

# Assessment of Long-term Groundwater Level and Quality Variations in Western Coastal Sandy Aquifers of Sri Lanka

A. Egodawithana, H.A.M. Prasadani, R.R.G.R. Rajapakse

**Abstract:** The densely populated Western coastal strip from Colombo to Negombo heavily relies on groundwater, mainly sourced from a productive coastal sandy aquifer system. However, unregulated groundwater extraction by industries and domestic use has led to declining groundwater levels and deteriorating quality. The study primarily focuses on this aquifer system, with some minor sandy aquifers found in local areas. Monitoring from 2012 to 2020 tracked groundwater levels and quality parameters. Despite an annual rainfall of 2,000 mm, groundwater levels range from 0.0 to 8.0 meters below ground. Notably, Katunayake industrial zone and the airport extract ~2000 m<sup>3</sup>/day and >2200 m<sup>3</sup>/day respectively. At the initial phase of monitoring comparatively higher Electrical Conductivity (EC) and total hardness were observed (200-450 µS/cm and 280-500 mg/l), a peak in 2018, but thereafter with rapid drop was observed. In overall, the groundwater quality decrease is attributed to factors like freshwater reduction in the shallower sandy aquifers during dry periods. Localized sea water intrusion impact vulnerable zones in Seeduwa, Negombo, and Katunayake, with noticeable EC and groundwater level changes. Groundwater level correlations with precipitation were not significant and possible lateral recharge from inland play as a dominant source. Isolated sandy aquifers beneath laterite caps had deeper groundwater due to low laterite permeability. Total iron varied widely (0.002-5.7 mg/l) due to laterite leaching.

**Keywords:** Coastal sandy aquifer, Recharge, Groundwater, Shallower aquifer

## 1. Introduction

Sri Lanka is a country with many rivers crossing over it, but with all of this surface water, it cannot be relied upon for irrigation, industrial and domestic uses. Some communities use groundwater as their source of irrigation, industry, and domestic applications. Groundwater is the purest form of water on Earth and is found to be an unlimited natural resource at the lowest cost (Musa & Ahanonu, 2013).

*Mr. A. Egodawithana., B.Sc. Geol. (Hons) (Peradeniya),  
M.Sc. (GIS & Remote Sensing).  
Provincial Manager, WRB  
Email: abeysingheniranjana@gmail.com*  
*Mr. R.R.G.R.Rajapakse., B.Sc.Sp. Geol. (Hons)  
(Peradeniya), M.Sc. (WREM)(Netherlands)  
Assistant General Manager (R & D), WRB  
Email: ruwanrajapaksee@gmail.com*  
*Mrs. H.A.M. Prasadani., B.Sc.Sp. Geol. (Hons)  
(Peradeniya), M.Sc. (Eng & Hyd).  
Hydrogeologist, WRB  
Email: prasadiham@gmail.com*

Groundwater, a vital natural resource, flows through aquifers over long distances, serving many people. It is continuously recharged by rainwater during the wet season. However, human activities like excessive abstraction and unsustainable withdrawal can lead to declining groundwater levels and environmental impacts on aquifers. These issues are challenging to address, given the varying recharge patterns of different aquifers. Therefore, the study focused on the Colombo-Negombo coastal sandy aquifer in Sri Lanka, which is highly sensitive. Monitoring of wells in this area began in 2012, covering parts of Waththala, Jaela, Katana, and Negombo Divisional Secretariat Divisions. The coastal sandy aquifer stretching from Colombo to Negombo is a highly sensitive and productive aquifer in Sri Lanka, situated on the western coast of the country. The region includes a marshy area extending from Wattala to Pamunugama. The area near the Colombo-Negombo Road is densely populated and urbanized, with the Katunayake export processing zone and the Katunayake Airport located here. Additionally, numerous factories are dispersed throughout the area. This coastal sandy aquifer is one of the country's most abundant groundwater sources, known for its water-bearing capacity and easy recharge.

Water flows rapidly through sandy aquifers, making them susceptible to pollution from industrial and domestic sources. Groundwater levels decline during the dry season due to evapotranspiration, domestic use, and industrial extraction, particularly around the Katunayake Industrial Zone and Katunayake International Airport. This can lead to seawater intrusion and vulnerability in coastal sandy aquifers.

The study's primary goal is to establish a groundwater level monitoring network using test boreholes to collect quarterly data, helping to manage and conserve the aquifer without harming the environment. These test wells are strategically located to assess groundwater quality and represent all parts of the aquifer.

## 2. Literature Review

The primary basement rock types in the area are Hornblende biotite gneiss, Charnokitic gneiss, Granitic gneiss, Garnet sillimanite gneiss, and undifferentiated metasediments. Recent formations include alluvium, unconsolidated silica sands, clays, peat, laterite, and recent soils. The sand layer's thickness varies from moderate to deep formation, with alluvial deposits extending up to 6-8 meters in the flood plains of the study area's tributaries

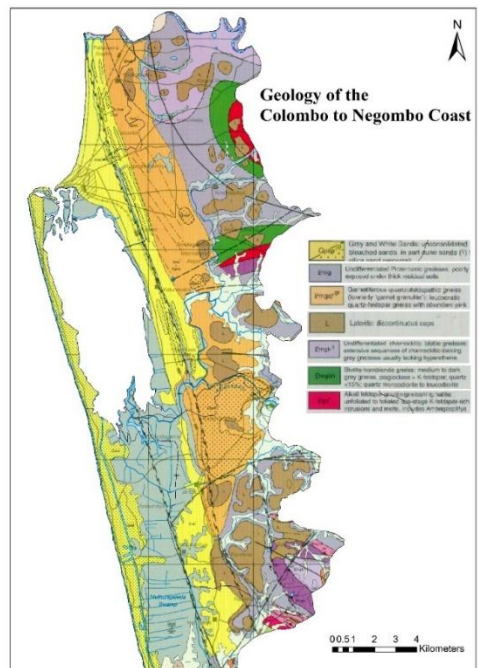


Fig 1 - Geology of the Study Area (GSMB)

(Attanagalu Oya, Kelani Ganga, and Ma Oya). These flood plains are characterized by alternating layers of sand and clay. The study area has a consistent surface geology but features various morphological elements like sand dunes, water bodies, lagoons, and marshy areas. It consists of shallow aquifers, including alluvial, coastal sandy, lateritic, and deeper fractured crystalline aquifers. Our study focuses on the coastal sandy aquifer, which is prevalent under lateritic-capped hillocks. This coastal sandy aquifer is shallow, highly permeable, and sensitive to geochemical changes. Due to its flat terrain and proximity to saline water bodies, its freshwater storage primarily relies on rainwater infiltration, particularly from monsoon rains.

### **3. Methodology**

Initially, 50 tube wells were constructed to represent the coastal sandy aquifer in the coastal strip from Ma Oya to Kelani River, covering Waththala, Ja-ela, Katana, and Negombo DS Divisions. Of these, 30 test wells were continuously monitored for groundwater levels, while monitoring of the other 20 wells was disrupted due to the Covid-19 pandemic and other reasons. The monitoring of groundwater levels commenced in 2012 and continued until 2020. Rainfall patterns were assessed by quarter, considering four major seasons with two monsoons and two inter-monsoons (Panabokke & Kannangara, 1996). Monthly rainfall data from the Katunayake rain gauge station for the years 2012 to 2020 were obtained from the Department of Meteorology. Borehole logs of the test wells were

analyzed to determine subsurface stratigraphy and aquifer location.

## **4. Results and Discussion**

### **4.1 Rainfall Variation**

The monthly rainfall variations of the study area during 2012-2020 are shown. The maximum rainfall was found throughout May to June during the South-Western monsoon period and September to November during the South-Western inter monsoon period of the area. The minimum rainfall was found between December and March, and very little or no rainfall occurred during January and February in the study area. The study results also illustrate that the maximum rainfall was recorded in May, 2016. The studied results show that the general rainfall pattern widely varies during the study period and shows the non-linear relationship.

### **4.2 Relationship between Rainfall and Groundwater Level Fluctuations**

The results of the analysis entailed that; annual rainfall of the area is fluctuating during the studied time period. Similarly, for groundwater level observations in figures 04, 05, and 06, the results show a good relationship among the parameters, which indicates that the higher the value of the rainfall, the groundwater level was also higher. The study area is divided into three sections (figure 02) for ease of discussion and illustration.

Figure 03, 04, and 05 illustrate the trends in the water table of the study area during 2012 to 2020. The results showed that, the minimum was in 2014, 2016 and 2019 due to minimum rainfall and even though the rain occurred in the

beginning, some wells, such as 2012/39 and 2012/19, recharged with delay because of lack of the rain fall receiving in the area where the above wells are located. Hence the over abstraction was not possible because of 2012/39 use in church and 2012/19 use for domestic purposes as well as maximum groundwater level was in 2017, 2018 and 2019 due to different in rainfall, infiltration and runoff (Seiler & Gat, 2007). This long - term study indicates the highest deflection occurred in 2014, and the groundwater table gradually increased until it recharges and fluctuate with the rainfall received in area 01 and 03 except well no 2011/32 in area 03. In area 02, the general groundwater level decreased up to September 2017 and the water table increased until it recharged in October 2017 in the inter-monsoon period and it will be maintained until 2020 except in January–March 2019.

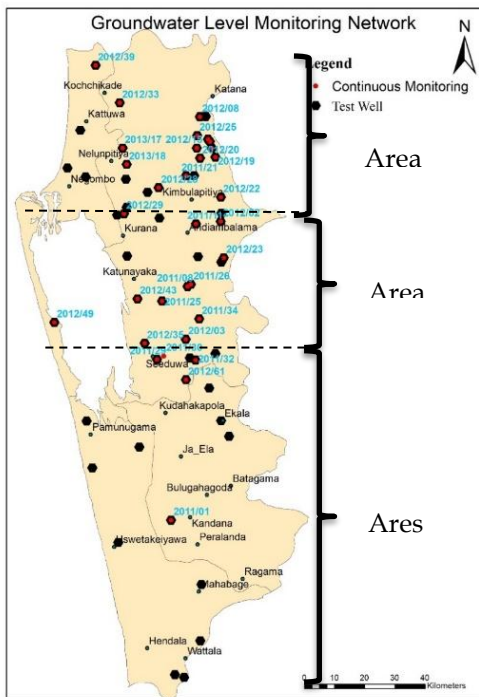


Fig 2 - Groundwater Level Monitoring Network

Generally, groundwater level fluctuation range was identified as 0 m to 12 m from the existing ground level. The study area can be considered as an almost flat terrain. Therefore, zero groundwater level indicates the water table existed at the ground level. However, overall yearly water table results indicate groundwater level trends are due to unsuitable abstraction of groundwater, especially in area 02, which is where most industrial zones and high-water consumption areas are located and this played a vital role in water level fluctuations in the area of the coastal sandy aquifer.

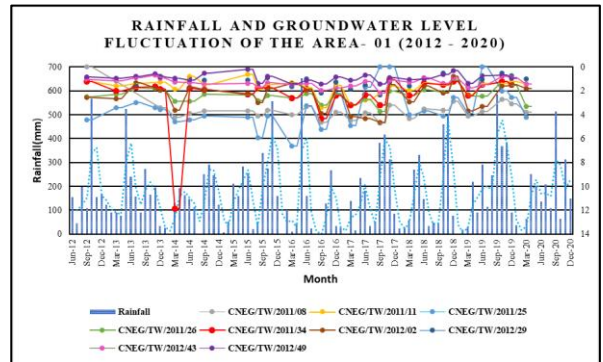


Fig 3 - Seasonal Groundwater Level Fluctuation in Area 01

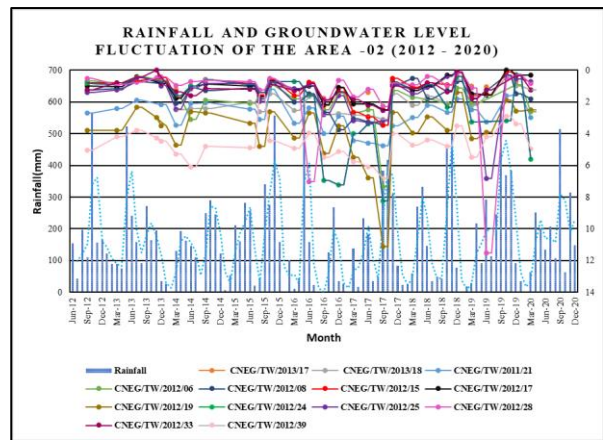
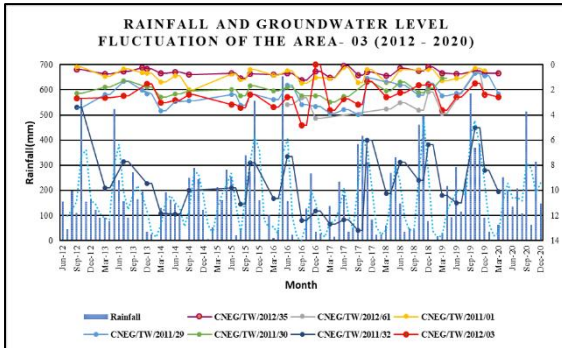


Fig 4 - Seasonal Groundwater Level Fluctuation in Area 02



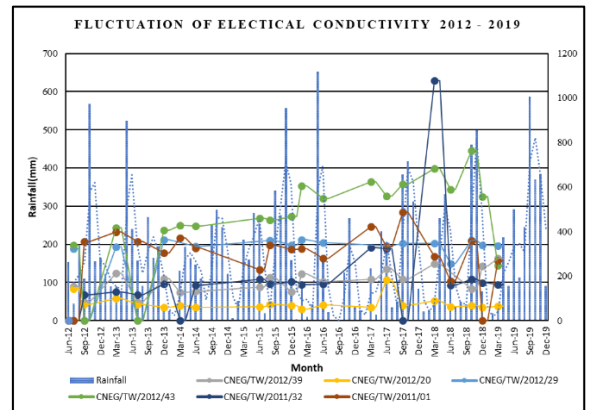
**Fig 5 - Seasonal Groundwater Level Fluctuation in Area 03**

Sand is an effective aquifer due to its high porosity, allowing it to retain water and recharge quickly thanks to its high transmissivity and permeability (Filippin et al., 2015). However, this same high permeability and transmissivity can lead to a sudden drop in water levels during high abstraction as water easily flows towards the pumping well.

**4.3 Variation of Chemical parameters over the period**

A 2012-2019 study assessed water quality parameters (EC, Total Hardness, Total Iron, Nitrate) in Katunayake industrial zone and Katunayake International airport area (CNEG/TW/2012/43), both reliant on groundwater. High groundwater extraction (2000 cubic meters/day from the industrial zone, 2200 cubic meters/day from the airport) raised sustainability and quality concerns. During the monitoring period, trends in electrical conductivity (EC) and total hardness of the extracted groundwater were observed. Initially, EC ranged from 200 to 450 uS/cm, and total hardness fluctuated between 280

and 500 mg/L. Notably, both parameters showed a consistent upward trend until 2018, signaling a decline in groundwater quality possibly due to over-extraction and external contamination sources. In September 2018, a notable change took place. Electrical Conductivity and groundwater hardness both significantly decreased, with EC falling to 150  $\mu$ S/cm and hardness to 200 mg/L. This abrupt shift raised questions and prompted a need for further investigation into its underlying causes. The degradation in groundwater quality in proximity to the ocean was not solely due to seawater intrusion. Instead, localized factors played a significant role. One key factor was the reduction in fresh water thickness in shallow sand aquifer systems, especially during dry periods in Pamunugama.



**Fig 6 - Variation of Electrical conductivity in groundwater sources**

This reduction in available fresh water likely contributed to changes in groundwater composition. Additionally, localized seawater intrusion occurred in vulnerable areas like Seeduwa, Negombo, and Katunayake, leading to seasonal fluctuations in groundwater

levels and increased electrical conductivity. These events raised EC by approximately 12  $\mu\text{S}/\text{cm}$ , 20  $\mu\text{S}/\text{cm}$ , and 100  $\mu\text{S}/\text{cm}$  in Seeduwa, Negombo, and Katunayake, respectively, and resulted in significant groundwater level declines of 3.0 meters, 1.0 meter, and 2.0 meters in those areas. Notably, these intrusion zones were localized and limited in scope. The impacts of seawater intrusion were temporary and effectively alleviated by rainfall. Rainwater had a restorative effect, leading to a rapid recovery of groundwater quality parameters. This resilience and recovery were confirmed through long-term monitoring and analysis conducted over the observation period.

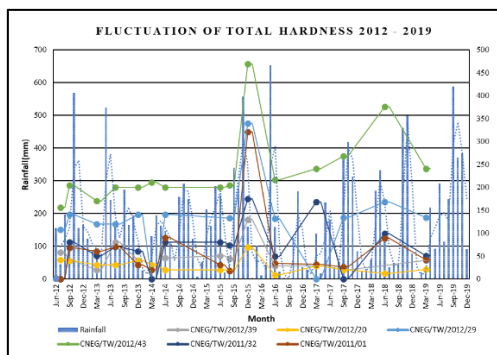


Fig 7 - Variation of Total Hardness

During the monitoring period, nitrate levels in the groundwater remained stable. This consistency could be attributed to various factors, such as land use and localized nitrate sources. It's possible that agricultural and industrial activities, common contributors to nitrate contamination, were not as prevalent in these areas. Alternatively, effective land use practices and regulations might have limited the introduction of excessive nitrates into the groundwater. As a result, the risk to human health and the necessity for extensive water treatment

to combat nitrate contamination may have been lower in this specific context.

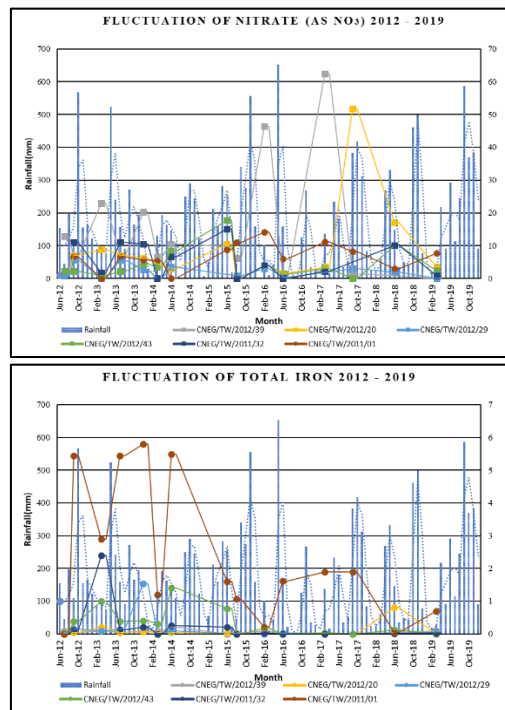


Fig 8 - Variation of Nitrate and Total Iron

In some wells in the area, the total iron concentrations in groundwater showed irregular fluctuations rather than stable levels throughout the monitoring period. These fluctuations may be associated with the geological features of the region, notably the presence of laterite and clay.

#### 4.4 Borehole data and groundwater table decline in sandy aquifer

The borehole information reveals a consistent stratigraphy in the coastal sandy aquifer area. Small laterite bodies are scattered throughout the terrain, often forming capped hillocks due to slow weathering. Borehole logs indicate the presence of a sandy aquifer below the laterite, with laterite weathering resulting in clayey sand or sandy clay, as observed in the borehole data. Figure 7

illustrates the borehole data, showing a common subsurface stratigraphy pattern across most wells. In this sandy aquifer, groundwater levels are notably lower than in the coastal sandy aquifer, even during wet seasons. Several wells, such as 2011/32, 2012/23, 2012/20, and 2012/22, are located in this type of sandy aquifer. Well No. 2012/20 in the Kondagammulla area has been continuously monitored and exhibits consistently low groundwater levels (Figure 03). While the wells 2011/32, 2012/23, and 2012/22 in Raddoluwa, Andiambalama, and Kimbulapitiya were not continuously monitored, they also showed relatively low water table levels, particularly during the dry period (figures 9).

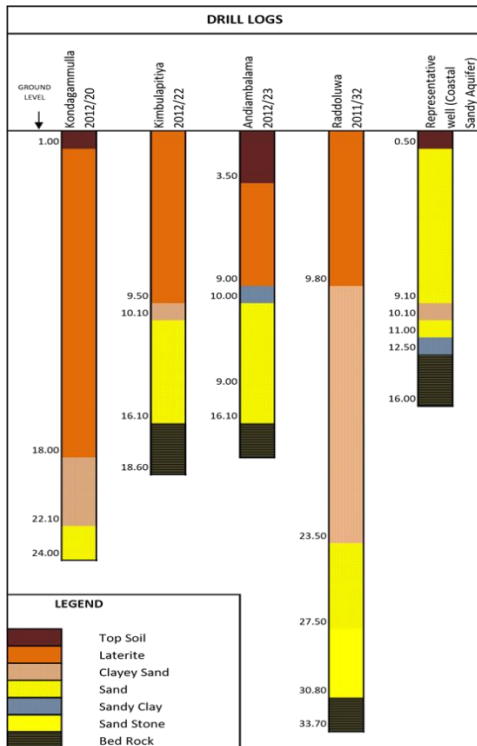


Fig 9 - Borehole Log Information

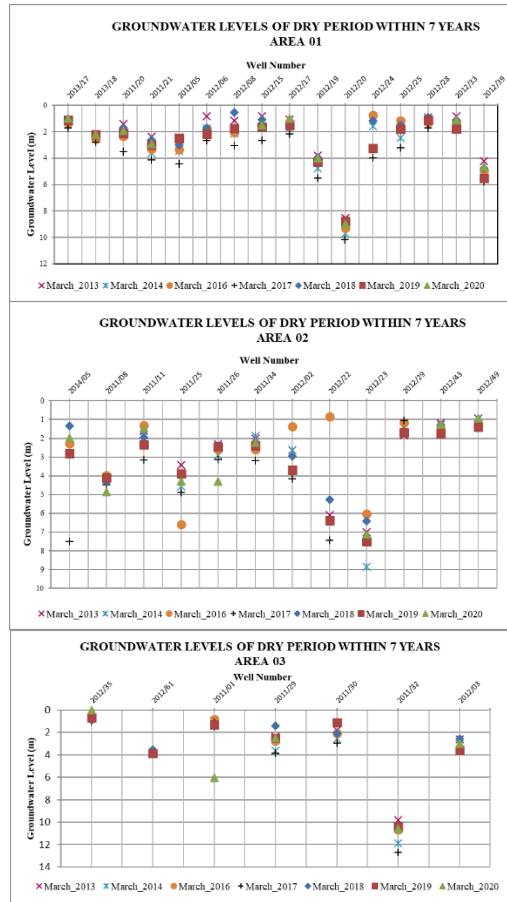


Fig 10 - Groundwater Level in Dry Period (Area 01, 02 and 03)

In the sandy aquifer, groundwater storage and other aquifer parameters are relatively similar to the coastal sandy aquifer. However, the decline in groundwater levels is primarily attributed to the limited infiltration capacity, indicating the low permeability and transmissibility of laterite, as noted by Omeje *et al.*, (2022). This results in gradual recharge of the aquifer. The analysis of groundwater level depletion during the dry period in specific wells (Figures 9) revealed that well numbers 2011/01, 2011/25, and 2014/05 exhibited

significant depletion in 2020, 2016, and 2017, respectively, while other wells showed similar declines in groundwater levels. However, the groundwater level depletes rapidly in dry period due to evapotranspiration and especially due to domestic use and groundwater abstraction around the Katunayake Industrial Zone, Katunayake International Airport and scattered factories in the area. Because of the lagoon area and the sea side, the electrical conductivity is generally much higher in near coastal areas and it was observed that the average electrical conductivity of some areas is 17,500  $\mu\text{s}/\text{cm}$ , which can be identified as seawater intrusion areas. Therefore, over-abstraction can lead to seawater intrusion towards peripheral land areas.

## 5. Conclusions

The long-term groundwater analysis indicates that recharge in the coastal sandy aquifer is closely tied to intense seasonal rainfall due to its high porosity and transmissivity. Groundwater quality deteriorated due to significant extraction in the Katunayake industrial zone and airport area, with increased Electrical Conductivity (EC) and total hardness until 2018, followed by a decline. This decline resulted from local hydrogeological factors, not just seawater intrusion, including reduced freshwater storage in dry periods. Seasonal seawater intrusion affected vulnerable areas, causing fluctuations in groundwater levels and EC, recovering after rainfall. The deeper sandy aquifer beneath lateritic caps in certain regions led to rapid groundwater depletion during the dry season, attributed to factors like evapotranspiration, domestic use, and extensive groundwater extraction near industrial areas. Seawater intrusion in specific zones

heightened the risk, calling for careful management and monitoring. Combining rainfall analysis with the water-table fluctuation method can help investigate groundwater recharge. Hence, a long-term groundwater level monitoring strategy with proper management is vital to sustain these groundwater resources.

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