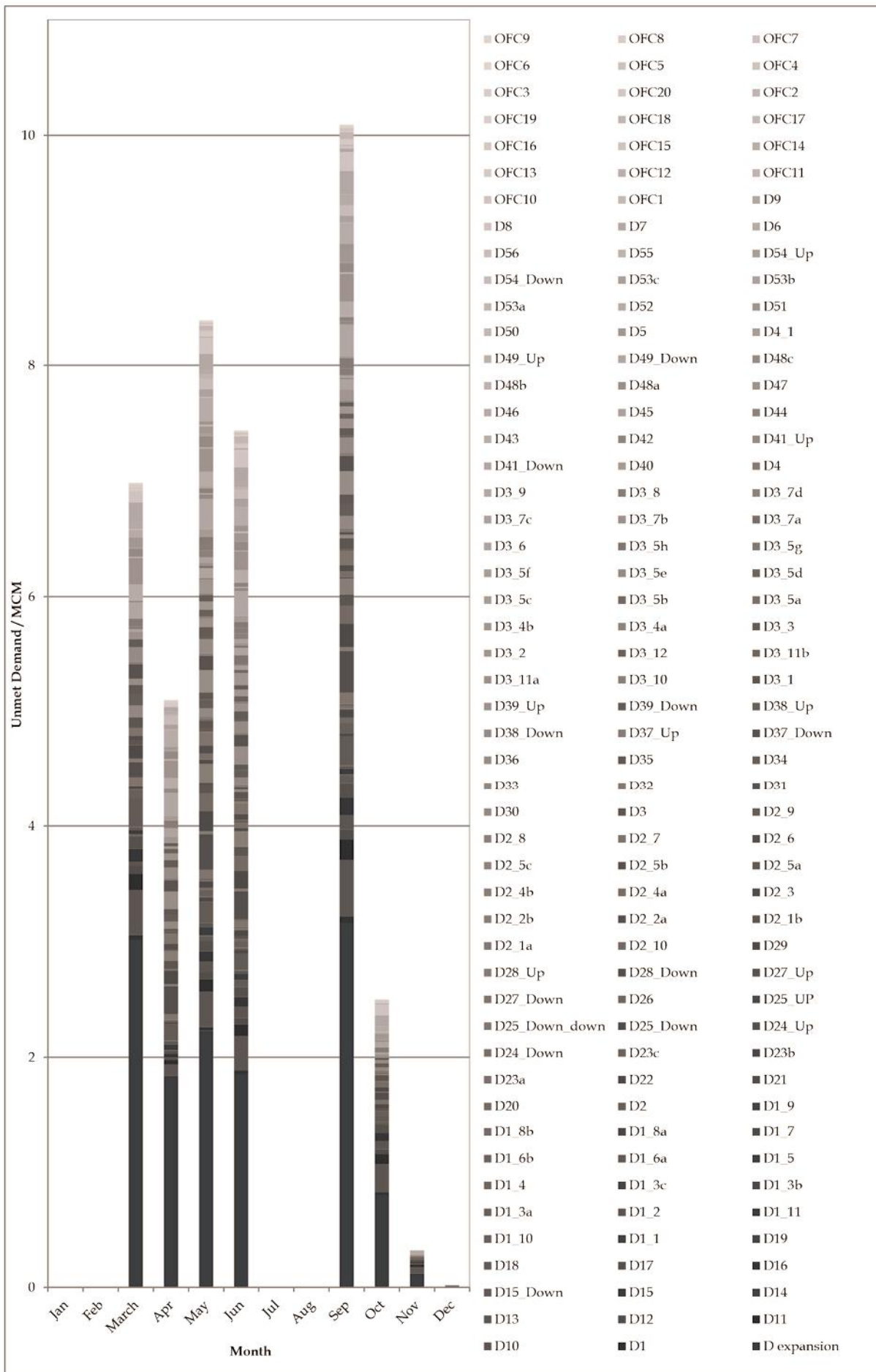**Figure 14 - Unmet Demand from 2000 to 2010**

Figure 15 - Monthly Unmet Demands in Year 2009

4. Conclusions

- The annual water requirement from LB canal of the Deduru Oya reservoir to achieve 100% cropping intensity in the LB canal development area varies from 26 MCM to 41 MCM during 2000 to 2010 period when the existing tank based irrigation systems are operational.

- Model is useful to estimate the releases from small tanks and required releases from the LB canal into the tanks in order to supplement irrigation demands for different cultivation patterns in the command areas of the respective tanks.

- Model which is built using HEC-HMS, CROPWAT and WEAP is a useful tool to plan water resources development and irrigation water management under changing climate in the LB development area of the Deduru Oya Project.

Acknowledgements

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