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## Ganga River Bank Erosion and its Impact on Land Resources: A Hydrogeomorphic Study of Haridwar District, Uttarakhand

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**ABSTRACT:** Riverbank erosion is a major hydrogeomorphic hazard observed in foothill and plain areas of the hilly state of Uttarakhand. Haridwar city, located at the foothill of Siwalik is facing various kinds of fluvial hazards, such as; seasonal flood, water logging, river bank erosion, channel shifting, channel avulsion, rill and gully erosion etc. Among these hazards, river bank erosion creates maximum damage of the settlement areas, agricultural areas and transport network. The Ganga river bank areas near Haridwar city can be delineated in different geomorphic zones such as; toe zone, splash zone, bank zone, terrace zone etc., to find out the mechanism of bank erosion in different geomorphic zones of river bank. The present paper is an attempt to analyse the nature and causes of the Ganga river bank erosion and its impact on land resources in Haridwar district.

**KEYWORDS:** Riverbank erosion; hydro- geomorphic hazard; channel aggradation

### I. INTRODUCTION

The term hydro-geomorphology was used by Scheidegger (1973) to connote the geomorphologic study of water and its effects. Hydro-geomorphology is a term to mean the study of fluvial processes and the related forms and their interrelations. Riverbank erosion is a major hydro-geomorphic hazard observed in foothill and plain areas including some portions of deltaic parts. The present paper is concerned with hydro-geomorphic mechanism of bank erosion of the Ganga river and its impact on land resources in Haridwar district, Uttarakhand. Haridwar city, located at the foothill of Siwalik is facing various kinds of fluvial hazards, such as; seasonal flood, water logging, river bank erosion, channel shifting, channel avulsion, rill and gully erosion etc. Among these hazards, river bank erosion creates maximum damage of the settlement areas, agricultural areas and transport network. Due to shifting of river channels many villages are found abandoned.

#### Area and location

The study area finds its location extended from 29°35'37"N to 30°13'29"N latitude and 77° 52' 52"E to 78° 21' 57"E longitude.(Figure1) The study has been conducted in three tehsils of Haridwar district namely Haridwar; Roorkee and Laksar. The six blocks in these three tehsils chosen for field study were: 1) Bhagwanpur, 2) Roorkee, and 3) Narsan, 4) Bahadrabad, 5) Laksar, and 6) Khanpur.

# International Journal of Innovative Research in Science, Engineering and Technology

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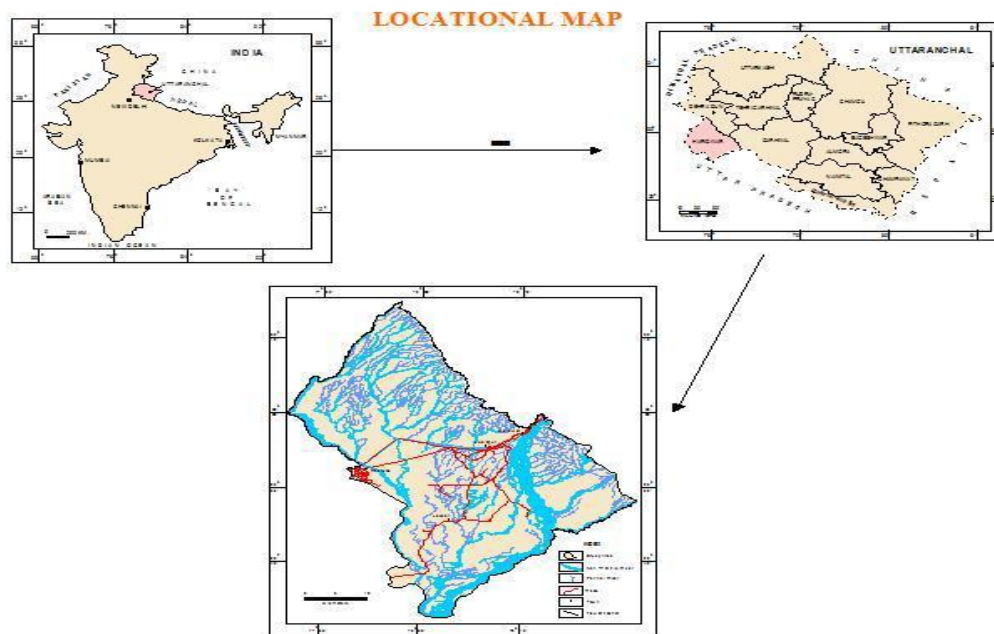


Figure 1: Location of study area

## Research Method adopted

The present study embraces the three stages i.e.,

- 1) Pre Field
- 2) Field
- 3) Post Field.

**Pre Field:** In the pre field stage the study area related maps were collected from different Government organizations like; topographical sheets (53 K/1, 53 K/2, 53 K/5, 53 J/4, 53 G/13, 53 G/14, ), district planning map from Survey of India. District resource map of Saharanpur from Geological Survey of India, Satellite Imagery mainly LISS-III, LISS-IV(1997,2005) from National Remote Sensing Centre(NRSC) and other maps (water resource map, rainfall map etc.) from National Atlas and Thematic Mapping Organization (NATMO) and imagery and data from USAC Uttarakhand

**Field:** Field study involves the ground truth verification, collection of primary data about slope, river velocity, cross sectional study of river Ganga, Ranipur rao, Rawali rao, Betban rao, land use survey and household survey etc. with help of the instruments like Global Positioning System (GPS) handset, Clinometer, Dumpy Level and Prismatic Compass etc. and secondary data were collected from various offices and Institutes like Wadia Institute of Himalayan Geology. Measurement of river bank erosion at different sites of Ganga river, Ranipur rao , Betban rao has been done with the help of Global Position System(GPS) receiver.

**Post Field:** In the Post field study, processing of raw data, tabulation and preparation of diagrams and finalization of maps like physiographic zonation, Geological map, Drainage map, Geomorphological zones of riverbank, etc. have been prepared. The maps were prepared with the help of advanced GIS and Remote Sensing software like ERDAS Imagine 8.4, Surfer, Arc view etc. and MS Excel have been used to process the data. Superimposing the topographical sheet (1971) and LISS-III image (2005), bank erosion zone map of the entire study area has been prepared.

## Hydrogeomorphic Processes of stream bank erosion

The various mechanisms of stream bank erosion (Plate-1) generally fall into two main groups (i)Bank scour and (ii) Mass failure. In many cases of bank instability both will be evident, often with either scour or mass failure being dominant.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

**Bank scour:** Bank scour is the direct removal of bank materials by the physical action of flowing water and the sediment that it carries. As flow speed increases, the erosive power of flowing water also increases and scour may occur. Increases in flow speed can be the result of natural and/or human induced processes.

**Mass failure:** Mass failure which includes bank collapse and slumping, is where large chunks of bank material become unstable and topple into the stream or river in single events. Mass failure is often dominant in the lower reaches of large streams and often occurs in association with scouring of the lower banks. In the study area mainly in Terai zone mass failure is very common. Near Nildhar area both processes are jointly operating bank erosion problem.



Plate-1: Sediment stratification of River bank of Ganga and other tributaries of the study area

### Geomorphic zones of riverbank

The author has identified the river bank areas in different geomorphic zones (Fig-3) such as ; toe zone, splash zone, bank zone, terrace zone (Hollis H. Allen, James R. Leech, 1997) to find out the mechanism of bank erosion in different geomorphic zones of river bank.

# International Journal of Innovative Research in Science, Engineering and Technology

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Vol. 3, Issue 7, July 2014

**Toe zone:** The toe zone is that portion of the bank between the bed and average normal stage. This zone is a zone of high stress and can often be undercut by currents. Undercutting here will likely result in bank failure unless preventative or corrective measures are taken.

**Splash zone:** The splash zone is that portion of the bank between normal high-water and normal low-water flow rates. Splash zone and the toe zone are the zones of highest stress. The splash zone is exposed frequently to erosive river currents and debris movement, wet-dry cycles. The water depths will fluctuate seasonally, and by location within the splash zone.

**Bank zone:** The bank zone is that portion of the bank usually above the normal high-water level; yet, this site is exposed periodically to erosive river currents, debris movement, and traffic by animals or man. The water table in this zone frequently is close to the soil surface due to its closeness to the normal river level.

**Terrace zone:** The terrace zone is that portion of the bank inland from the bank zone; it is usually not subjected to erosive action of the river except during occasional flooding. This zone may include only the level area near the crest of the unaltered —high bank or may include sharply sloping banks on high hills bordering the stream. The terrace zone is less significant for bank protection because it is less often flooded, but can be easily eroded when it is flooded if vegetation is not present.

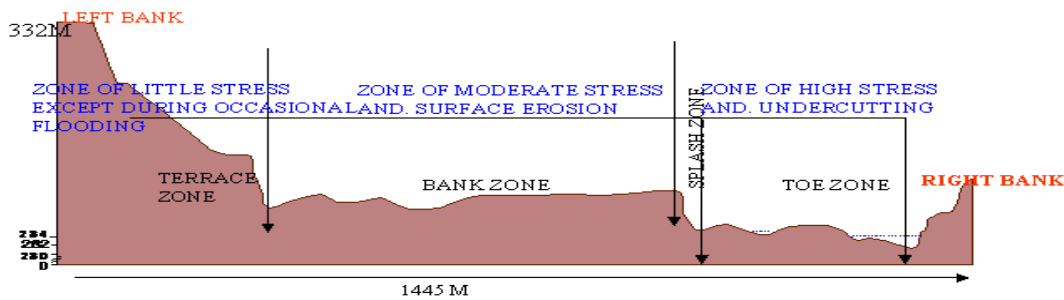


Fig. No.3- Geomorphic zones of Ganga River bank, near Chandi bridge. (Based on field survey by the researcher, May, 2008 ).

Fig-5: CHANGING WIDTH OF RIVERS IN RAMJI NATIONAL PARK AT HARDWAR- SHAKUMBHARI ROAD

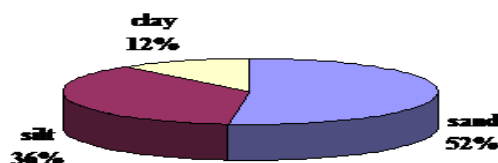
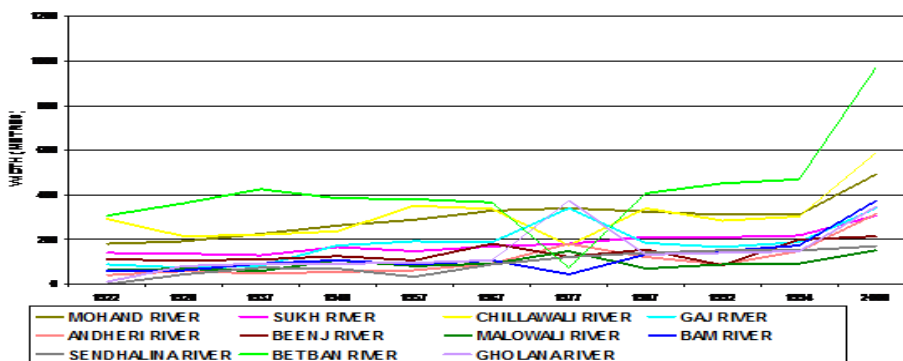


Fig.No.4 - Percentage of Sand Silt and clay of the different Soil samples.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

Various factors are responsible for riverbank erosion in this area like - Geological factor, climatic factor, topographic and drainage characteristics of the study area.

**Topographic characteristics and surface flow** Broadly speaking, the area is a representative of the distinct polycyclic and polygenetic landscape including four major erosion surfaces (Dutta, 2010) with the dominance of neotectonics under humid environment. At the Siwalik foothill due to sudden decrease of gradient of slope river velocities decrease and the materials transported by river are deposited over river bed. On the other hand, during dry period scarcity of rainfall in upstream region decreases water supply in river channel, so that materials could not be transported and deposited on river bed. As a result, during monsoon river channel cannot bear excessive rainwater and floods occur in most of the rivers of the Tarai zone of study area and due to occurrences of flood riverbank erosion process is accelerated in the Tarai area.

<b>Table-1: Major natural factors influencing riverbank erosion in the study area</b>	
Factors	Characteristics
Flow property	Magnitude and variability in river discharge. Eddies formed by obstruction in channel. Distribution of velocity and shearing stress.
Geo-lithological composition of bank	Size, cohesivity and stratification of bank sediments.
Climate	Amount, duration, intensity of rainfall, wet-dry cycle.
Surface run-off	Soil moisture, Surface run-off over bank.
Subsurface condition	Seepage forces, Porewater pressure.
Channel property	Width, depth and slope of channel. Channel curvature. Integration of channel bars.
Riverbank geometry	Height and angle of the bank.
Source: field survey, 2006, 2007, 2008, 2009, 2010, 2011	

### Magnitude and variability in river discharge

In the study area river bank erosion is controlled due to heavy fluctuation of stream discharge. Except Ganga all of the rivers are non-perennial in nature and that is why during monsoon water discharge in every tributaries increased many folds and the excessive water enhances fluvial erosion power and it creates hydraulic pressure on the channel wall of the streams and during post-monsoon or during lean period entire stream channel becomes waterless and that is why, sudden release of hydraulic pressure from side wall rocks is occurred. This entire mechanism is very important for occurrences of river bank erosion. From the hydrograph of the Ganga river at Rishikesh (2001), the variability in river discharge is very prominently observed (approx 3000 cusecs) between January and August.

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Vol. 3, Issue 7, July 2014

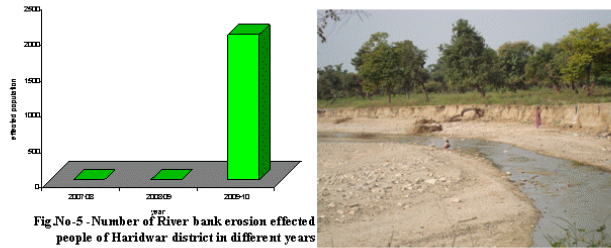


Fig.No-5 - Number of River bank erosion effected people of Haridwar district in different years



Plate -2:Bank erosion occurred by 2010 flood near Kangri village

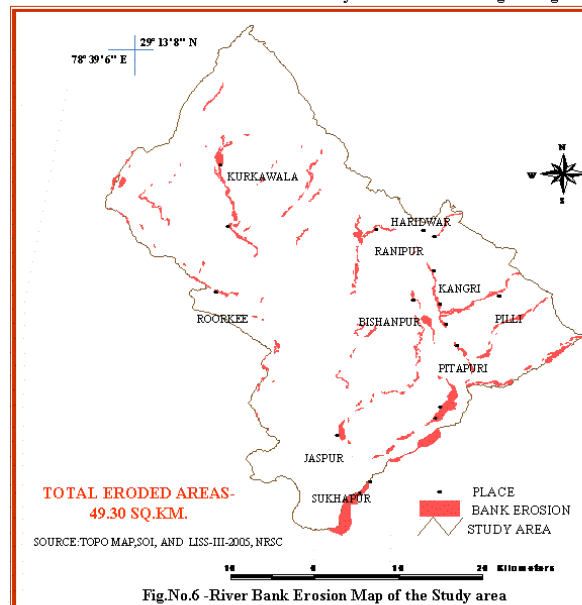


Fig.No.6 -River Bank Erosion Map of the Study area

## Geological factors

Geologically Siwaliks are a Tertiary formation (Fig-2) and essentially are made of vast deposits of alluvium, brought by river and glacial action from the Himalayas several million years ago. These deposits were subsequently thrown up in the form of a mountain range by tectonic activity. The northern portion of the study area includes young folded Tertiary Himalayan mountain and southern part falls under Ganga-Yamuna Doab. In north-south direction the region extends from Siwalik Himalaya to Tarai. The region is dominated by Himalayan Frontal thrust (HFT), Bhimgoda thrust and some other neotectonic faults. The upper Siwalik is composed the conglomerates of sand and clay. The middle Siwalik consists of sand-rock and the Nahan sandstone. Below the Siwalik, the submontane tract called Bhabar which is formed by widespread fan alluvium. In the south of the Bhabar tract lies the narrow and moist belt of Tarai covered with riverine alluvium. The whole formation from top to bottom is extremely prone to erosion from run-off.

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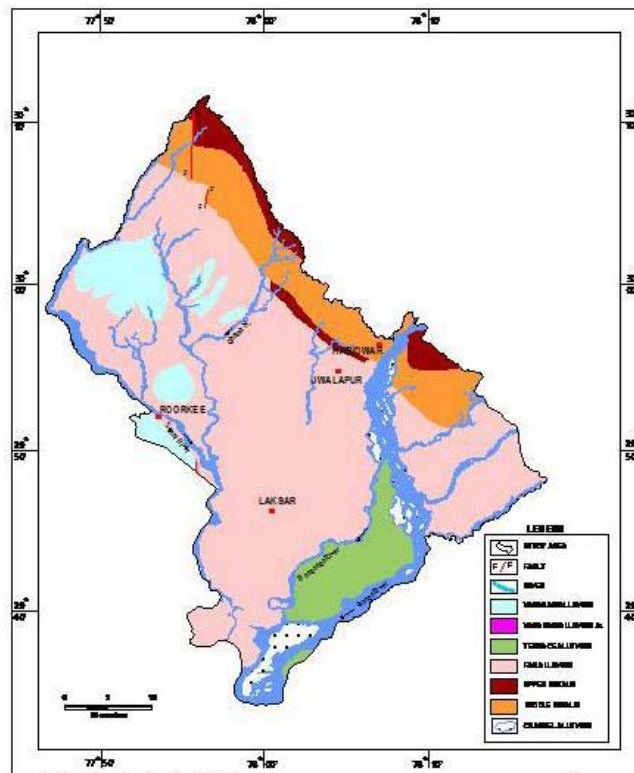


Fig.2: Geological Map

### ***Fragile geo-lithological structure***

Vulnerable geolithological formation is responsible for rapid river bank erosion. The researcher has also vigorously studied the physical and chemical properties of river bank soil and different soil samples were tested in laboratory (Fig.No.4) and it has been observed that the quantity of sand in the soil is more than 50 per cent and which proves the sandy nature of soil along riverbank and that is why the soil of the area is so much erosive in nature. From the over going discussion it is very clear that the fragile geolithological formation is not able to resist the fluvial erosion.

### ***Climatic factor***

The area is under the Tropical Monsoon type (modified) of climate with average annual rainfall of 124 mm. Maximum rainfall is observed during July-September. The maximum temperature of the year 2000 recorded at Haridwar was 40.3°C during June and the minimum was 6.1°C during January. Average annual temperature range is about 30°C. Mean annual temperature and rainfall (Table-2 & Table-3) have a great role in physical and chemical weathering of rock of the study area.

## International Journal of Innovative Research in Science, Engineering and Technology

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Issue 7, July 2014

year	Mean annual temperature (°C)
1997	23.31
1998	24.02
1999	24.62
2000	23.69
2001	23.88
2002	24.15
2003	23.43
2004	24.25
2005	23.06
2006	24.84
Source: NIH, Roorkee(2012)	

Year	Mean annual rainfall (mm)
2001	96.75
2002	96.91
2003	91.25
2004	94.50
2005	95.50
2006	92.32
2007	92.66
2008	94.41
2009	91.66
2010	130.5
Source: Revenue Office Haridwar(2012)	

**Integration of channel bars** In the study area a unique cause of river bank erosion is the integration of channel bars. The researcher vigorously studied the number of channel bars in Ganga river and it has been found that in 1967 (S.O.I., 1967) there were 180 channel bars in Ganga river and in 2005 (LISS III, 2005) the number of channel bars in Ganga river were 134. So it is very clear that the number of channel bar is declining from 1969 to 2005 and the researcher has also studied that the area of the bars are gradually increasing. So, from this investigation it is also evident that the bars are gradually increasing in size due to rapid channel deposition. From the field survey it is very evident that excessive channel deposition and integration of channel bars are very common phenomena in the area. This channel bars(Plate-2) are rapidly increasing with the reduction of the hydraulic radius of the channel .As a result, the lateral erosion in Ganga river channel is very prominent.

**Impact of bank erosion and channel shifting on land resources of Haridwar district**

According to Uttarakhand Space Application Centre (USAC) the Ganga river in Haridwar district has shifted 500 metres from its course over the past four decades. The state government agency said that the erosion of the river banks may be speeding change of course. According to M.M.Kimothi, director of USAC the absence of erosion preventive measures might be the reason for such accelerated shift,.The Uttarakhand Space Application Centre (USAC), which had conducted the count of pilgrims on the last Shahi snan in Haridwar through satellite imageries, has noticed this gradual shift in the course of the Ganga in the past four decades. The latest Haridwar imagery taken during the Shahi bath was compared to the 1970 Survey of India topographical sheet and the change was revealed. The shift was first noticed in the satellite images taken a year ago when USAC was collecting data for the Kumbh preparations. Moreover, the imageries taken through satellites in 2003 and 2006 were also taken into consideration, thus, further confirming the gradual shift in the course of the Ganga river in Haridwar.



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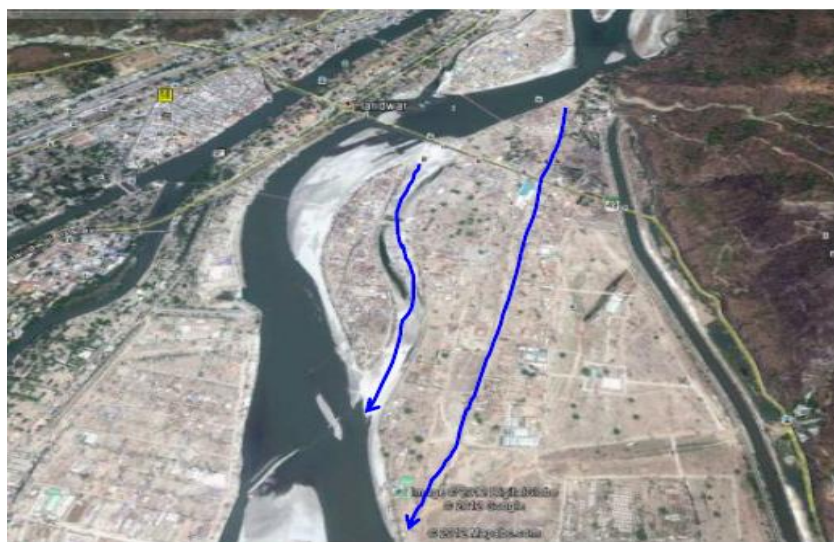


Plate-2: Identification of abandoned channel of Ganga river, near Haridwar city with GPS survey, Google image-2010

## II. CONCLUSION

The major land use pattern of this area are natural forest, grass and scrubland, man made forest, arable land (unirrigated), arable land (irrigated), settlement and built-up area, other including waste land etc. Recently the land surfaces are found to have been greatly changed by the human intervention. The holy Ganga along with its several tributaries- Solani, Ratmau Rao, Banganga etc has debouched from Siwalik. Thus spreading out huge amount of silts and other sediments of different size over the riverine plain to the south of the siwalik downstream is found. Because of the development of a distinct knicks/break across the Siwalik (through the Ganga tear fault) the characteristics of the river Ganga exhibits a drastic change. Such changes involve the formation of a series of depositional landforms in channel and active erosional effect along the bank of the river Ganga and its tributaries. Depending on field survey, the present researcher has identified some major hydrogeomorphic mechanism of riverbank erosion. Both geomorphological and hydrological factors are mainly responsible for bank scouring and bank failure. From over-going discussion it is obvious that shifting of channel, bank erosion are the major problem of the area. As a result, settlement area, agriculture and other man-made constructions are badly damaged by this hazard. Proper hazards zonation map, scientific land use map should be prepared and deforestation should be stopped in hilly areas by the local people and social forestry programme would be properly maintained by government and non-government agencies.

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**Vol. 3, Issue 7, July 2014**

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