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Assessment of Rainfall, Runoff and Sediment Losses of the Bheta Gad Watershed, India

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Abstract

Rainfall, runoff and sediment loss data were collected from four natural experimental plots of 20 x 5m. These were established on the four most common land cover types on three sub-catchments and at one main outlet during 1999 to 2002 in Bheta Gad watershed, Kumaon Hills in the central Himalayas. Land use and land cover details, the quality of streamwater, and soil characteristics under different land covers were also analysed. Plots were established for rainfed agriculture, pine forest, degraded pasture land, and tea plantations. The study found an annual variation of total runoff of from 51.1 to 3593 m^3/ha, and of soil loss of between 0.06 and 5.47 tonnes/ha from the experimental plots. The range of runoff from the sub-catchments and watershed ranged from $2.51x10^8$ to $176.45x10^9$ litres with sediment loss of between 118.78 and 1605.15 tonnes/km^2). The paper quantifies differences in terms of concurrent rainfall and the other variables and compares runoff and sediment loss in the watershed.

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Introduction

Complex meteorological, ecological, climatic, and geomorphological processes control water runoff and sediment discharge from a watershed. These processes are very important in the Hindu Kush-Himalayan region. The Himalayas are the youngest and most fragile mountains in the world and millions of tonnes of eroded fertile soil are transported downstream every year. Although they are the major source of water for the entire Indo-Gangetic plain area, tens of millions of upstream and downstream inhabitants suffer from serious water shortages.

It is therefore crucial to build a better understanding of the natural processes that cause runoff and sediment generation and to identify the influence of human activity on these processes. However, there is little reliable data to fully understand the processes involved.

The Bheta Gad watershed is a tributary of the river Gomti in the Ganga river system. It lies in the central Himalayas. The authors started an extensive study in this watershed in 1997 at plot, sub-catchments, and watershed level to investigate the relations between rainfall, runoff, and soil erosion.

Review

A number of authors have studied the dynamics of natural resources in the Himalayas and other mountainous areas of the world (Narayan et al. 1991, Singh 1999, Stewart et al. 1967). Negi (2002) has reviewed soil and water conservation studies conducted in the Indian

Himalayan region. Ram and Ramakrishnan (1988) and Bhatt et al. (1993) studied the plot runoff characteristics of terraced, shifting cultivation, forest, and barren lands in northeast India. Pathak et al. (1983), Pathak and Singh (1984), Loshali and Singh (1992), Negi et al. (1998), and Sen et al. (1997) studied the same for the central Himalayas in the Pinder and Pranmati catchments. Plot-scale soil conservation studies of the Shivaliks have been carried out by Lohan et al. (1996).

Medium-scale sub-catchment and watershed based runoff studies have been conducted by Joshi et al. (1996), Kumar and Satyal (2000), Valdiya and Bartarya (1989), Rawat and Rawat (1994a, 1994b), and Rawat and Rai (1997). These studies quantified the runoff and sediment losses from watersheds of the central Himalayas over different types of land cover — chiefly forest, agriculture, grass and wastelands. Similar studies have been carried out in the eastern and western Himalayan region by Rai and Sharma (1998a, 1998b), Singh (1997), Bahadur (1996), Rana and Subehia (1996), and Chaudhary and Sharma (1999).

Other relevant studies have included:
- Valdiya and Bartarya (1991) on the impact of land use, geology and anthropogenic pressure in the Gaula catchment, Kumaon, lesser Himalaya;
- Joshi and Kothyari (2003) on the influence of geo-hydrological features on the water chemistry of springs in the Bheta Gad watershed;
- Negi et al. (1998) on three high-altitude forested watersheds in the Nanda Devi Biosphere Reserve, central Himalayas;
- Malmer (1996) on the hydrological effects and nutrient losses of forest plantation in an experimental catchment in Sabah, Malaysia; and
- McGrath et al. (2001) who compared soil nutrient data from different land uses across Amazonia identifying patterns of nutrient concentration and variation with land use type.

These and other studies provide useful information for planning and managing cropping systems and for overall land use management in mountainous areas. However, there is little information available on the linkages of overland flow, soil erosion and nutrient losses that can be used in soil and water conservation for mountain land use planning. This paper aims to fill part of this gap by assessing overland flow and soil losses from different land uses in the Bheta Gad watershed at plot, sub-catchment, and watershed levels.

Study area

The Bheta Gad sub-watershed (Figure 11.1) drains an area of 23.5 km^2 in the central Himalayas in Uttaranchal state, India. It has a population density of 375 persons/km^2 and is typical of other watersheds in this region. It is characterised by a large altitude range (1,090-2,060 masl), and variations in slope aspect, forest cover, soil characteristics, land use and socioeconomic attributes (Bisht and Kothyari 2001). The area has a sub-tropical to temperate climate with three pronounced seasons of summer, monsoon, and winter. The mean annual precipitation is about 1400 mm and the mean monthly temperature varies from -2 to 38°C. Mica and chlorite schist, gneissic schist, biotite schist and gneisses, marble, granites and pegmatite are the area's major rock types (Valdiya 1979).

Chir pine (*Pinus roxburghii*) is the predominant conifer species and accounts for 69% of total forest cover. The important broadleaf species are *Quercus leuchotrichophora* (banj oak), *Alnus nepalensis* (utis), *Myrica esculanta* (kafal), and *Rhododendron arborium* (surans). They are found in mixed forests and in a few pure patches. Chir pine forests, tea plantations, upland agriculture, and grazing-cum-degraded lands areas are the most common land use types (Bisht and Kothyari 2001). The rainfed cropping land is fertilised with farmyard manure whilst irrigated agricultural fields receive light doses of inorganic fertiliser.

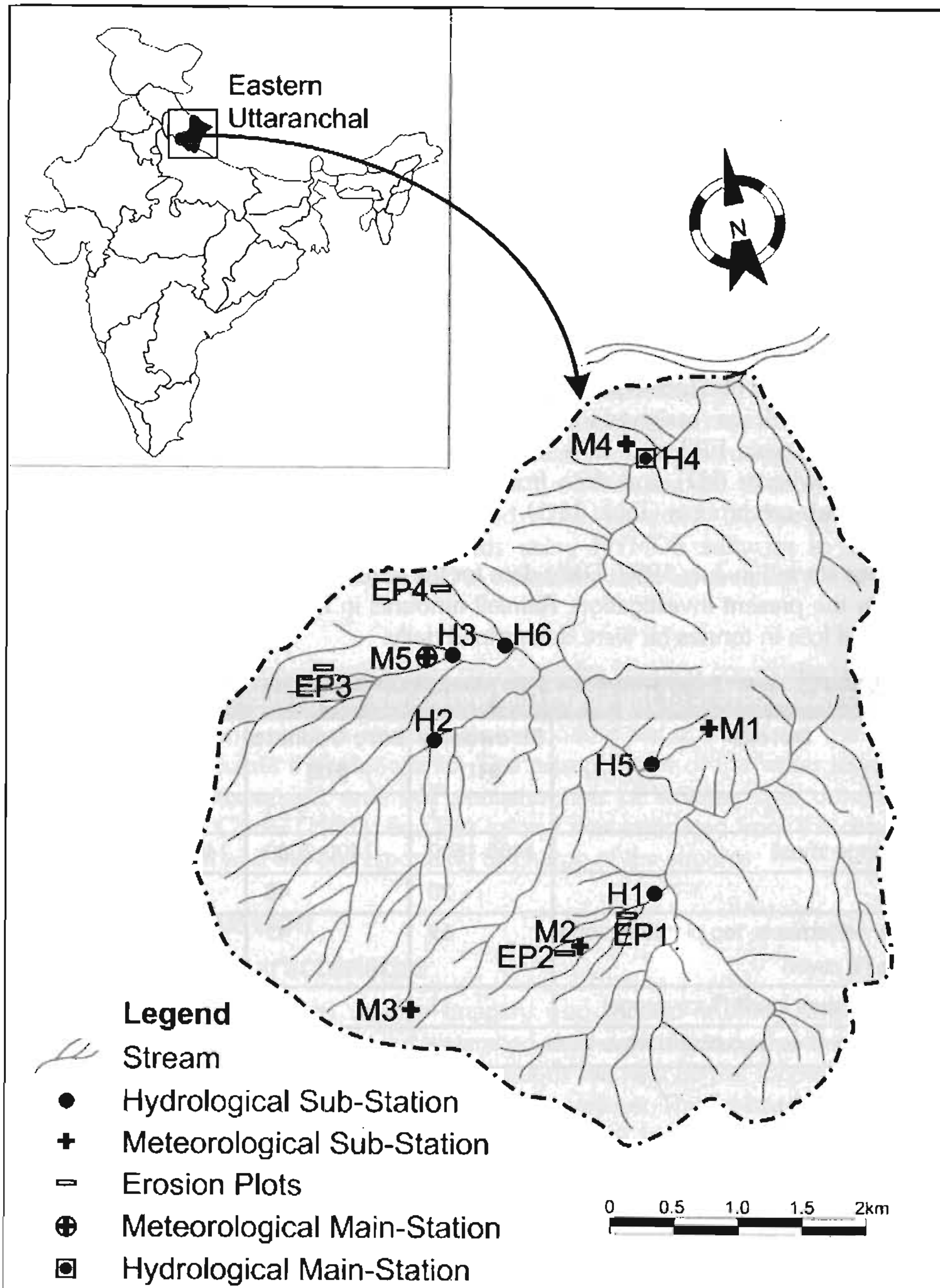

Figure 11.1: **Location of Bheta Gad watershed showing hydro-meteorological observation network**

Materials and Methods

Land use and land cover

Data on the land use and land cover characteristics of the watershed were collected from geographical information system (GIS) and remote sensing imagery, topographical maps, GIS software, and in other ways based on the study of Bisht and Kothyari (2001). The study's base map was based on the 1:50,000 Survey of India's topographical map, 1963. The GIS and remote sensing study of the watershed was carried out using ARC/INFO software backed up with ground truthing. Images from 1986 and 1996 satellite photographs (IRS-1A/1B, LISS-II bands 2, 3 and 4 at 1:50,000 scale) were digitised to assess changes over time (Bisht and Kothyari 2001).

Soil properties and precipitation

The chemical properties of the soil under the different land use systems where analysed as per Jackson (1962) and physical properties following Allen (1989). Meteorological stations were systematically placed in the watershed and were assigned to the nearest plots (Ramprasad et al. 2000). Precipitation was recorded with a tipping bucket rain gauge and a non-recording rain gauge at the five meteorological stations with data consolidated at a daily scale. Rainfall data from station M2 was assigned to plots EP1 and EP2, and data recorded from station M5 was assigned to plots EP3 and EP4. Rainfall data from M2 was assigned to the micro-catchment Strawberry (H1) and data from M5 was assigned to Bara Gadhera (H2) and Temple (H3) sub-catchments (Table 11.1).

Observations started in July 1997. Daily data for the January 1999 to December 2002 period was used in the present investigation. Rainfall amounts in mm, runoff volume in m^3/ha and litres, and soil loss in tonnes/ha were determined daily.

Table 11.1: **Land use details of the Bheta Gad watershed and its sub-catchments**

Details	Strawberry (H1)	Bara Gadhera (H2)	Lawbanj (H3)	Bheta Gad (H4)
Area (km^2)	1.1	2.63	1.7	23.5
Elevation range (masl)	1400-1600	1400-2000	1400-1800	1077-2000
Forest (%)	20	48	22	42
Agriculture, settlements, tea plantation and horticulture (% cover)	69	45	64	49
Barren and pasture land* (% coverage)	11	07	14	09

*: includes cultivable and uncultivable waste lands

Experimental plots

The four 20m x 5m experimental plots (EP) EP1, EP2, EP3, and EP4 were delineated along the slopes of four common land use types with different slope aspects and soil types but similar slopes (18.5 to 28 degrees). Details of each plot are given in Table 11.2.

The percentage of surface vegetal cover and crown area, tree density, and the basal area of tree cover were measured (Mishra 1968) for the watershed's four main land use types. The infiltration capacity of each erosion plot's soil was measured using a double ring infiltrometer.

Only the agricultural plot (EP3) received significant amounts of external inputs with farmyard manure applied each year. No external inputs were applied to the other three land uses (EP2, EP3 and EP4).

The surface runoff from the erosion plots was collected in a tank which overflowed into a second tank via a seven–slot divider that allowed the overflow into the other tank. Volume of flow collected in these tanks {volume of first tank + (volume of second tank x 7)} was considered as the plot runoff for storm events. The total amount of eroded soil — including both splash and sheet erosion — was estimated by filtrating a composite sample collected from both tanks after thoroughly mixing the collected runoff and sediment (Heron 1990, Hudson 1993). The soil loss samples were collected daily at the same time and were filtered as quickly as possible on the same day at Lawbanj field laboratory in the watershed. The sediment retained after filtration (paper type: Whatman No. 1, pore size 1.2 μm) was dried at 40°C for 24 hours and then weighed and compared with the weight of a control filter paper that had filtered an equal volume of pure water. The calculated soil loss was converted into sediment yield in tonnes/ha.

Hydro-meteorological observations were made from a set of nested stations (Hofer 1998). Hydrological monitoring was carried out in three micro-catchments (H1, H2 and H3) and at the watershed's main outlet (H4). Continuous analogue water-level recorders were set up on the perennial streams. Discharge was measured at random intervals using the current meter method (using pigmy, price, and propeller-type instruments), the salt dilution method (using conductivity meters), and the bucket method. The recorded discharge values were extrapolated for the entire water level records using HYMOS software to calculate the regression equation and the rating curve and to transform water level values to corresponding discharge at hourly intervals.

The suspended sediment concentration was measured by filtrating composite water samples collected at random intervals (Heron 1990, Hudson 1993). A regression analysis of the suspended sediment concentration and the corresponding water level from the floater was then carried out to calculate the relationship. The extrapolation of the water level values to calculate the hourly suspended sediment concentration of streams was done using the regression equation in Clarke (1981). Soil loss (g/day) was estimated from the concentration of suspended sediment and the corresponding discharge of the streams.

Results and Discussion

Land use and soil characteristics

Preliminary studies of the 1996 satellite imagery and ground truthing showed that the predominant land uses in the Bheta Gad watershed were agriculture and settlements. Of this 49% was rainfed agriculture lands, with tea plantations the next largest followed by scattered settlements and areas of irrigated lands mainly in the valleys. The forested areas are mostly either chir pine forest or pine-dominated mixed forests. A large patch of pine-dominated mixed forest covers much of the Bara Gadhera (H2) catchment. The third major land use is barren and degraded lands spread through the watershed. During 1996-97, a large tea plantation was established over about 7% of the area that obviously did not appear on the 1996 satellite image.

The characteristics of the soil were measured for the watershed's major land uses. The study was carried out over three elevation zones. The lower part of the watershed (below 1200m) is mainly covered by pine forest, and agriculture and settlement land including a large area of irrigated land (Table 11.3). The middle part (1200-1600m) is covered with pine forest, new tea plantations, and rainfed agricultural land. The areas over 1600m are mostly covered with pine-dominated mixed forest and rainfed agriculture and settlement areas.

The soil is mainly brown coloured and the texture is sandy loam or loamy sand. The pH varied from 5.88 to 6.35, representing a neutral soil. Its water holding capacity varied from 24.2 to 36.8%, with higher rates in areas of tea plantation, agricultural land, and patches of mixed forests. The pH is lower in pine forests and degraded lands.

Organic carbon was highest in soils in patches of mixed forest due to the accumulation and gradual decomposition of the leaf litter of broadleaved trees. The next highest was on soils on agricultural land, due to the application of farmyard manure. Soils on degraded land had the lowest organic carbon.

The soils in mixed forest and agricultural lands had higher levels of total nitrogen due to the accumulation of dead biomass and the application of farmyard manure respectively. The higher levels of nitrogen on irrigated agricultural lands were due to applications of inorganic fertilisers. The levels of available phosphorus and potassium were also higher in agriculture, tea plantations, and mixed forest land, with the least in degraded land soils.

Experimental plot results

Rainfall-runoff relationships

Runoff volumes were greater from the pine forest EP1 plot, followed by the grazed or degraded plot (EP4), the tea plantation plot (EP2), and the rainfed agricultural plot (EP3). The maximum interception of rainwater occurred on plot EP3 which is an area of terraced agricultural fields with seasonal cropping. Most intercepted rain infiltrated into the soil in spite of the fact that the infiltration capacity of the soil there was not so high (Table 11.2). The runoff coefficient for the tea plantation plot (EP2) was comparatively less due to its all year round cover. Although the infiltration capacity of the grazed/degraded plot's soil (EP4) was very high it intercepted very little rainwater. The EP1 pine forest plot had the maximum biotic pressure and the least vegetation cover, and so unsurprisingly produced the most runoff of all four plots.

Runoff–soil loss relationships

There was a poor correlation between the monthly soil loss and rainfall values. A significant correlation was found between corresponding values of soil loss and runoff. This indicated that the process of sheet erosion is more dominant than splash erosion in these areas. The pine forest plot (EP1) showed the most soil erosion, followed by the tea plantation (EP2) and the grazed degraded (EP4) plots. The plot agricultural land plot showed the least soil erosion, probably because terracing encourages soil sedimentation rather than removal.

Annual rainfall, runoff, soil and nutrient loss relationships

The annual values of rainfall, surface runoff, and soil losses in different years for each of the plots are listed in Table 11.4. Quite a few storms happened in the study period of an intensity above the infiltration capacity rate. The maximum rainfall intensity ($I10_{max}$) recorded for the watershed was 157.2 mm/hr. Annual runoff varied from only 51 m^3/ha on the agricultural plot

Table 11.2: **Physiochemical characteristics of soil of experimental plots in Bheta Gad watershed**

Plot no.	Land use	Slope	Slope aspect	Elevation (masl	CEC (meq/100g)	pH	OM (%)	N (%)	P (kg/ha) as P_2O_5	K (kg/ha) As K_2O	Bulk density (gm/cc)	Infiltration capacity (cm/hr)	C:N ratio
EP1	Pine forest	18.5°	SE	1460	8.68	6.39	2.29	0.143	38.3	229	1.43	5.8	11.5
EP2	Tea plantation	20.1°	E	1620	14.56	6.16	2.55	0.167	38.3	286	1.15	8.7	7.44
EP3	Rainfed agriculture	22.5°	E	1390	11.79	6.24	3.04	0.236	22.9	315	1.05	4.2	6.28
EP4	Degraded land	28.0°	S	1350	12.16	6.84	1.64	0.102	11.8	137	1.31	10.6	9.34

Abbreviations: C = Carbon; CEC = cation exchange capacity; OM = organic matter; N = nitrogen; P = phosphorous; P_2O_5 = phosphorous pentaoxide; K = potassium; K_2O = potassium oxide

Table 11.3: **Soil and vegetal cover characteristics of experimental plots of Bheta Gad watershed**

Plot no.	Soil colour	Soil texture	Sand (%)	Silt (%)	Clay (%)	WHC (%)	Surface veg. cover (%)	Tree density (no./ha)	Total tree basal area (m^2/ha)	Crown cover (%)
EP1	Light grey	SL	63	22	15	30.8	47±12	240 *Pinus roxburghii*	32±0.42	52±03
EP2	Greyish-brown	SL	66	25	09	31.9	56±04	1800 tea plants	0.72±0.03	73±05
EP3	Light gray	SL	63	25	11	33.9	75±03	150 *Grewia oppositifolia* and *Pyrus pashia*	4.80±0.11	26±06
EP4	Reddish brown	LS	73	16	11	26.6	41±08	0	0	0

SL = sandy loam; LS = loamy sand; WHC = water holding capacity

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Table 11.4: **Annual rainfall, runoff and soil losses from experimental plots in Bheta Gad Watershed**				
Land use	**Year**	**Rainfall (mm)**	**Surface runoff (m3/ha)**	**Soil loss (t/ha)**
Open pine forest (EP1)	1999	103.2	1554.4	4.24
	2000	176.5	3593.1	4.39
	2001	114.7	1357.0	2.08
	2002	118.1	1101.9	1.90
Tea plantation (EP2)	1999	103.2	452.0	0.90
	2000	176.5	1022.0	1.51
	2001	114.7	202.6	0.56
	2002	118.1	157.7	0.18
Rainfed agriculture (EP3)	1999	101.1	147.1	0.20
	2000	198.9	155.2	0.13
	2001	112.5	51.1	0.06
	2002	108.4	60.8	0.10
Degraded/grazing land (EP4)	1999	101.1	522.3	0.56
	2000	198.9	2266.8	2.48
	2001	112.5	930.6	0.86
	2002	108.4	679.6	1.24

in 2001 to 3593 m^3/ha from the pine forest plot in 2000. Soil loss varied from 0.06 to 4.39 tonnes/ha during the study period. Rai and Sharma (1998b) reported relatively higher rates of soil loss (4.2 to 8.8 tonnes/ha/year) from the Mamlay watershed in the Sikkim Himalaya (northeast India) under agricultural land use. Nevertheless, both of the above mentioned values are within the range of 500–1000 tonnes/km^2/year reported for the Himalayan region by Milliman and Meade (1983). Collins and Jenkins (1996), however, reported soil losses in the middle hills of the Nepal Himalayas similar to those observed in the present study.

Micro-catchment and watershed studies

The annual total rainfall, runoff, and soil loss for all three micro-catchments and for the Bheta Gad watershed as a whole at its outlet point are presented in Table 11.5. This table also gives the calculated soil loss per km^2 area. The rainfall values considered for the whole watershed is taken as the mean by using Thiessen's polygon method, considering the weighted mean of values from the five meteorological stations.

The values of rainfall varied from 989 to 1946 mm. The runoff ranged from 55 x 10^8 to 176.45 x 10^8 litres and annual total soil loss varied between 4,814 and 37,759 tonnes. The loss of soil varied from 205 to 1605 tonnes/km^2. Similar values (616 tonnes/km^2) were reported by Rai and Sharma (1998b) from the 30 km^2 Mamlay watershed in Sikkim.

Soil loss values reported from other watersheds have been considerably higher. Soil loss values, have been reported from other watersheds as follows:

Table 11.5: **Annual rainfall, runoff and estimated soil loss in Bheta Gad watershed sub-catchments**

Sub catchments	Year	Rainfall (mm)	Runoff (l) x10^6	Soil loss (t)	Soil loss (t/km^2)
H1	1999	989.7	2.51	130.65	118.78
	2000	1810.9	7.88	1531.97	1392.70
	2001	1139.8	3.55	312.51	284.10
	2002	1181.1	2.74	178.22	162.02
H2	1999	1011.5	9.72	998.74	379.75
	2000	1946.5	26.90	3917.14	1489.41
	2001	1124.2	7.42	770.49	292.96
	2002	1083.9	5.36	483.95	184.01
H3	1999	1011.5	6.35	1007.72	592.78
	2000	1946.5	16.20	2648.72	1558.07
	2001	1124.2	4.45	477.80	281.06
	2002	1083.9	2.90	278.67	163.92
H4	1999	1012.9	97.62	11287.71	479.84
	2000	1796.6	176.45	37759.45	1605.15
	2001	1084.7	93.10	8998.17	382.51
	2002	1119.0	55.14	4814.42	204.66

- 200 tonnes/km^2 by Rawat and Rawat (1994a and 1994b) from Nana Kosi catchments;
- 469 to 913 tonnes/km^2 by Rawat and Rai (1997) from two micro-watersheds in Garhwal Himalayas;
- 957 tonnes/km^2 by Chaudhary and Sharma (1999) from Giri catchments, Himachal Pradesh;
- 3596 tonnes/km^2 by Rana and Subehia (1996) from Bater micro-catchments, Himachal Pradesh; and
- 362 to 2250 tonnes/km^2 by Bahadur (1996) from Palampur.

Note that the quantity of soil and sediment loss from any watershed is also governed by factors other than rainfall intensity such as size of area, steepness, soil and geological characteristics, vegetation types and density.

Conclusions

Concurrent data on daily rainfall, runoff, total soil loss and estimated suspended sediment transport were observed from four natural experimental plots with different land covers from three micro-catchments, and from the overall Bheta Gad watershed. The study recorded the most runoff and soil loss from pine forest areas. The catchments data also shows the proportional increase of runoff and subsequent suspended sediment losses with amount of rainfall.

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