

# Simulation of Groundwater Flow in the Coastal Area of Kanyakumari, South India, by Three – Dimensional Mathematical Model

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## Article Info

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## Abstract

Three dimensional mathematical model was used for a detailed experimental study to analyse groundwater flow in the region of coastal area Kanyakumari, South India. The study area is analysed and characterized by high intensity of rainfall, less extraction of underground water for domestic and agricultural purposes. Sandy clay soil aquifers are in the study area. 75 well stations in the study area are located used to analyse and design the mathematical model as major pumping stations. Groundwater heads are simulated by the, groundwater model using MODFLOW was developed for the aquifers.

The MODFLOW model was used to study groundwater flow conditions over an area of about 860 km<sup>2</sup> 18km width and 70km long with a grid size of 500m X 940m having 20 rows, 140 columns with total grids of 1828 in a single layer. The model is analysed to simulate a transient- state condition for the period 2000 – 2020. Transient and Steady state conditions MODFLOW model was calibrated. Observed and computed ground water heads there are reasonably matched between them.

Under various scenarios of pumping and recharge the MODFLOW model was run in transient state condition until the year 2020 to forecast groundwater flow. Results of modeling indicates, that the aquifer system is stable at the present rate of ground water pumping in the coastal area of Kanyakumari.

## Article History

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## I. INTRODUCTION

Increasing need and demand for underground water due to increasing populations has the effective of available groundwater resources. Modeling of groundwater can serve various purposes such as providing a frame work for organizing quantifying the properties, hydrologic data and the behaviour of the systems. To study and simulate ground water flow, three dimensional groundwater model is used. Groundwater modeling studies and analysis are carried out in various parts of the country for effective groundwater analysis. Such a detailed study was attempted for the Kanyakumari coastal area located in Southern India by a mathematical

model. MODFLOW is a common tool to design the groundwater flow model in the coastal area of Kanyakumari for the simulation of groundwater heads.

## STUDY AREA

Coastal belt of Kanyakumari District is located approximately between latitudes 8° 05' 30" to 8° 34' 30" and longitudes 77° 06' 30" to 77° 35' 00". Area covers 167184 Hectares in which along the coastal belt approximately length is 70 km and width is 18 km, Kanyakumari to Colachel coastal belt of 860 sqkm area is taken as study area after

Tsunami in 26<sup>th</sup> December 2004. (Refer Figure.1) Average intensity of annual rainfall in the basin is about 1448.6 mm. The climatic condition is subtropical. Types of soil available are River alluvium, Red soil, Laterite soil, Sandy clay, and Coastal alluvium.

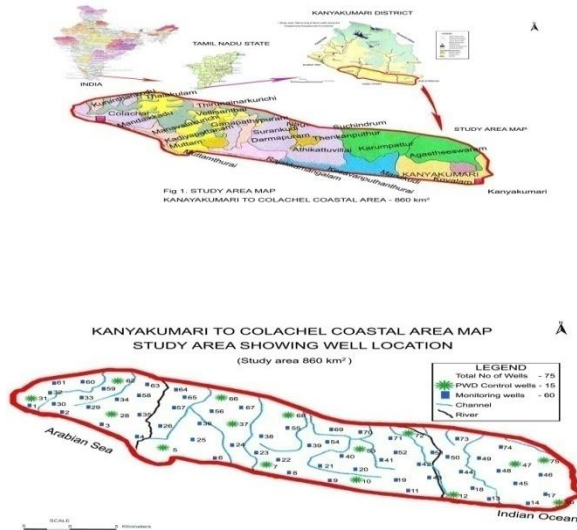


Figure 1 Study area with Location of Monitoring wells

**MODEL GRID - Grid Design**

The study area of the model grid is 860 km<sup>2</sup> and was discretized into 500 m × 940 m grid size with 140 columns and 20 rows vertically by one layer is as shown in Figure 2. The total numbers of grids in the area are 1830. The length of model cells is around 70 km along south – west and 18 km along north – east directions of the study area. Well properties are considered at each grid for the design of flow modelling.

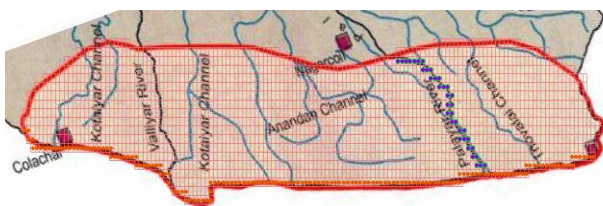
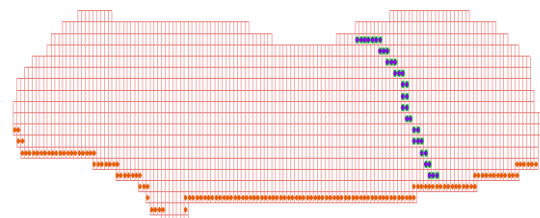


Figure 2 Model Grid

**Study Area Boundary**

The southern, eastern and western boundaries of the study are formed by watershed boundary. The water flows from these boundaries are negligible in the system shown in Figure 3. About 8 km in the north – western part of the area has alluvial soil deposits of 10m thickness and are taken as variable head boundary in the region. The eastern side of this area is surrounded by the Bay of Bengal, southern side is Indian Ocean, and the western side is Arabian Sea which is taken as a constant head boundary. The Pazhayar River was considered as specific head. The aquifer top and bottom in the study area were derived mainly from the lithology of 15 boreholes (PWD 2000) and by intensive field surveys. The unconfined aquifer is treated as a single layer, as sandy clay. The thickness of the layer varies in the range 0 m - 60 m, with maximum thickness.

Variable head boundary



Constant head boundary

Figure 3 Model grids with boundary condition

**Input Parameters**

The input parameters of the model are aquifer parameters, initial groundwater head, recharge, pumping and evapotranspiration.

**Aquifer Thickness**

The physical parameters, that include aquifer cross sectional elevation, were assigned to the model as shown in Figures 4 and 5 respectively. The elevation of aquifers is arrived from borehole logs. The aquifer top elevation ranges between 1 m and 25 m above ground level and the bottom elevation is fixed as 25 m below the MSL.

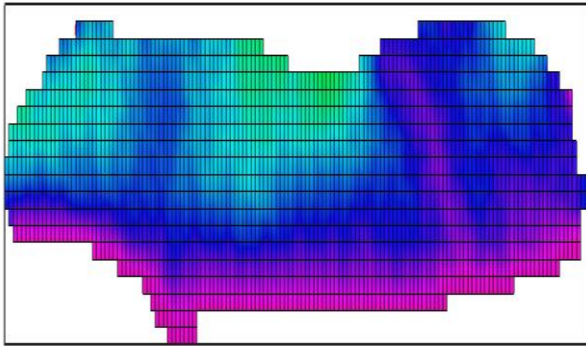


Figure 4 Aquifer top elevation

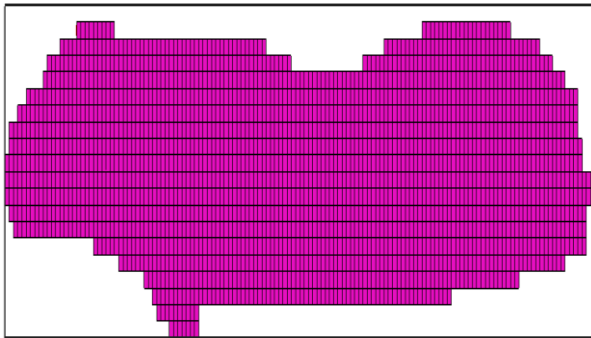


Figure 5 Aquifer bottom elevation

## AQUIFER CHARACTERISTICS

Specific yield of 0.22 was uniformly assumed for the area. The horizontal ( $k_h$ ) and vertical hydraulic conductivity ( $k_v$ ) designed for the model were derived from pumping tests carried out by PWD and were taken as 30 m/day and 10 m/day respectively and was assigned in the areas comprising of sand and sandy clay. Groundwater recharge varies from 0.00022 m/day to 0.0018 m/day.

## MODEL CALIBRATION

### Steady State Calibration:

Model run was carried for January 2000 because the total rainfall for the year 2000 was close to the seventy year annual average rainfalls of 1448.6 mm both the dry and wet climatic seasons (six months each) are closely marked, and so are the variations in the rise of the hydraulic heads. In the steady state calibration, only hydraulic conductivity values were varied. between 10 m/day and 30 m/day.

### Transient State Calibration:

Simulation of transient state was analysed 20 years from January 2000 to January 2020, with period of monthly stress of 120-h time steps. The trial and error process by which the transient model calibration was achieved between the computed and observed heads over space and time. Table 1 indicates the calibrated and initial hydraulic conductivity arrived after calibration. Based on the values computed heads from January 2000 to January 2020 at 75 observation wells were distributed throughout the aquifer, the transient models were considered to be calibrated satisfactory. The sensitivity of the model by determining the root mean square error of the simulated heads compared to the measured heads. These analyses show that the model is having sensitive recharge. The root mean square error arrived at the end of transient state calibration was 0.985.

Table 1 Hydraulic parameters

Sl. No.	Geology of the area	Hydraulic conductivity K (m/day)				Specific Yield (S)	
		Horizontal		Vertical		Initial	Calibrated
		Initial	Calibrated	Initial	Calibrated		
1	Sandy clay	37	30	1.5	1.0	0.18	0.2

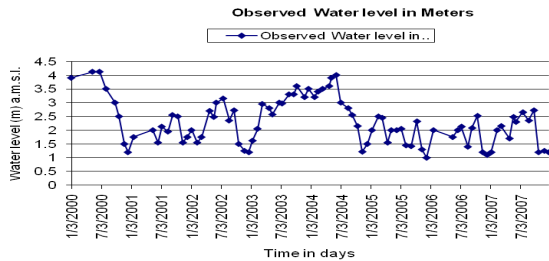
## MODEL SIMULATION

### SIMULATION RESULTS

The model was simulated in transient and steady condition for the time interval of 20 years in the period January 2000 to January 2020. The study of the simulated potentiometric surface of the aquifer defines that along the western side of the study area the highest heads are found, which is the reflection of the topography. Towards the southeast the groundwater regional flow direction is identified.

Figure 6 shows the computed and observed water heads in well nos. 28 and well nos. 53 are shown in

Figure 7 are analysed for groundwater flow modelling. The computed water head values mimic the observed water head values. Over ten years there is a constant and gradual increase in groundwater head except in some stress period the water head decreases.



a) *Computed water level in Meters*

—◆— Computed Water level...

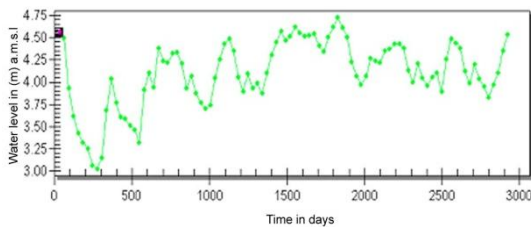
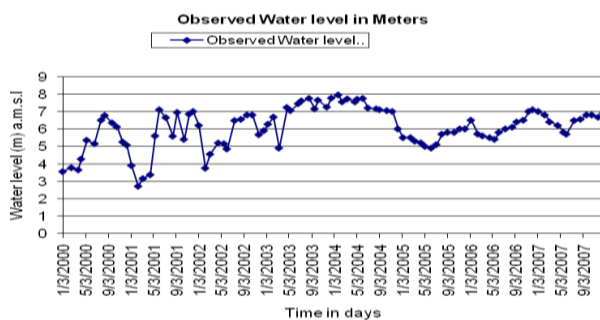


Figure 6 Comparison of observed and computed data of water heads at Well No.28



**Computed water level in Meters**

—◆— Computed Water level...

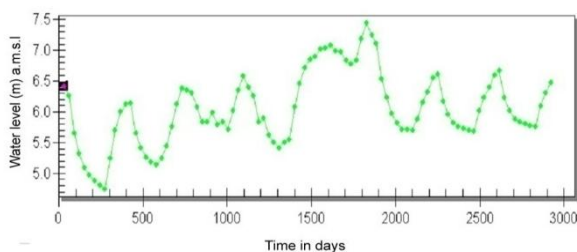


Figure 7 Comparison of observed and computed data of water heads at Well No.53

However in general, studying the entire simulated results the groundwater head in the area is progressively good and which will fulfill the requirements.

**MODEL FORECAST**

In order to sustainably manage the coastal aquifer system the aquifer response for different input and output fluxes was studied. The model was run for a further period of 2000 to 2020 January. Before the commencement of simulation, the data of average rainfall, abstraction, lakes, ponds, water, river flow recharge and aquifer parameters during January 2000 were put into the model as in put data and run for the stress period of 120 months.

Analysis of the past 20 years of simulated groundwater flow data shows that the groundwater level remains the same and gradually increases due to continuous rainfall as recharge of aquifers.

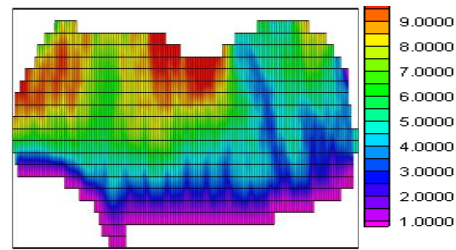
However there is no abnormal change in the water head. Therefore, the groundwater flow in Kanyakumari coastal area is good during all seasons throughout the year. Figure 8(a-k) shows the variations of groundwater head from January 2000 to January 2020.

One layered finite difference flow model was used in the coastal area of Kanyakumari for a period of 20 years, (ie) January 2000 to January 2020 for a better understanding of the aquifer system. The simulated results indicate that under the present pumping these aquifer systems are stable. Even with the present level of pumping the groundwater head is increasing gradually and in some period groundwater head is constant or slightly decreasing above MSL along the coast area during all seasons throughout the year because of continuous rainfall, sufficient recharge of aquifers and less extraction of groundwater.

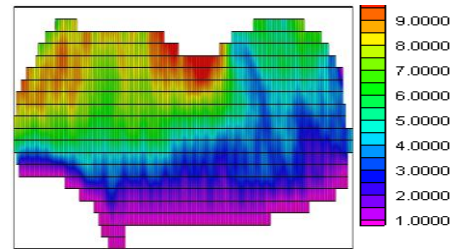
For the present level of pumping, the groundwater head varies above 10m along the north eastern and

south western parts, 5 m to 8 m in the inner middle parts along south west region, 3 m to 5 m in the south eastern and south western region and 0.5 m to 2 m in the study region. However simulated results in the coastal area aquifers, the water head is good and stable in all periods throughout the year due to periodical rainfall in all season of monsoons, less extraction of groundwater, high degree of recharge from surface water and sub tropical climate.

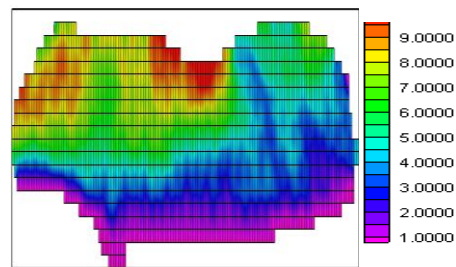
For well no.28 and well no.53, simulation of groundwater flow in the study area were studied by water head observation from January 2000 and the model was run for a stress period of 120 months, up to January 2020. Observed water head graph was prepared for well no. 28 and well no.53 are shown in Figure 9 and 12. The computed water head graph for well no.28 and well no.53 are as shown in Figure 10 and 13 for different stress period was obtained by running the model for its stress period. The observed and computed water heads were compared for the well no. 28 and well no. 53. Comparing the results observed and computed water heads; about 90% of computed water head was matching the observed water head and are shown in Figures 11 and 14. The variation of water head is around 0.1 m to 0.8 m in all aquifer in the study area. A comparative chart matching the observed and computed water head data for different stress period represent how both values are matching each other are shown in Figure 15 in which the root mean square error is 0.985.



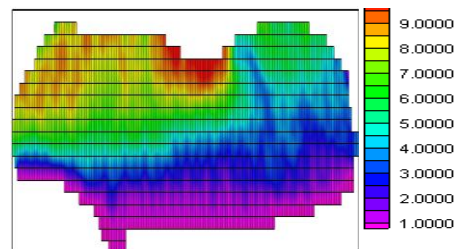
(b) January 2002



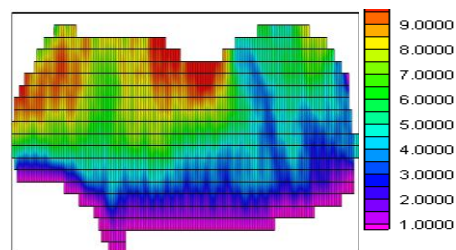
(c) January 2004



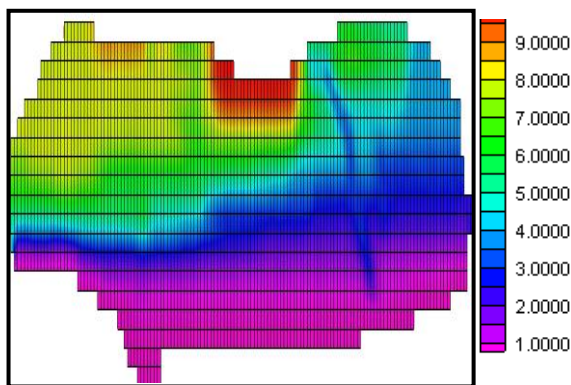
(d) January 2006



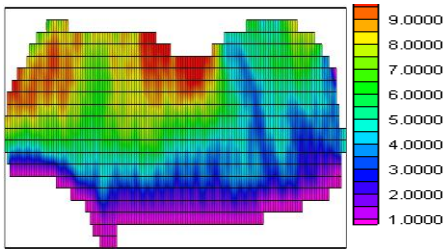
(e) January 2008



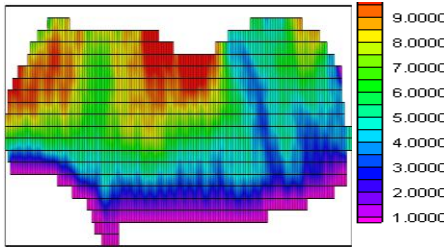
(f) January 2010



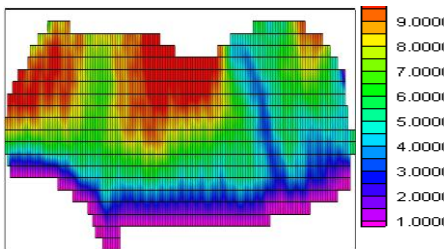
(a) January 2000



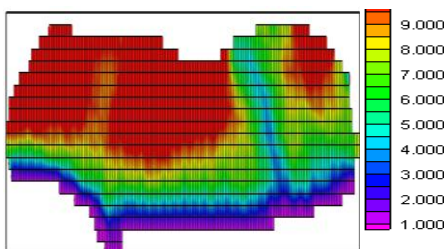
(g) January 2012



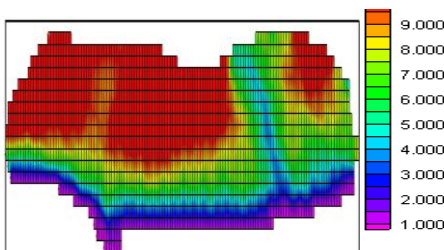
(h) January 2014



(i) January 2016



(j) January 2018



(k) January 2020

Figure 8 Groundwater head variations from January 2000–2020

Studying the simulated results of groundwater head from 2000 to 2020 and the comparison of computed and observed water level from 2000 to 2007 and thereby up to 2020 in the Kanyakumari Colachel coastal area aquifer, the water head is good and stable in all periods throughout the year due to periodical and seasonal rainfall, less extraction of groundwater, high degree of recharge from surface water.

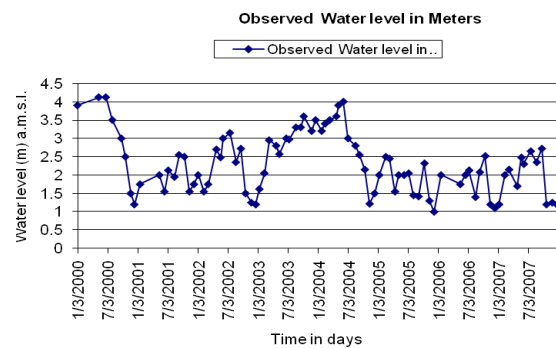


Figure 9 Observed water heads - Well No.28

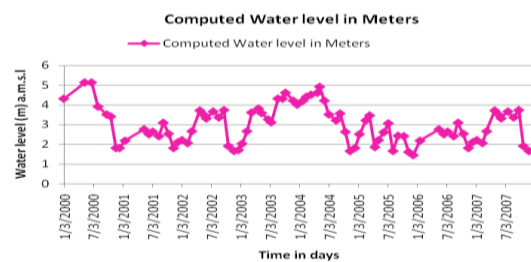


Figure 10 Computed water heads - Well No.28

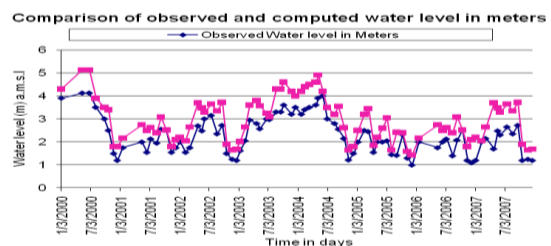


Figure 11 Observed and Computed water heads - Well No.28

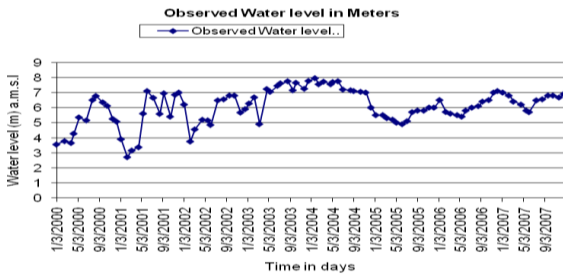


Figure 12 Observed water heads - Well No.53

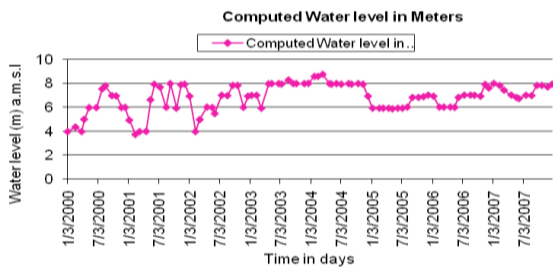


Figure 13 Computed water heads - Well No.53

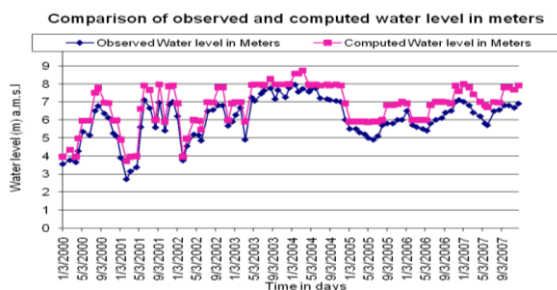
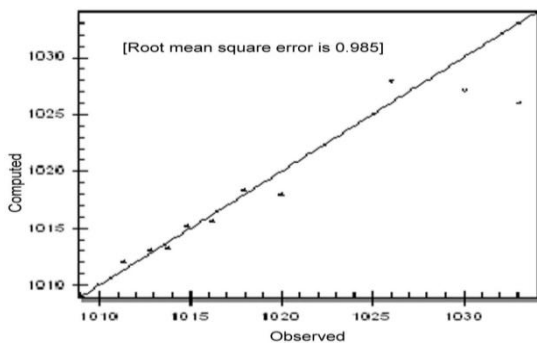


Figure 14 Comparison of observed and computed water heads - Well No.53

Observed vs. Computed values of groundwater head



[Root mean square error is 0.985]

Figure 15 Comparison of observed and computed groundwater heads in (m)

## CONCLUSION

A one – layered finite – difference flow model was used for a period of 20 years (2000 – 2020) to simulate the groundwater head in the coastal area for a better understanding of the aquifer system. The simulated results indicate that under the present pumping the aquifer systems are stable. Even with the present level of pumping the groundwater head is increasing gradually and in some period groundwater head is constant or slightly decreasing above MSL along the coast area during all seasons throughout the year because of continuous rainfall, sufficient recharge of aquifers and less extraction of groundwater. For the present level of pumping, the groundwater head varies above 10m along the north eastern and south western parts, 5m to 8m in the inner middle parts along south west region, 3m to 5m in the south eastern and south western coastal region and 0.5m to 2m in the coastal belt of study area. However studying the simulated results of groundwater head in the coastal area aquifers, the water heads are good and stable throughout the year in all periods.

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