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Abstract: This paper focuses specifically on the irrigation field and water supply tanks for ways to improve efficiency of water use and increase the resilience to climatic variability. The purpose of this paper is to develop an excel-based water balance model that will allow the maximum cropping area be planted in the upcoming agricultural season. The model consists of three modules: a crop water requirement calculator that allows the water requirements of specific crops to be compared, a water tank balance model, and a model which simulates the storage in the permanent wetland attached to the irrigation tank. The hydrological computation has been used with either daily rainfall data or predictions on water of availability for the upcoming agricultural season.

Climate change is predicted to further increase irrigation water requirements on the East Coast of Sri Lanka. Modelling shows a reduction of 26-45% in the area available to be cultivated due to increased irrigation water requirements and reductions in water availability. A number of scenarios have been investigated that increase the resilience of Sri Lankan farmers to climatic variations. Crop diversification decreases water requirements as crops other than rice don't require the maintenance of standing water. This significantly reduces the loss of water through seepage and percolation. Modelling shows that by substituting half the rice cultivated with maize, cropping area can be increased by 50%. Starting the irrigation season early proved the most successful measure and allowed cropping area to be increased by approximately 100% while having the irrigation tank and permanent wetland at 97% and 74% full respectively at the end of the first cultivation season.

Keywords: irrigation water requirement; water balance model; irrigation tank; climate change

1 Introduction

Climate change is predicted to significantly impact the East Coast of Sri Lanka by reducing rainfall totals and increasing irrigation water requirements (De Silva et al., 2007). While it is possible to quantify the possible impacts of these changes fairly simply across the region it is more difficult quantify the impacts on a local scale. Water balance models have been used since the 1940's for assessing the seasonal patterns of water supply and irrigation demand as well as catchment hydrology and the impacts of climate change (Xu & Singh, 1998).

While modelling software currently exists it is often too expensive and relatively inaccessible for the local Sri Lankan Agricultural Planning Authorities. Planning of the cultivation area is currently undertaken at a meeting prior to the commencement of the agricultural season with little scientific input. In isolated areas such as the East Coast of Sri Lanka only limited existing data is available due to the recently concluded civil war. Across Sri Lanka an estimated 7500 small irrigation tanks currently support cultivation (Panabokke, 2002). The study site (Kathiraveli Village) on the east coast of Sri Lanka contains a permanent wetland (Viloo), which is maintained by shallow groundwater and is seasonally fed by both a regional river and local catchment of 150 ha. The Viloo is connected to an irrigation tank which directly irrigates about 60 ha of land. The difference in height between the Viloo and water storage tank prevents the Viloo from completely draining into the irrigation tank thus protecting the ecosystem within the Viloo.

The challenge for this paper is to develop a model that relies on available local data and existing regional data and physical principles. A balance between existing regional data and local field data is reached to allow the simulation and planning for the upcoming agricultural season. The model has been developed within excel to ensure that it can be made easily accessible and simple to use and refine. The accessibility and simplicity of the model is advantageous in that it reduces the amount of data required to be input into the model to operate it. As well it allows the model to be modified by any user competent in excel. However the outcome of the result of the relative simplicity of the model is that it is not able to be used to investigate more complicated issues such as irrigation scheduling. The development and analysis of the system even before calibrating the model over an irrigation season will reduce the uncertainty around the computational processes and allow preliminary recommendations to be discussed.

The water balance model is used to assess the potential impacts of climate change. Possible mitigation strategies are also investigated such as crop diversification, changes to season starting times and irrigation infrastructure upgrades.

2 Water Balance Model

The water balance model has been designed to reflect the natural system at Kathiraveli Village (Figure 1). The three modules of the system are all connected through culverts and include the Viloo, the Irrigation Tank and the Irrigation Field. The Viloo and Irrigation Tank both contain inflows from direct rainfall and a seepage outflow that is relative to the volume and water height within the tank. The hydrological computation is then incorporated into the Viloo to simulate runoff generated in the local catchment. It has been developed using equations revised by Jayatilaka et al.(2001) and model parameters from Sakthivadivel et al. (1996). The Viloo also includes a volumetric inflow at the start of the irrigation season and occurs during a river flood event. It is input as a measurement of the depth of water within the Viloo, the model then calculates the volume of water within the Viloo based on storage height relationships. Evapotranspiration is determined by FAO derived single coefficient equation (Allen et al., 1998).

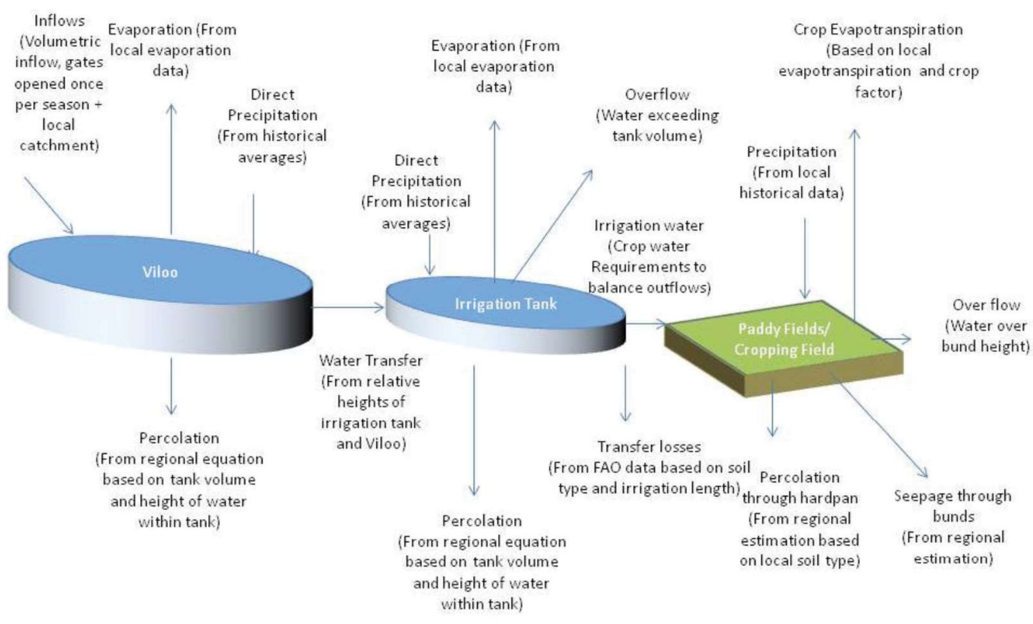

Figure 1. Water balance model layout.

The Irrigation Tank has an overflow component that occurs when water within the tank exceeds the height of the flood weir. Transfer of water between the two tanks is determined by the relative heights of water within the Irrigation Tank and Viloo. The irrigation field allows the simulation of water requirement for three different non-rice crops and a rice crop. Irrigation efficiency can also be adjusted for each crop independently as well as the seepage rates.

3 Baseline Scenario

The baseline scenario is considered the conservative estimate of actual conditions at Kathiraveli in any given Yala Season (minor cropping season). Seepage and percolation from a tank is proportional to its storage. An average value of 0.5% is found for the Irrigation Tank while 0.3% for the Viloo due to shallow water table (Matsuno et al., 2003). For the hydrological model estimates of standard expected parameters for Sri Lankan context have been used (runoff coefficient = 0.25) (Sakthivadivel et al., 1996). The local catchment area has been estimated as 150 ha.

For the irrigation field initial water requirements is estimated as 50 mm however as this largely supplied by seasonal rains is a conservative estimate (Department of Agriculture, 2006). Transfer losses are estimated as 30% of total irrigation water (Brouwer et al., 1989). This is reflective of the local soil type. Crop factors developed specifically for Sri Lanka have been used (Manchnayake & Bandara, 1999). Seepage in the paddy fields has been derived through studies of simular soil types as 8 mm/day.

3.1 Results

To simulate irrigation season the above parameters were input into the model. All parameters were kept constant while the maximum cropping area was adjusted to find the maximum possible cropping area that could be irrigated while ensuring that the irrigation tank didn't become dry. The maximum cropping area that could be irrigated over the Maha Season (major cropping season) was 29.9 ha. Increasing the cultivation area above this, results in the irrigation tank running dry.

3.2 Water Balance

Figure 2 below shows changes in water storage over the simulation period within the Viloo. A slow decline of the total water storage is observed. The outflows to the irrigation tank have the largest influence on the water balance. Evaporation has the second largest influence. Precipitation, seepage and inflow from the local catchment are the next three smaller contributions; this is a clear indication of why the steady decline in the Viloo storage occurs.

Figures 3-5 show the different components of inflow and outflow to the Irrigation Tank, Cropping Field and Viloo, respectively. Initially the inflow from the Viloo maintain the total volume within the Irrigation Tank to around 500,000 m^3, however after the first month the amount of water needed to change the relative height within the Irrigation Tank begins to reduce. Therefore the amount of water transferred from the Viloo begins to reduce as the transfer of water becomes restricted by the storage capacity within the tank that is below the current height of the Viloo.

By comparing rainfall and evapotranspiration data over time the irrigation scheduling starts after the peak in rainfall occurs. With no further inflows from the river and increasing irrigation water requirements over the irrigation period it seems unlikely that any water will be able to be stored for irrigation in the Yala Season; no matter other parameters are input into the model. As it is not possible to irrigate the entire cultivation area (60 ha) there is no water left to irrigate during the Yala Season. The irrigation water requirements slowly increase as the evapotranspiration increases. Figure 3. Irrigation Tank inflows and outflows.

Figure 4 below shows that the largest component of the irrigation requirement of rice is due to seepage. Evapotranspiration however is also a significant factor as effective precipitation is considerably less. Therefore seepage rates within the paddy field are critically important in determining the water balance as it has the most significant influence on the water balance within the Irrigation Tank. The most significant factor within the Viloo as shown in Figure 5 is outflows to the Irrigation Tank that are required to irrigate the land.

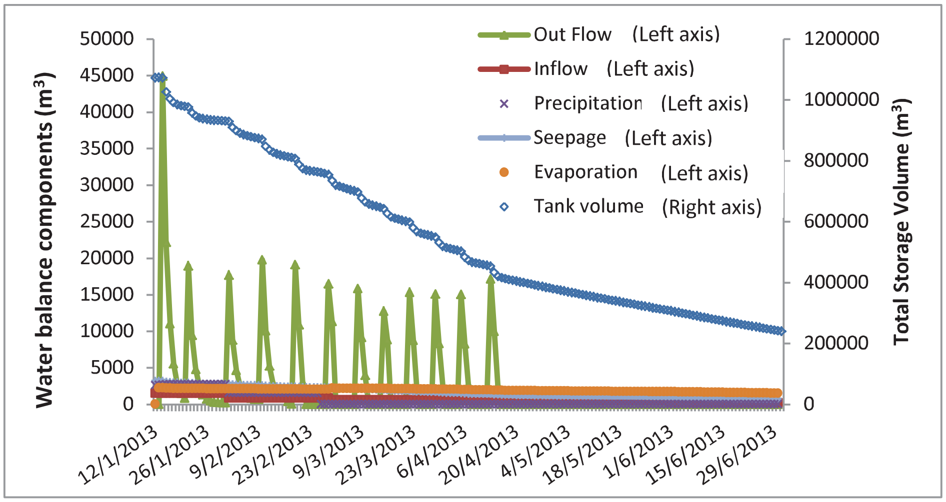

Figure 2. Baseline simulation water balance components within the Viloo.

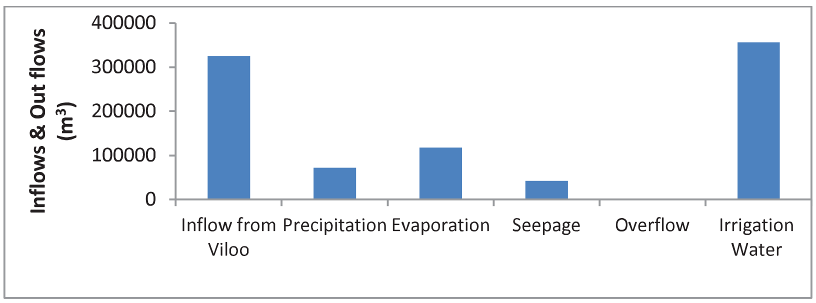

Figure 3. Irrigation Tank inflows and outflows.

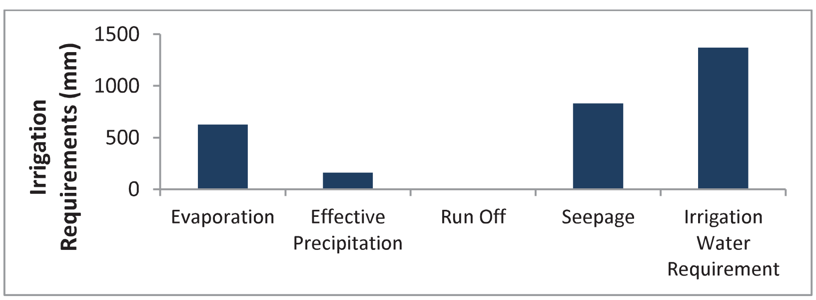

Figure 4. Paddy field inflows and outflows.

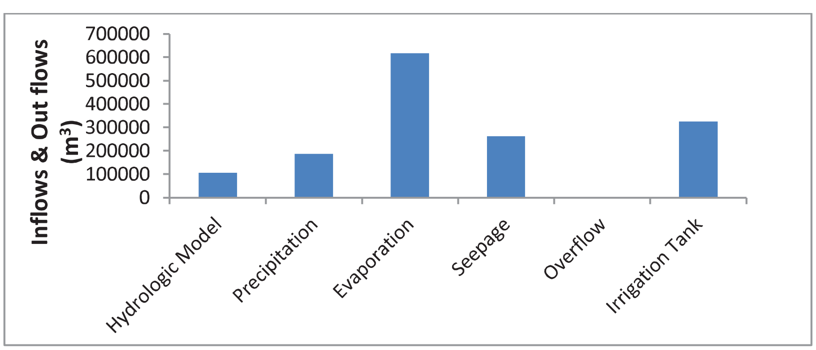

Figure 5. Viloo inflows and outflows.

4 Uncertainty Analysis

4.1 Rainfall

To investigate the impacts of the highly variable rainfall that Kathiraveli receives the daily time series from a number of different years will be used and impacts to changes in cultivation period recorded. The years tested are included in Table 1 below.

Table 1. Summary of rainfall tested and outcomes

Year	Annual Rainfall (mm)	Maximum Cultivation Area (ha)	Observations
1995	1086	26.6	Significant January rains mean that even though yearly total is low the area available to be cultivated is only slightly less than the baseline scenario
1996	1403	18.8	Caused by slight decrease in effective precipitation which is significant when spread over entire cropping area. Not significant rainfall during cultivation season
2003	1461	30.8	February Rains result in significant inflows from local catchment and direct on tank rainfall
1989	1490	36.3	A number of Rainfall events throughout the season contribute to inflows and also reduce the crop water requirements
1984	2299	70.0	Consistently high rain reduces need to irrigate throughout the season so area available to be irrigated is greater than available farming area

4.2 Paddy Field Seepage

Seepage values are based on estimates of seepage from simular soil types. The impacts of halving and doubling the seepage rates are examined to provide an estimate of the model to their sensitivity. A change in the seepage rate within the paddy field has considerable impacts to the total cultivation area. As shown in Figure 6, halving of the seepage rate resulted in an increase in the possible irrigation area by almost 16%. Doubling the seepage rate reduced the area able to be irrigated by over 14%. Therefore it can be concluded that the seepage rate of the paddy fields is an important parameter to be considered with assessing water requirements for the system.

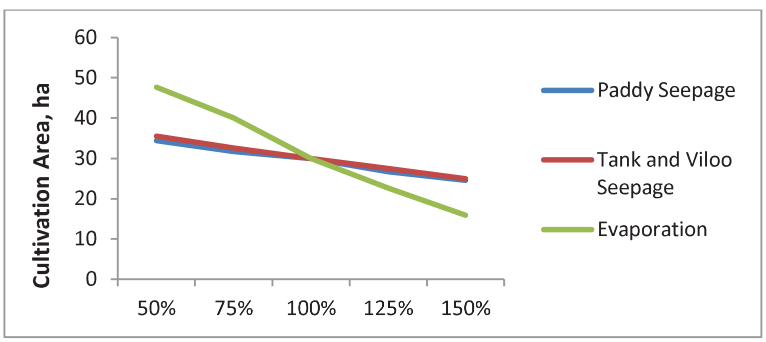

Figure 6. Sensitivity analysis, changes in maximum cultivation area resultant from key changes in model parameters.

4.3 Tank and Viloo Seepage

Seepage rates are taken as estimates from a typical irrigation tank within Sri Lanka with a slight adjustment made to the Viloo as it is very large and also has a shallow water table. Seepage rates from the Irrigation Tank and Viloo both are able to significantly influence the amount of area that is able to be cultivated. If using the percentage of volume method, seepage rates are significantly lower than the relative height method. Doubling the seepage loss rate of 0.5% per day for the Irrigation Tank and 0.3% for the Viloo significantly reduces water available for cultivation as large amounts of water are lost to the subsurface.

Despite physical conditions (presence of a shallow water table) appearing to more closely match the seepage rates calculated using the relative height method, using the relative height method significantly over estimates seepage as no area is able to be irrigated and tanks empty within 90 days.

4.4 Evapotranspiration

Changes in evapotransration results in water losses in all modules of the model. The only available evapotranspiration data is from 1985 and reported as monthly average of a reference crop. It therefore may be possible that changes have occurred to the data since that time. Out of all the tested variables relative changes to evapotranspiration make the largest changes to maximum cultivation area as shown in Figure 6. This highlights that updated and accurate evapotranspiration data is be the most important to be accurate.

5 Model Predictions

After understanding the limitations of the developed model it has been used to understand the impacts over a number of different future impacts and possible changes to management strategies. It focuses on water use during the wet season. This is unless water is carefully managed throughout the Maha Season no water will be available for irrigation during the dry season. All modelling within the following sub-sections uses the parameters stated within the baseline scenario unless specified.

5.1 Impacts of Climate Change

To test the impacts of climate change, evapotranspiration and rainfall rates were adjusted according to predictions by De Silva et al. (2007). If predictions for climate change are accurate irrigation in Kathiraveli will become considerably more stressed. If a business as usual case was followed by farmers cultivation areas would be decreased between 22% and 46% as shown in Table 2. This amounts in significant loss and livelihoods and also loss of food and possible starvation. It therefore is important that future irrigation planning looks to reduce current susceptibility to water storages.

Table 2. Predicted impacts of climate change by 2050 on the East Coast of Sri Lanka (De Silva et al., 2007) and its impacts on cultivation area predicted by the water balance model.

Scenario	Rainfall	Evapotranspiration	Reduction in cultivation area
A2	-16%	+45%	46%
B2	-12 %	+15%	22%

5.2 Changing Cropping Regimes

The impacts of cultivating different crops are investigated below. Non-rice crops don't require the maintenance of standing water and therefore require considerably less irrigation water. Four different cropping scenarios have been developed based on local research and are shown in Table 3.

Table 3. Cropping scenarios tested.

Crop	Cropping Scenario 1	Cropping Scenario 2	Cropping Scenario 3	Cropping Scenario 4
Maize		50%	30%	25%
Paddy	100%	50%	30%	
Big Onion			20%	25%
Soya Beans				25%
Peanuts/Ground nuts			20%	25%
Total cultivated area (ha)		46.5	65.3	75.6

5.3 Irrigation Efficiency

High rates of water are lost through poor farming practices and lack of resources to repair damaged infrastructure. A simple way to increase irrigation efficiency is to line irrigation channels. Lining irrigation channels can increase irrigation efficiency by up to 95% (Brouwer & Heibloem, 1986). Therefore the baseline scenario has been modified to increase its irrigation efficiency to 90% as a conservative estimate.

Increasing the irrigation efficiency by lining the channels would allow an extra 1.4 ha of land to be cultivated. Considering the sensitivity to changes in evaporation and seepage the impact of increasing irrigation efficiency is small for Kathiraveli Village.

5.4 Different Start of Cultivation Season

The baseline scenario was modified so that the irrigation season began on the 1st of November. To account for the earlier starting time of the season it was assumed that 25 mm of water was required to prepare the paddy field and a 150 mm delay was used for the hydrological model. Despite the increases in these water losses the area that could be irrigated was considerably increased from 28 ha to 50 ha. At the same time the water storage within the Irrigation Tank and Viloo would remain at 97% and 74% respectively. This indicates that with proper timing of the cultivation period can considerably increase the amount of produce to be grown.

6 Discussion

Modelling outcomes show that cropping area and therefore the productivity could be significantly increased by starting the cropping season earlier. In a typical year starting the irrigation period in November would leave enough water available to undertake a second crop in late February/early March. Incorporating these changes with crop diversification would further increase the potential agricultural yields by reducing the amount of water required. The difficulty is that rainfall in Kathiraveli is highly variable and it is difficult to predict future rainfall therefore by starting the season later as currently done the risk is reduced as the tank is already full at the beginning of the season. This could be overcome by undertaking multiple volumetric inflows. Once the water level within the river was high enough the Viloo could be opened and filled. A second inflow in January (as shown in Figure 7) would then maximise the amount of water available for cropping within the Yala Season.

If the predictions of climate change are realised significantly more water will be required to maintain current food production levels and therefore future work needs to go into increasing the water efficiency. There are two different methods that could be undertaken for minimal effort:

- Significant amounts of water are lost through evaporation for the water tanks. It is therefore recommended that methods to reduce evaporation be investigated, such measures could have multiple benefits include the revegetation of wind breaks to slow wind speeds and reduce evaporation. Wind breaks also would help to slow and filter water as it enters the irrigation tank.
- The second is beginning to diversify cropping area from rice. There are other crops that are equally profitable that can be partially substituted. Competitively allocating the cropping area to

different crops based on water requirements is shown in the results to be particularly successful in reducing water requirements whilst maximising total cropping area. Furthermore increasing the diversity of crops that are grown increases resilience to pests and diseases as one pest typically targets one type of crop and therefore cannot damage an entire field cultivated with different crops.

It is important to validate the performance of the model and test these findings as the inter-annual and intra-annual rainfall and thus conditions within the system are highly variable. Initial calibration to field data has however performed well.

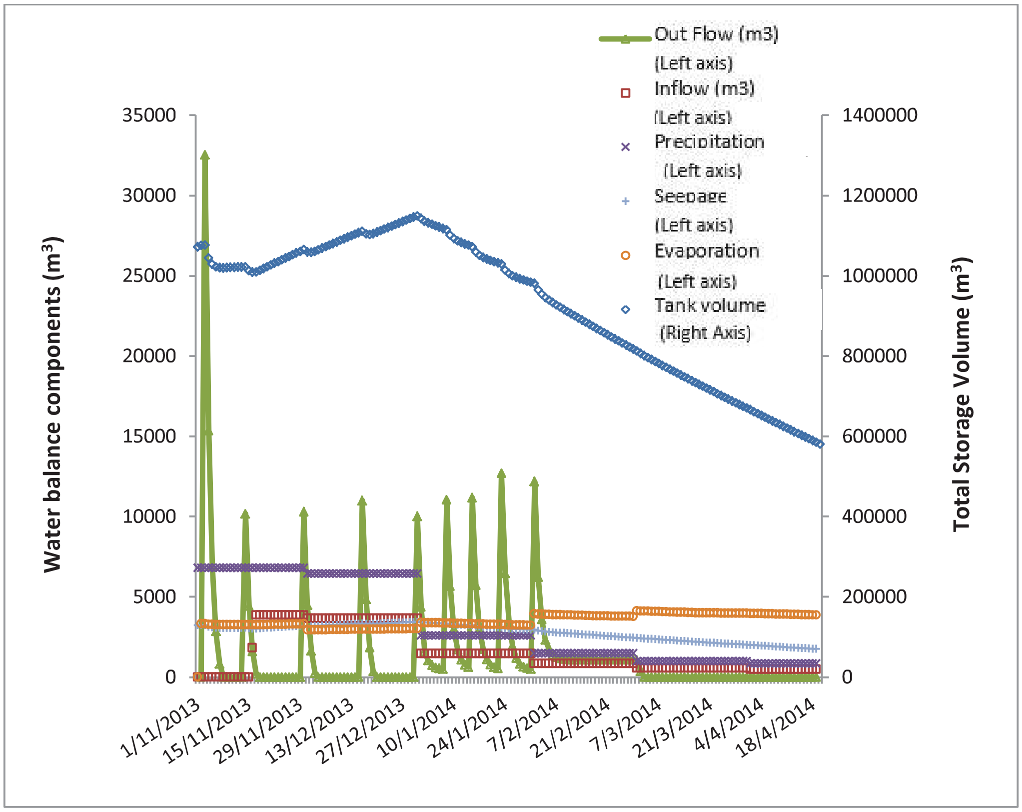

Figure 7. Water balance components within the Viloo with an earlier starting date.

7 Conclusion

This study builds on an investigation undertaken on how the developed water balance model was refined and further developed through the incorporation of a third module and improved estimations of input parameters. After important considerations such as the inter-annual and intra-annual rainfall variability and the history of irrigation within Sri Lanka the model was applied to a baseline scenario composed of best estimate of actual conditions. Uncertainty analysis highlighted that changes in all of seepage, evaporation and rainfall can have significant impacts to model predictions. Finally a number of scenarios were investigated. Predictions of climate change show significant reductions in the area available to be cultivated. Changes to the start of the irrigation period and efforts towards to crop diversification could significantly increase cropping area and allow for a second cultivation season during the Yala Season. More generally it is shown that achievable changes in the approach to irrigation, particularly in isolated rural communities can significantly increase cropping area and water productivity. Furthermore changes in established practices in crop selection or the start of cultivation season can be more effective than expensive engineering approaches such as channel lining.

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