Tropical Agricultural Research Vol. 20: 326 - 335 (2008)

Modelling the Influences of Unnichchai Irrigation Tank on the Batticaloa Lagoon

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ABSTRACT. *Discharge from irrigation tanks may have impacts on lagoon hydrological systems, and, consequently impact on the local ecology. This study presents a methodology to simulate the impacts of discharges from Unnichchai irrigation tank on the hydrological system of Batticaloa lagoon. A simulation model, UnTil v1.0 was developed using the icon based system modelling software platform Stella v7.0.3. Though three major and twenty minor irrigation tanks are connected to the Batticaloa lagoon, this model assumes and uses the discharges of only one major irrigation tank i.e. Unnichchai tank, to explain the effect of irrigation tank discharges on the hydrological system of the Batticaloa lagoon. The inputs to this model are monthly data of spill discharge and the issued water volumes from the Unnichchai tank, and the outputs generated are, rise in the water levels, drop in salinity levels, and excess water (related to lagoon spread and consequent flooding) in the lagoon system, and associated bar mouth condition/s. According to simulated outputs, rise in lagoon water levels by the influence of irrigation tank, was observed in yala cropping season coupled with considerable drops in salinity. Excess water, originating from the lagoon, is the cause for the flooding in surrounding area and it is also influenced by tank discharges in some years. The tank discharges influence the opening and/or closing period/s of Batticaloa lagoon's bar mouth. Finally, though the model presented in this paper is a simplified version of the system of concern, it can be used to warn flood hazards in the area.*

INTRODUCTION

Lagoons are coastal brackish water bodies and are in connection with the sea permanently or seasonally. Lagoons resemble the sea having more or less the same biological and chemical conditions. The organisms in the lagoon are highly adapted to the environmental conditions of the lagoon or to the adjacent sea. However, input of extra freshwater into the lagoons would render them unsuitable to existing aquatic species. One of the major impacts of irrigation water is the rising of water levels in the lagoons. It makes feeding sites unavailable for many water birds and reduces the salinity level of the lagoons. It also converts rare brackish coastal water into freshwater sinks/reservoirs. All these have a

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profound impact on the associated biota in the lagoon (Smakhtin and Priyankarage, 2003). Further, since the lagoons traverse through settlement areas, rises in the water level pave the way for flooding and associated socio-economic impacts. These types of effects are a common annual feature in mismanaged systems of the Batticaloa lagoon, situated in eastern Sri Lanka.

Batticaloa Lagoon is the third largest lagoon in Sri Lanka and takes an area of 115 km^2, which is 56 km in length (Shanmugaratnam, 1995) and has an average depth of 4.8 m (Arulananthan, 2004). Since this lagoon communicates with the sea through two bar mouths known as Palameenmadu bar mouth and Koddaikallar bar mouth, this lagoon could be classified as a choked lagoon (Kjerfve, 1986). Both bar mouths of the Batticaloa lagoon are opened by human interventions in most instances contradicting the natural rhythmic patterns governing the opening/closing of the bar mouths. The Palameenmadu bar mouth is cut open by Road Development Authority when the water level rises under the Kallady Bridge by 0.838 m Mean Sea Level (Sivapalasundaram, 2005). However, the bar mouth at Koddaikallar does not show the normal rhythmic behaviour *i.e.* opening during wet season and closing during dry season for several years. This is attributed to adulteration of the system by human intervention. Because of the rich biological and ecological diversity present in this lagoon, it is an important socio-economic supporting mechanism for the people living in its peripheries. Further, in the southern parts of the lagoon where salinity is zero, the lagoon water is also used for irrigation.

Catchments of this lagoon include (seasonal) rivers, major and minor irrigation tanks and runoff from the adjacent land mass. Eight seasonal rivers drain into the lagoon. All such rivers make catchments area of 1593 km^2 for Batticaloa lagoon (Sivapalasundaram, 2005). About 20 minor irrigation tanks are located along the lagoon and have connection/s with the lagoon. Apart from this, three major irrigation tanks drain into the lagoon (Navakiri tank drains into southern part of the lagoon, while Unnichchai tank and Rugam tank drain into northern part of the lagoon). However, the inputs from all these tanks are seasonal (only during the wet season). Along with other freshwater inputs, discharges from these irrigation tanks have profound impacts on the lagoon system. The inputs of freshwater have several impacts on Batticaloa lagoon such as rise of lagoon water level, subsequent flooding, erosion of the lagoon's banks in some areas, dropping of lagoon salinity nearly to zero, adulterating ground-water recharge in its lagoon peripheries, disturbing the life cycle of some lagoon organisms and de-synchronizing/ adulterating the bar mouth mechanism.

The present study investigated the impacts on the Batticaloa lagoon by freshwater inputs from the irrigation tanks through a system modelling approach. This approach has been adopted since an in-depth field study of the problem of concern is not practically feasible, unless undertaken for at least a decade in a multi-faceted mode. Further, since acquiring the data for all the 3 major and 20 minor irrigation tanks is difficult, the modelling approach simplifies the system as one irrigation tank connected to the lagoon. Thus, the water discharge data of Unnichchai Tank and its connectivity to the Batticaloa lagoon was considered.

Unnichchai tank, which is an irrigation tank, is situated about 12 km away from the Batticaloa lagoon and was constructed by throwing an embankment across the Mahilavedduvan river and is located in the Unnichchai village in Manmunai west DS division in the Batticaloa district. It supplies irrigation water during the *maha* season for paddy cultivation but in the *yala* season the water that exceeds its water holding capacity is spilled out. The water holding capacity of the tank is 41,500 Ac.ft[4]. The issued water and spilled water are ultimately discharged into the north portion of the Batticaloa lagoon.

The aim of this study is to analyse the impacts of irrigation tank discharge on Batticaloa lagoon using system modelling approach by considering the Unnichchai tank discharge.

METHODOLOGY

This paper, being contradictory to the standard field based investigation and reporting approach, presents a systems case study using environmental modelling as the tool of investigation. The data for this modelling exercise were collected from the year 2000 to 2006. Monthly data of issued water volume and spilled discharge of the Unnichchai tank were collected from Irrigation Department, Chenkalady, Batticaloa.

A conceptual model was developed (Figure 1), based on the general idea of a hydrological system. This is aimed for defining the hydrological framework of the lagoon system dynamics by the inputs of Unnichchai irrigation tank and direct rainfall. This model uses assumptions to make ease of modelling using a systems thinking approach, where the aim of the systems modeller is to present the most possible simplistic representation of the system that can depict its functionalities comprehensively (Hardisty *et al.,* 1993). Assumptions of this conceptual model are listed as follows.

1. Entire water released from Unnichchai tank reaches the Batticaloa lagoon.
2. Batticaloa lagoon is assumed as a (singular and closed) hydrological system - which contains only one catchment (*i.e.* Unnichchai tank) which is driven by direct rainfall as the primary inducing input.
3. Batticaloa lagoon is assumed to have only one bar mouth at *Palameenmadu*.
4. Mechanism of bar mouth is only influenced by natural functions without any human interventions.

From the conceptual model (Figure1), simulation model, UnTil 1.0 (Unnichchai Tank impacts on lagoon) (Figure 2) was developed using Stella v7.0.3 as the modelling platform. Stella (Structural Thinking Experimental Learning Laboratory with Animation) is widely used among the environmental scientists and/or system scientist communities to develop models for different scientific/research needs. This modelling approach offers a practical way to dynamically visualize and communicate how complex systems and ideas really work.

RESULTS AND DISCUSSION

From the simulation model **UnTil 1.0**, outputs were obtained for the period of 2000 to 2006 for the parameters such as rise of water level in the lagoon, water level of the lagoon, excess

[4] Acre-feet (*Ac. ft*) is the unit often used in irrigation engineering to express the volume of irrigation tanks. One acre-feet is equal to 1233.5 cubic meters.

water, salinity drop, flood chance and bar mouth conditions. Each parameter was plotted against months of each year.

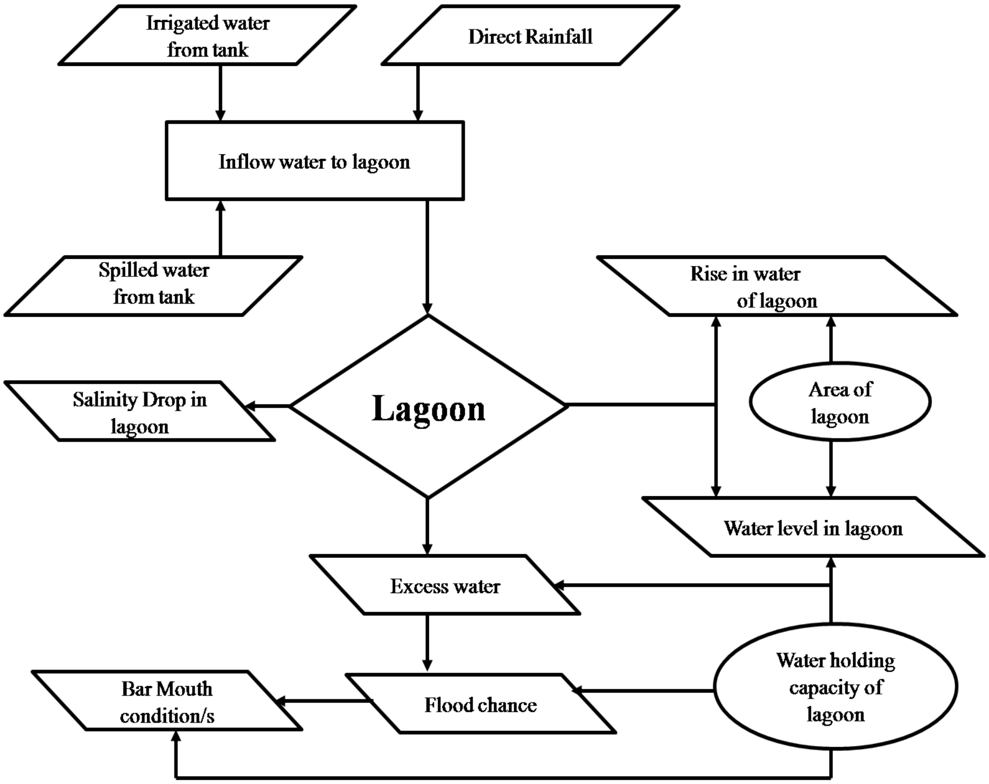

Figure 1. Conceptual model developed based on the general idea of a hydrological system

The output 1 (Figure 3) indicates the rise of water level in the lagoon only by the influence of the tank releases. According to the results obtained, the water level in the lagoon increased every year especially in the *yala* cropping season (April to September) to about 0.1 m. This is due to the release of water from the Unnichchai tank for cultivation purposes in the *yala* cropping period. This effect will be multiplied if all the tank discharges are taken into consideration. Further, in the year 2005, the water level increased by a high magnitude *i.e.* in 2005 by 0.9 m and in 2006 by about 0.28 m. This is due to the increased spill discharge from the Unnichchai tank. At the end of the year 2004, the Batticaloa district experienced heavy rainfall (after Tsunami devastation). Due to this, heavy discharge was recorded in this period.

Output 2 (Figure 4) indicates the salinity drop in the Batticaloa lagoon by the influence of the Unnichchai tank discharge. Salinity drop is the magnitude by which the salinity of the lagoon decreases. This is based on the Equation 1 (Stanzel *et al.,* 2002), where as the influx water volume increases in the lagoon, salinity decreases.

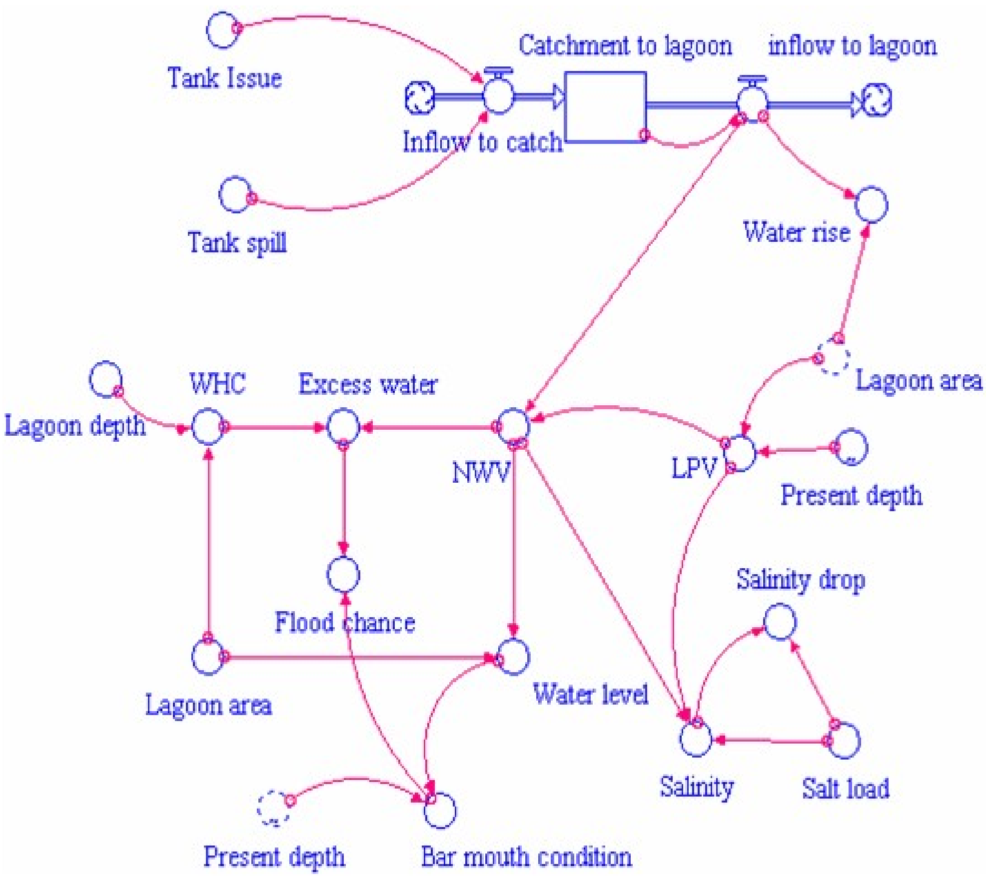

Figure 2. Simulation model UnTil 1.0, developed using Stella v7.0.3 (NWV-Net water volume; LPV- Lagoon present water volume; WHC-Water Holding Capacity of the lagoon)

$$C = \frac{L}{V} \qquad [1]$$

Where;

C- Concentration of salts in the lagoon
L- Load of salts in the lagoon
V- Volume of water in the lagoon

Hence, the final salinity is calculated in the model UnTil 1.0 using Equation 2.

$$Final\_Salinity = (Salt\_load*LPV)/NWV \qquad [2]$$

Where LPV - Existing volume of water
NWV - Net water volume in the lagoon

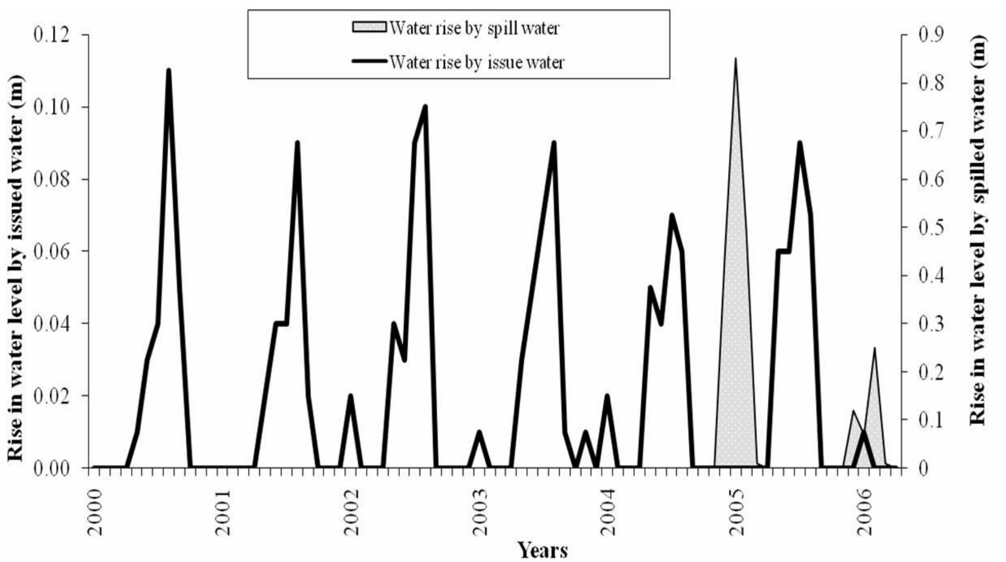

Figure 3. Variation of water level in Batticaloa lagoon for six years in relation to spilled and issued water from Unnichchai tank

Salinity drop is calculated by subtracting the final salinity level from the original lagoon salinity or salt load of the lagoon. According to this output, the drop in salinity, by the influence of Unnichchai tank water, is obvious during April to September (*yala* season). This trend is more or less same in all the years except in 2005 and 2006. Due to the heavy rainfall (at the end of the year 2004 and the beginning of the year 2005) in Batticaloa district, spill discharge was high from tanks and thus, it resulted in high magnitude of salinity drop in Batticaloa lagoon. This effect is multiplied when coupled with the discharges of other irrigation tanks. Salinity decreases in lagoon convert the whole lagoon or particular part/s of lagoon, into freshwater aquatic system/s, which then leads to devastation or to migration of biota from that particular locality. Only the organisms which have broad spectrum of salinity tolerance will survive while others which have narrow spectrum of salinity tolerance will migrate out of that area or die.

Output 3 (Figure 5) indicates the excess water in the Batticaloa lagoon due to the influence of Unnichchai tank discharge. The excess water means the volume of water that exceeds the water holding capacity of the lagoon. This is calculated in the model using the following formula.

$$\text{Excess water} = \text{NWV} - \text{WHC} \quad [3]$$

Where NWV-Net Water Volume
WHC-Water Holding Capacity of the Lagoon

Output 3 indicates that high volume of excess water is released in the beginning of the year 2005, and some excess volumes are produced in 2002, 2004 and 2006 only by the influence of Unnichchai tank discharge. However, this excess volume is increased when it is coupled with other tank discharges. This excess water is the cause for flooding in the surrounding areas, especially when the bar mouth is closed. The risk of flooding is high during the rainy season (North-East Monsoon period) and inundates several settlement areas, cropping lands and access roads, mainly of Batticaloa-Trincomalee main road. This type of seasonal flooding is observed frequently in the areas of Sathurukkondan, Eachantheevu, and Pankudaweli. The risk of flooding is associated, in addition to excess water, with other factors such as encroachment into the peripheral wetlands or modifying their drainage to lagoon and constructing the bridges across the lagoon with reduced flow of natural water. These factors will not allow the excess water in lagoon, during rainy season, to spread out to their peripheral wetlands and to other parts of the lagoon. Thus flash flooding is the result. Further, this flooding ultimately results the erosion of lagoon bank and this erosion can be observed in Pankudaweli, where 500 m (inland) x 1000 m (lagoon shoreline) area has already been eroded (Sivapalasundaram, 2005).

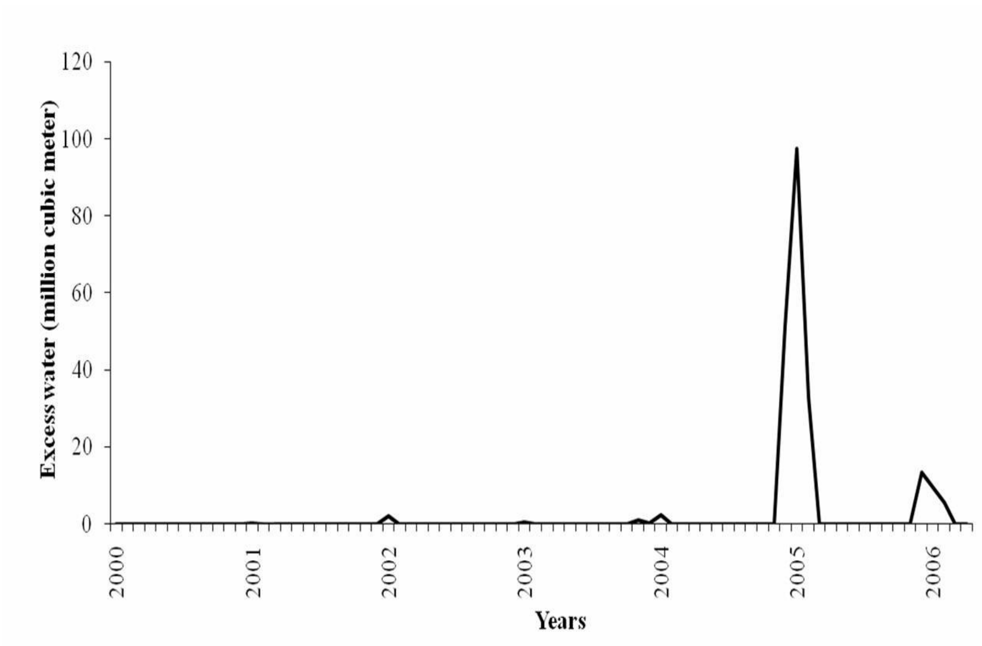

Figure 4. Salinity drop in the Batticaloa lagoon

Output 4 (Figure 6) compares the bar mouth condition at normal situation and when tank water discharges into the lagoon. Bar mouth of a lagoon usually has a rhythmic process *i.e.* closing in dry season and opening in the wet season of every year (Santharooban and Manobavan, 2006). The elapsed time between complete closing of bar mouth by the siltation and its opening is influenced by the input of water into the lagoon from various sources. Hence, the Unnichchai tank also influence the bar mouth mechanism. In this model, the bar mouth condition is determined by a logical function, which sets for the plotting purpose, to elicit a dummy non-zero constant (usually 1) for open mouth phase and zero for closed mouth phase (this method of bar mouth representation was adopted from Smakhtin, 2004).

The non- zero constant results when the water level exceeds some level, *i.e.* very closer to the lagoon depth, else the number remains zero. The number one indicates that the bar mouth is opened and the number zero indicates that the bar mouth is in closed position. According to Figure 6, this tank discharge changes the bar mouth opening and/or closing period. In the year 2001, it induced early opening, while in 2004 and 2005, it induced late closing. In year 2002, it changed both opening and closing periods. The elapsed time between opening and closing of bar mouth in all years will further be increased when other tank discharges are also taken into consideration. This malfunction of bar mouth mechanism may have impacts on biota of the lagoon and groundwater recharging to adjacent areas.

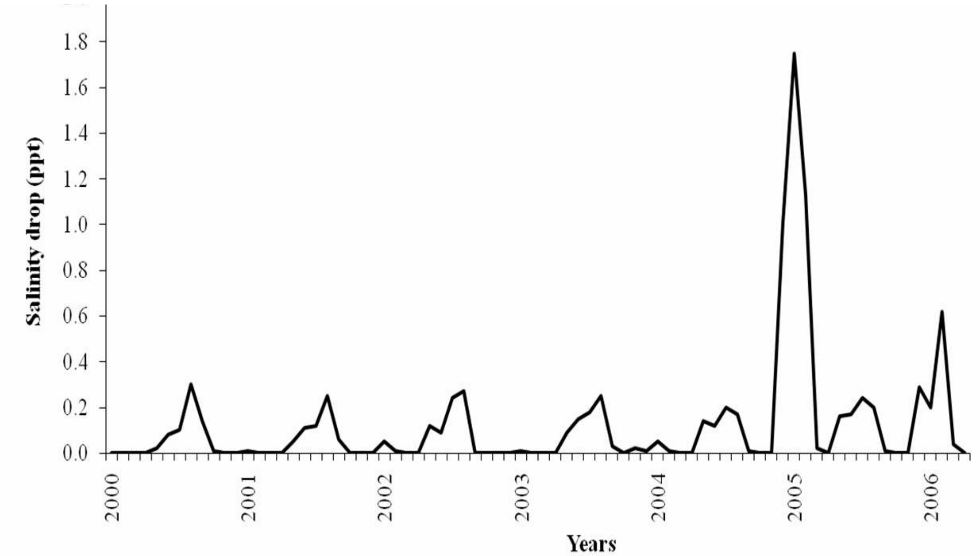

Figure 5. Excess volumes of water in the lagoon by the influence of Unnichchai tank water

CONCLUSIONS

The study has focused on simulation of changes in hydrology of the Batticaloa lagoon, as a result the input of Unnichchai Tank discharge. The Model **UnTil 1.0**, developed using Stella platform provides an important quantitative as well as qualitative tool, which is easy to set up and run and allow different scenarios of future management of the hydrology of the Batticaloa lagoon in respect to tank discharges. As such, this model outputs show that the irrigation tank inputs increase in the water level in *yala* cropping season (North East monsoon period), in lagoon salinity drop, and induce natural flood by raising the level of excess water and also it changes the bar mouth condition/s.

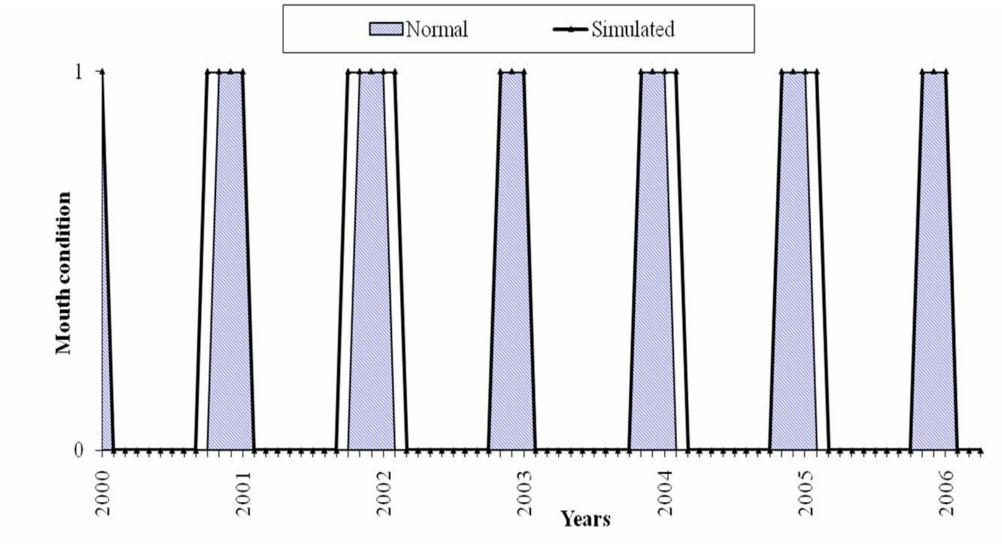

Figure 6. Normal and simulated bar mouth conditions of the lagoon

The effects or changes observed in the model outputs are multiplied several times if the discharge of all the irrigation tanks are taken into consideration and results in drastic changes in the lagoon, which ultimately adversely impact on the existing biotic community in the lagoon and on surrounding human settlements.

Testing the possible future scenarios is also possible in this model with forecasted rainfall and tank discharges. Through the testing of such scenarios, the period in which flooding risk is high, can be predicted approximately. This prediction will allow the district administration to adopt measures to reduce the flood risk that can include either evacuation of people from the flood prone area just prior to the predicted flood risk period or cut open the bar mouth prior to the flood risk period.

However, this model is a more simplified version of the reality and therefore a more detailed field study is necessary on the channel morphology and the hydrograph of tank discharges to develop a comprehensive model, which will enable more precise prediction on hydrological changes and its impact on the entire system.

ACKNOWLEDGEMENTS

We would like to express our thanks to Navagiri Range Office of the Department of Irrigation (Central), Chenkaladi, Batticaloa , for giving hydrological data on the Unnichchai tank.

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