River Basin Modelling for Optimum Water Usage: Uma Oya Downstream Development Area

K.P.S.T. Pathirana, R.M.A. De S. Thanapathy and K.D.W. Nandalal

Abstract: Water is a basic need of all living beings and the management of water in an optimum manner has therefore now received worldwide attention. This optimum management of water is achieved through the construction of reservoir systems and their optimal operation. This paper presents a simulation study carried out using Water Evaluation and Planning System (WEAP) software at the proposed Uma Oya Downstream Development Project in the Kirindi Oya basin in Sri Lanka. To investigate the impact of the proposed system, one model was developed for the existing system and another for the proposed system. Crop water requirements and irrigation schedules for three climatic conditions were determined using CROPWAT software. Climatic conditions were those of the years which received rainfalls with 20%, 50% and 80% probability of exceedance representing wet, normal and dry years respectively. Daily rainfall, runoff and other meteorological data were the information collected for the study. Availability of water for the irrigation of existing and newly proposed areas was ascertained from the model. Optimal operation patterns were developed for the newly built Alikota Ara and Kuda Oya reservoirs and the enlarged Handapanagala reservoir for different climatic conditions. Results indicated that even when the system is operating in accordance with optimum operating rules, there can be supply deficits. A study was made on the system performance with reduced irrigable areas and different crop types which were observed to bring in reduced deficits.

Keywords: Reservoir system simulation, Crop water estimation, Reservoir operating rules

1. Introduction

The availability of land and water resources is vital for the agriculture of any country. Water being a scarce resource and a commodity that will have an exponential demand with the growth of the population, it is important to use this resource in the most effective and efficient manner. To achieve this objective, the Government of Sri Lanka planned and implemented a major multi-purpose water resources development project to divert water from Uma Oya to Kirindi Oya, generating hydro-energy at the same time. Water that is diverted will be available for irrigation in the Kirindi Oya basin located in the South-East Dry Zone of the country. This project named “Uma Oya Downstream Development Project” includes the construction of two new reservoirs, raising an existing dam and the construction of a network of irrigation canals for improving the irrigation facilities in the area.

The project envisaged, is a very complex one and the planning and management of such a project demands the use of systems analysis techniques. The systems analysis techniques available for such tasks could be broadly categorised into two types: optimization methods and simulations. Although optimization techniques can provide the best solution, they will need many simplifications, which may affect the real situation. In contrast, simulation models though not guaranteeing the best solution may represent the actual situation and will thus be acceptable to many. It has to be noted that simulation addresses “what and if” questions, while optimization addresses “what should be” type of questions [1].

Simulation is a process of mimicking the dynamic behaviour of systems over time [2]. The simulation models adopted in reservoir operation and management are generally based on reservoir continuity or mass equation, and represent the hydrological behaviour of the systems considering inflows and other operating conditions [3]. It has been observed that optimization techniques have high efficiency when coupled with simulation modelling and that they offer better results in handling reservoir management problems.

Miss. K.P.S.T. Pathirana, Student Member of IESL, B.Sc.Eng.(Hons), Lanka Hydraulic Institute, Katubedda, Moratuwa. Email:kpsachi.25@yahoo.com

Miss. R.M.A. De S. Thanapathy, Student Member of IESL, B.Sc.Eng.(Hons), Ceglex Engineering (Pvt) Ltd, Colombo 02. Email:mriu.e3250@ gmail.com

Eng. (Prof.) K.D.W. Nandalal, Int.P.Eng (Sl). C.Eng., FIE(Sri Lanka), B.Sc.Eng.(Hons), MEng(AIT), Ph.D. (The Netherlands), Senior Professor, Department of Civil Engineering, University of Peradeniya. Email:kdwu@psu.ac.lk
However, the results obtained through these optimization-simulation models may not be practicable due to social and other issues. The simulation models allow a more detailed and faithful representation of a real world system performance than the optimization models [3]. Therefore in this study, a simulation model has been used.

Water Evaluation and Planning System (WEAP) software has been used in this study. It has a large number of applications. In order to reduce the stress on water, the Jordan valley has been modeled for different climatic conditions using WEAP software. The impact of changes on cropping patterns has also been studied [4]. WEAP software has been used to evaluate and analyse the existing water balance and expected future water resource management scenarios by considering different operating policies on the efficient management of desalination of sea water and inter-basin transfers [5]. The usefulness of WEAP for integrated water resource management in the Gaza strip which has a semi-arid Mediterranean climate has also been studied. In that area, the main water resource for domestic, industrial and agricultural use is groundwater supplemented by water imported from Israel and storm water that has been collected [6].

CROPWAT is an irrigation management and planning software, which facilitates the estimation of crop evapotranspiration, irrigation scheduling and agricultural water requirements with different cropping patterns for irrigation planning. The use of the CROPWAT model to calculate crop water requirement has been investigated by many [7]. The CROPWAT model has been used to simulate various options for water supply and irrigation management and to study yield losses under irrigated and rain fed conditions [8].

In this study, WEAP software was used for modelling the Uma Oya Downstream Development Project while CROPWAT programme was used for the estimation of crop water requirements and different irrigation schedules. The objective of the study was confined to demonstrating the use of the above two models at the planning stage of a water resources development project and it has to be stressed here that this study was not a feasibility study of any project whatsoever.

2. Study Area

2.1 Uma Oya Multipurpose Development Project

The Uma Oya Multi-Purpose Development Project, which is presently under construction, intends to divert about 145×10^6 m^3/yr from the Uma Oya basin in the wet zone to the Kirindi Oya basin in the dry zone, generating electrical energy during the process. Two reservoirs built on the two main tributaries of the Uma Oya, viz., Dalgolla Oya and Mahathotilla Oya at Puhulpolo and Dyraaba respectively, are supposed to store and divert water through a series of tunnels to an underground hydro-power plant built at Randeniya which would finally release water to Alikota Ara, a tributary of the Kirindi Oya.

It is proposed to use water reaching Kirindi Oya to enhance agricultural activities in the basin and to supply water to meet industrial and drinking water requirements, through a development project called “Uma Oya Downstream Development Project.”

2.2 Uma Oya Downstream Development Project

Water transferred to Alikota Ara after generating hydro-power will finally reach Kirindi Oya. There are presently a few structures within the area that have to be developed, viz., Handapanagala reservoir, Handapanagala anicut and Ussella anicut to provide irrigation water to the ongoing irrigation activities in the area. The proposed plan is to enlarge the existing Handapanagala reservoir and to build two new reservoirs on Alikota Ara and Kuda Oya along with a canal system to enhance the water supply to the existing irrigation areas and also to proposed new irrigation areas. The stream network of the Kirindi Oya and the locations where reservoirs are to be constructed are shown in Figure 1. It also shows two locations where the stream flows are gauged by the Irrigation Department.
feeding new irrigable areas. Water stored in the Kuda Oya reservoir will be available for cultivations along the Kuda Oya right bank main canal coming under the Ussella anicut scheme located downstream of the Kuda Oya reservoir on Kuda Oya. Alikota Ara also would release water to Kirindi Oya which will be picked up at the Handapanagala anicut and stored in the Handapanagala reservoir. The left bank and right bank main canals of the Handapanagala reservoir which would have a capacity 16.5×10^6 m^3 will feed many of the existing and new irrigation areas directly as well as through the existing minor irrigation tanks in the area. Water spilling over the Handapanagala anicut and the Ussella anicut and the drainage water from the irrigation areas will flow into Lunugamvehera reservoir through Kirindi Oya. This additional water reaching the Lunugamvehera reservoir will be available for the development activities in Hambantota.

3. Methodology

3.1 Data Collection

The WEAP software based system simulation model requires monthly stream flow data, existing and proposed irrigation areas and irrigation demands and the characteristics of the existing and proposed reservoirs while the CROPWAT programme needs rainfall, minimum and maximum temperatures, relative humidity, sunshine hours and wind velocity at daily time steps.

Kirindi Oya flow data at Wellawaya and Thanamalwila gauging stations and Kuda Oya flow data at the Kuda Oya gauging station were collected from the Department of Irrigation. There are three main rainfall gauging stations located within the study area. They are at Handapanagala, Thanamalwila and Wellawaya. Thanamalwila gauging station from among the three was selected to collect rainfall data for the study which were obtained from the Department of Meteorology. Climatic data which were needed for the CROPWAT programme were obtained from the data recorded at the Agunakolapalassa weather station, the weather station closest to the study area, through the Natural Resources Management Centre of the Department of Agriculture. The station is within the same climatic zone as the study area.
The Uma Oya diversions reaching Alikota Ara were obtained from the Technical Pre-feasibility Study of FARAB [9] while the details of the reservoirs and irrigation areas were obtained from a report on the Uma Oya Multi-purpose Development Project of the Irrigation Department [10]. The details of the soil were obtained from the soil map of the country.

Based on the available data, a period of 15 years spanning from 2000 to 2014 was selected as the period of analysis. As Uma Oya diversions were available only up to 2008, the latest 8-year flow values available were repeated for the period from 2008 to 2014.

3.2 CROPWAT Programme

The CROPWAT (Ver 8.0) computer programme has been developed by FAO for the calculation of crop requirements and irrigation requirements based on the type of soil, climate and crop data. The CROPWAT program allows the development of irrigation schedules for different management conditions and the calculation of the scheme water supply for varying crop patterns.

Crop water requirements were calculated for four different rainfall scenarios. They were years with rainfalls of 20%, 50% and 80% probability of exceedance, representing a wet year, normal year and dry year respectively.

Irrigation requirements were calculated for the Yala season (mid-March – early May) and Maha season (mid-Sept/ Oct – late Jan/Feb) for the above four cases. Thereafter, cropping calendars were shifted forward and backward by two weeks for all the above four cases and crop water requirements estimated. Different crops have different water demands. In the study, replacement of paddy with chilli in a part of the irrigable area was studied to estimate the irrigation water requirements of paddy and chilli.

3.3 WEAP Software

Water Evaluation and Planning System (WEAP) software is a tool used for integrated water resources planning in the allocation of limited water resources among agricultural, municipal and environmental users by integrating supply, demand, water quality and ecological considerations. WEAP software was used to model the proposed Uma Oya Downstream Development System to investigate different management scenarios with the aim of using water optimally. In this study, both the existing system and the proposed system were modelled.

4. Analysis and Results

4.1 Four Rainfall Scenarios

The three rainfall scenarios were determined based on the effective rainfall over the area. Effective rainfall is used to account for losses due to surface runoff and deep percolation. After studying the three methods: (i)Fixed percentage of rainfall, (ii) Dependable rain (empirical form), and (iii) USDA soil conservation method, it was decided to use the third method for the estimation of the effective rainfall as it resulted in a rainfall close to 75% of the total rainfall which is acceptable both practically and according to the literature.

Thereafter using the selected method, the annual effective rainfall was calculated for each year and ranked in the descending order. A wet year has a rainfall with a 20% probability of exceedance. Similarly, a dry year and a normal year were also selected.

Based on the data available for the period 2000-2015, the following years with the annual rainfalls indicated, were found to have different scenarios:

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Year</th>
<th>Rainfall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Wet year</td>
<td>2000</td>
<td>1428mm</td>
</tr>
<tr>
<td>Dry year</td>
<td>2002</td>
<td>1245 mm</td>
</tr>
<tr>
<td>Normal year</td>
<td>2006</td>
<td>1329mm</td>
</tr>
</tbody>
</table>

4.2 Crop Water Requirements

Crop water requirements were calculated for each season of the three years. Table 1 presents the irrigation water requirements per season for different planting dates estimated using the CROPWAT programme. The water requirements are for the whole season.

Considering the above observations and the practical difficulties faced, crop calendars given in Table 2 were selected as being most beneficial for the study.

4.3 WEAP Based Simulation

Two WEAP software based simulation models were created: (i) model for the water resources
system existing at present, and (ii) model for the proposed water resources system.

### Table 1 - Irrigation water requirements in mm

<table>
<thead>
<tr>
<th>Planting Date</th>
<th>Wet year</th>
<th>Dry year</th>
<th>Normal year</th>
</tr>
</thead>
<tbody>
<tr>
<td>01 August</td>
<td>538</td>
<td>692</td>
<td>543</td>
</tr>
<tr>
<td>15 August</td>
<td>434</td>
<td>---</td>
<td>481</td>
</tr>
<tr>
<td>01 September</td>
<td>439</td>
<td>570</td>
<td>412</td>
</tr>
<tr>
<td>15 September</td>
<td>411</td>
<td>549</td>
<td>361</td>
</tr>
<tr>
<td>01 October</td>
<td>451</td>
<td>547</td>
<td>266</td>
</tr>
<tr>
<td>15 October</td>
<td>---</td>
<td>520</td>
<td>---</td>
</tr>
<tr>
<td>01 November</td>
<td>---</td>
<td>483</td>
<td>---</td>
</tr>
</tbody>
</table>

### Table 2 - Selected crop calendars

<table>
<thead>
<tr>
<th>Yala</th>
<th>Wet year</th>
<th>01 February to 16 May</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry year</td>
<td>15 May to 27 August</td>
<td></td>
</tr>
<tr>
<td>Normal year</td>
<td>01 February to 16 May</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Maha</th>
<th>Wet year</th>
<th>15 August to 27 December</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dry year</td>
<td>01 November to 13 January</td>
<td></td>
</tr>
<tr>
<td>Normal year</td>
<td>15 August to 27 December</td>
<td></td>
</tr>
</tbody>
</table>

### Model for the Exiting System

This model comprises of the present Handapanagala reservoir, Handapanagala anicut, Ussella anicut, a network of canals and the existing irrigation areas. The present irrigation area is 1403 ha in total. The model uses only water available within the basin. This model will result in business as usual and the results will be used to compare and evaluate the improvements in the proposed system.

Stream flow records available at the Kuda Oya and the Kirindi Oya gauging stations shown in Figure 1 were transferred to the required locations using catchment area ratios. This was possible since hydro-meteorological conditions did not vary much within the study area. The present Handapanagala reservoir has a live storage capacity of $12.0 \times 10^6$ m$^3$.

### Model for the Proposed System

The proposed water resources system is shown in Figure 2. The Handapanagala reservoir is enlarged to have a storage capacity of $16.5 \times 10^6$ m$^3$. The Alikota Ara reservoir with a capacity of $6.5 \times 10^6$ m$^3$ and the Kuda Oya reservoir with a capacity of $33.4 \times 10^6$ m$^3$ are added to the system.

The proposed system is expected to provide a reliable supply of water for the existing irrigation system. The system is also expected to irrigate an additional area. The details of the irrigation areas are given in Table 3.

### Table 3 - Existing and proposed irrigation areas

<table>
<thead>
<tr>
<th>Irrigation Areas</th>
<th>Area (ha)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Between Alikota Ara and Kuda Oya reservoir</td>
<td>637.9</td>
</tr>
<tr>
<td>Downstream of Kuda Oya reservoir</td>
<td>623.5</td>
</tr>
<tr>
<td>Kuda Oya Right Bank Main canal</td>
<td>663.0</td>
</tr>
<tr>
<td>Ussella anicut</td>
<td>110.2</td>
</tr>
<tr>
<td>Handapanagala anicut</td>
<td>15.1</td>
</tr>
<tr>
<td>Handapanagala Left Bank Main canal</td>
<td>124.9</td>
</tr>
<tr>
<td>TOTAL</td>
<td>888.1</td>
</tr>
</tbody>
</table>

### 4.4 Comparison of Unmet Demands when only Paddy is grown

#### Performance during a Wet Year

Figure 3 compares the unmet demands in the existing system and the proposed system during a wet year. The demands are for the total irrigation area inclusive of both existing and proposed areas.

![Unmet demands in the present system](image)

![Unmet demands in the proposed system](image)
Performance during a Dry Year

Similarly for the dry year, the unmet demands related to the model of the existing system with proposed areas and the model of the proposed system are shown in Figure 4.

![Figure 4 - Unmet demands in the dry year](image)

Figure 4 - Unmet demands in the dry year

Performance during a Normal Year

The unmet demands of the normal year are shown in Figure 5 for both the existing and the proposed system.

![Figure 5 - Unmet demands in the normal year](image)

Figure 5 - Unmet demands in the normal year

4.5 Reservoir Operating Rules

Based on a large number of system simulations done by varying the operating pattern, the most suitable operational policies for the three reservoirs were derived. These optimum operation patterns obtained for different climatic conditions, that is for a wet year, dry year and normal year, are presented in Figures 6 through 8.

![Figure 6 - AlikotaAra reservoir operating rules](image)

Figure 6 - AlikotaAra reservoir operating rules

4.6 Reducing the Proposed Irrigation Areas

For each dry year, wet year and normal year, unmet demands were found in Alikota Ara and Handapanagala areas. The reason is due to the large increase in the extent of the areas: an increase of 98% in Alikota Ara and 1275% in the Handapanagala left bank. Therefore, the proposed areas of Alikota Ara and Handapanagala were reduced by 30%, 40% and 50% and analysed.

![Figure 7 - KudaOya reservoir operating rules](image)

Figure 7 - KudaOya reservoir operating rules

4.7 Cultivating Chilli along with Paddy during One Season of the Year

The replacement of paddy with chilli was carried out in steps of 40% and 50% in the proposed areas in the Alikota Ara and Handapanagala since they showed the highest number of unmet demands. The results obtained are shown below.

![Figure 8 - Handapanagala reservoir operating rules](image)

Figure 8 - Handapanagala reservoir operating rules
These optimum operating rules did not meet the irrigation demands completely. The insufficiency of Uma Oya diversions towards Kirindi Oya during the months when water is mostly needed, is a major reason for this behaviour. Therefore, several other alternatives that could be adopted to reduce the number of unmet demands were investigated. The alternatives studied are:

i. reduction of the proposed irrigation areas,
ii. cultivation of chilli along with paddy during one season of the year, and
iii. raising the dam of the Handapanagala reservoir to increase the volume of water stored.

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4.8 Raising of the Handapanagala Reservoir Capacity

When irrigation areas are compared, it could be seen that the number of demands catered to by Handapanagala reservoir was increased by about 3 times as compared to the existing areas. Due to this reason, during the analysis of the proposed model, a storage volume of 16.5 MCM was found insufficient to cater to the full demand. Therefore, an analysis was carried out by increasing the Handapanagala reservoir capacity. Figure 15 gives the results when the Handapanagala reservoir capacity is increased to 18.5 MCM and 20.5 MCM in all three types of years.

The replacement of paddy with chilli in the wet and normal years decreased the number of unmet demands in the Alikota Ara area and not in Handapanagala, which highlights the fact that the diversion cannot cater to the proposed areas.

Finally, it can be concluded that WEAP software is quite suitable for analysing complex water resource systems at the initial stages of designing and also later during their management.

References


Figure 14 - Unmet demands when Chili is planted in a normal year

4.8

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Figure 15 - Unmet demands when the Handapanagala reservoir capacity is increased

5. Conclusions

Even after the addition of Alikota Ara and Kuda Oya reservoirs to the system and the enlargement of the Handapanagala reservoir, there were still unmet demands. Increasing the storage capacity of the Handapanagala reservoir resulted in an improvement in the system reliability.

When the extent of the irrigation areas in Alikota Ara was reduced, the number of unmet demands also got reduced, indicating that the amount of diverted water was sufficient to cater to a part of the proposed areas. However, a reduction in the extent of the Handapanagala irrigation areas did not result in any significant reduction in the number of unmet demands which indicates that the amount of diverted water was not sufficient to cater to the proposed areas at all. This may be due to the increase in the irrigation areas in Handapanagala by more than 1000% whereas the tank capacity of Handapanagala has been increased only by 9.33 MCM to cater to the above mentioned large increase in the extent of the areas.

The replacement of paddy with chilli in the wet and normal years decreased the number of unmet demands in the Alikota Ara area and not in Handapanagala, which highlights the fact that the diversion cannot cater to the proposed areas.

Finally, it can be concluded that WEAP software is quite suitable for analysing complex water resource systems at the initial stages of designing and also later during their management.

References


Geotechnical Engineering Properties of Peat, stabilized with a Combination of Fly Ash and Well Graded Sand

S.Venuja, S. Mathiluxsan and M.C.M. Nasvi

Abstract:
Peat has several unfavourable characteristics such as low bearing capacity, high compressibility, high content of natural water and difficulty of access and thus is not suitable for Civil Engineering constructions. One of the widely used techniques for its improvement is its chemical stabilization through the addition of chemical admixtures such as ordinary Portland cement, lime, fly ash, natural fillers etc. This research was focused on stabilizing peat using low Ca fly ash (ASTM Class F) combined with well graded sand. An experimentally based approach was followed to analyse the stabilization of peat samples with different proportions of fly ash (10, 20 and 30 % by weight) and 125 kg/m³ of well graded sand. With the increase in the fly ash content, the Maximum Dry Density (MDD) increased while the Optimum Moisture Content (OMC) decreased. The Unconfined Compressive Strength (UCS) increased with the addition of fly ash up to 10 % by weight and thereafter it began to reduce as more and more fly ash was added. The UCS increase with curing period for all of the stabilized samples. Rowe cell test results showed that there was an improvement in the compressibility of peat after stabilization. On the whole, it was found that the geotechnical engineering properties of peat can be improved by stabilizing it using fly ash and well graded sand.

Keywords: Chemical stabilization, Fly ash, Peat, Rowe cell, Unconfined compressive strength

1. Introduction
Peat is an accumulation of partially decomposed and disintegrated plant remains under conditions of incomplete aeration and high water content. Peatlands cover nearly 400 million ha of earth in the world and in Sri Lanka alone there are 25000 ha of peat lands [1]. It has unfavourable characteristics such as low bearing capacity, low specific gravity, medium to low permeability, high compressibility, high content of natural water, high water holding capacity, high rates of creep and difficult accessibility [2, 3]. Based on its fibre content peat is classified mainly into two categories: fibrous peat and amorphous peat. Fibrous peat is dark brown or black in colour and has quite larger particles. Amorphous peat has smaller organic grains. It has a lower void ratio, a lower permeability and a lower compressibility than fibrous peat. When fibre content is higher than 20 %, it is known as fibrous peat and vice versa for amorphous peat [4]. In the Von Post scale system, peat is classified based on its degree of humification, water content, fibre content and botanical composition with a range extending from H1 to H10. H1 is completely fibrous peat and H10 is completely amorphous peat [5]. Engineers face many problems when they use peat lands for their construction work. The major problems are instability, slip failure, localized sinking and long term settlement [3, 5, 6]. There is a need for more land area for construction because of the increase in population. Therefore, it is necessary to improve peat lands so that they can be used for construction. There are two main common types of improvement techniques used in the stabilization of peat: - (i) mechanical method, and (ii) chemical method. The mechanical method of stabilization includes displacement and replacement, stage construction, pre-loading, stone columns, piles, vertical drains and lightweight fill [3, 5, 6]. In the chemical method, deep in-situ mixing and surface stabilization are used by adding chemical admixtures such as sand, cement, fly ash, gypsum, bentonite, sodium chloride etc., to peat [1, 7]. Generally, lime and cement are used in deep mixing. Dry Mixing Method (DMM), Dry Jet Mixing (DJM) and Wet Mixing Method (WMM) are the different types of deep mixing methods used [5].

This research focused on using chemical stabilization for improving peat using a combination of fly ash and well graded sand as stabilizers. There are many studies [1 - 12] that have focused on the stabilization behaviour of peat. The sections below summarize the findings of those previous studies.

Miss. S.Venuja
B.Sc. Eng. (Hons) (Peradeniya), Department of Civil Engineering, University of Peradeniya. Email: venusarma92@gmail.com

Mr. S.Mathiluxsan
B.Sc. Eng. (Hons) (Peradeniya), Department of Civil Engineering, University of Peradeniya. Email: smlunsan7@gmail.com

Eng. (Dr.) M.C.M.Nasvi, AMIE (Sri Lanka), B.Sc. Eng. (Hons) (Peradeniya), Ph.D. (Monash), Senior Lecturer of Civil Engineering, Department of Civil Engineering, University of Peradeniya. Email: nasvimcm@pdn.ac.lk