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Response of the Jakara stream channel to urbanisation

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ABSTRACT: This study assesses the morphological response of the Jakara stream channel to the effect of urbanization of its catchment. The proportion of the Jakara catchment under urbanization was determined using black and white air photographs taken in 1961and 1981, landsat imagery of 1987, 1995 and 2006. These were used together with land use maps, road maps and layout plans and ground truthing and three sites were identified thus: An upper watershed dominated by urbanization – Urban; A middle section that is under going urbanization - Semi urban and - A lower catchment that is primarily rural –Rural. Detailed field survey was conducted in six reaches of the Jakara channel, two each in urban, semi urban and rural sites to measure morphological variable. Morphological variables of the Jakara channel reaches under different levels of urbanization were compared. Consistent and significant differences in the sites were demonstrated in bankfull width, depth, cross section and wetted perimeter. Jakara channel is demonstrated to be consistently larger in the reach under urban land use than those under non-urban land uses, with capacity ratio of 2.36, width ratio 1.94, depth ratio 2.25. Most studies in humid tropical areas of Nigeria and temperate areas elsewhere reported smaller urban river channels enlargement. Sinuosity was 68.58% less in urban than rural reach. Channel density increased by 28.6% due to storm sewers, culverts and other runoff removal. The results of the study has implications for urban channel management and suggest that different strategies may be required for channel reaches based on the type of land use and that the selection of a mitigation strategy is dependent upon the extent to which the channel has been impacted by urban within the catchment.

Key Words: Channel site, Channel reach, Catchment, Impervious cover, Channel morphology

1. Introduction

Urbanization of catchment has been associated with serious problems that dramatically degrade both the form and function of stream ecosystems that can be difficult to mitigate (Booth and Jackson 1997). The complexity of urban land use and the varying responses reported present challenges for understanding the mechanisms by which urban impacts change channel structure and function (Booth *et al.*, 2004). These and several studies have shown that progressive urbanization of a catchment can result in among others changing channel morphology and hydraulic geometry of stream channels. A single disturbance event may trigger a variety of disturbances that differ in frequency, duration, intensity, and location (Klein 1979; Arnold *et al*. 1982; Booth and Jackson 1997; Trimble 1997; Nilsson *et al.*, 2003). These impacts have recently been referred to as Urban Stream Syndrome (Paul and Meyer, 2001, Walsh *et al.*, 2005a).

Despite the recognition of the problem, few studies have evaluated streams of semi-arid climates that have different hydrological characteristics with perennial streams. In Nigeria in particular, studies of urbanization impacts on river systems have concentrated in the humid tropics of south west and south east notably by Ebisimiju,(1989ab), Odemerho,(1992),Jeje and Ikezeato, (2002). There have been no such studies in the semi arid part; consequently, urban-induced channel changes in these areas are largely matters of anecdotal information with serious gaps in both our knowledge and the data. Thus relationships between urbanization and fluvial-hydrologic processes and channel morphology still remain a frontier waiting to be explored and better understood. This makes it difficult to establish proper understanding required to proffer suitable mitigation measures. Clearly no single study can cover all settings in which urban-induced channel change is observed. However, even a geographically limited set of new data can increase our understanding and predictive ability of this threat to aquatic-system integrity. This study was initiated to provide some of that new data, focused on a part of semi arid area where urban development is accelerating at unprecedented rates.

2. Study Area

The study is on the Jakara River catchment which is located between latitude 12^o 25 to 12^o 40 N and longitude 8^o 35 to 8^o 45E. The present climate of the study area is the tropical wet-end-dry type which is characterized by a wet season that lasts between June and September during which about 800mm of rain occur. Temperature is high throughout the year however, climate changes have occurred ending about 10,000 years BC (Olofin, 1991). During the arid phases desertic conditions are believed to have prevailed. On the other hand humid conditions wetter than the current tropical wet climate prevailed during the fluvial phases. The study catchment is located on the Basement Complex, and within the area where a wind drift material has concealed the pre-arid regolith and its associated ferruginous soils on the upland plain and old alluvial deposits on the river terraces.

3. Methodology

3.1 Site and reach selection

Impervious cover was used as surrogate to estimate the extent of urbanization in the Jakara catchment. Impervious area was estimated from airport photographs, land use maps, roadmaps, layout plans and land Landsat imagery and road map of Kano metropolis. The percent area under urban development for each site was calculated by summing the area of homes, streets and other structures and multiplied by average size of the development as determined by map inspection. These were truthed by fieldwork. Based upon the degree of urbanization, Jakara stream was divided into three sites with different levels of urbanization

a) An upper watershed dominated by urbanization (Fagge/Airport road/Nomansland)
b) A middle section that is under going urbanization exurban/semi urban (Gama kwari)
c) A lower watershed that is primarily rural (Dosara/Yadakunya)

The sites were selected after a field reconnaissance to establish that they conform to convention as demonstrated by Neller, (1988), May *et al*., (1997). Efforts were made to best represent the end members of the range. The percentage of impervious land was treated as an estimator of the percentage of land experiencing urbanization.

Having determined the three sites along the Jakara channel, two reaches were selected from each of the three sites for detailed study. The sample reaches were determined after a field reconnaissance to assess the overall character and the diversity of the channel morphology. Distortions especially points where a tributary or sewer joins the channel were avoided (Turner *et al.*,1991; Klauda *et al.,* 1998, Booth and Jackson,1997, Vannote *et al.,* 1980). The selected reaches were transacted to measure the morphological variables.

The following channel morphological variables were measured in the profiles at each of the six selected reaches:

Channel full dimension parameters: Cross section; Width; Depth; Wetted perimeter; Land use and Slope.

Channel Planform dimension parameters: Meander length; Meander width; Sinuosity and Number of threads (single or multiple)

Channel morphology was measured using tape, level rod and hand leveler to acquire detailed bankful cross-sectional data.

4. Results and Discussion

4.1 URBANISATION OF JAKARA CHANNEL

A detailed study of land cover of the Jakara catchment was conducted using black and white air photographs taken in 1961, 1981 and Landsat imagery for 1987,1995 and 2006. These were used together with land use maps, road maps and layout plans to determine the extent of urban land use from 1961 to 2006 along the catchment.

Up to 1961, the amount of urban structures on the Jakara catchment is minimal with less than 5% urbanization of the watershed. In addition, urban structures were not impervious (houses were made of up mud and most of the roads were laterite covered) and well outside the channel. A substantial part of the catchment is used for agriculture and grazing only. The amount of urban development within the Jakara watershed increased substantially from 1987, the period of high urbanization. When expressed as percentage of the total catchment area, the amount of the amount of urbanized land increased from 4% in 1961 to 27.95% in 1987.

Figs. 1, 2 and 3, were produced with data from Landsat imagery interpretation followed by intensive field verification show land use changes along the Jakara catchment for the years 1987, 1995 and 2006. The main concentration of urban/impervious surface is at the upper course where the catchment is 100% under impervious cover. The middle course is a transition area experiencing very rapid change from rural to urban with the impervious surfaces covering about 13%. The lower course is generally rural, with impervious areas covering only about 3% of the catchment.

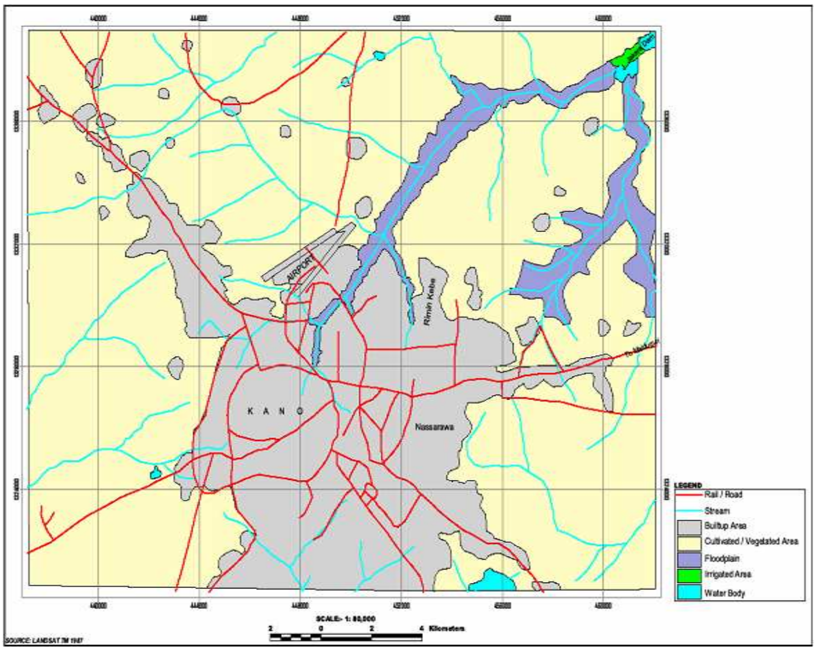

Fig. 2 Land use along the Jakara catchment Kano metropolis, 1987

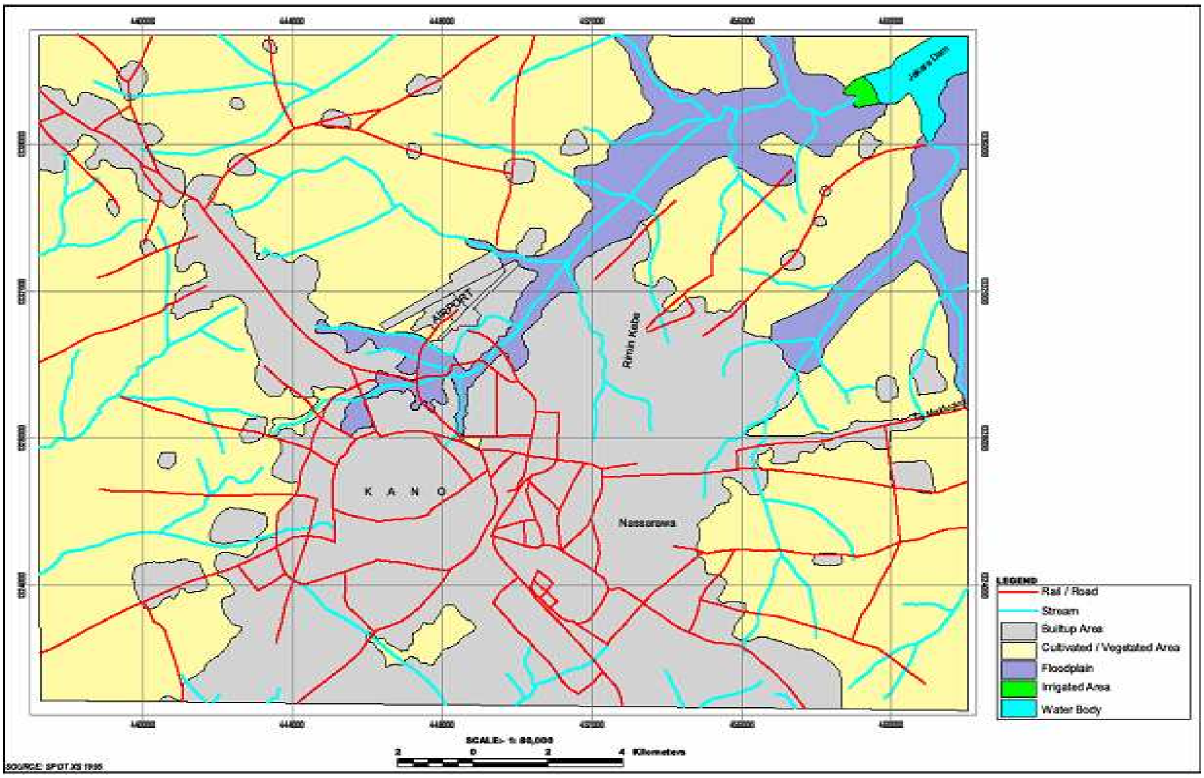

Fig. 3 Land use along the Jakara catchment Kano metropolis, 1995

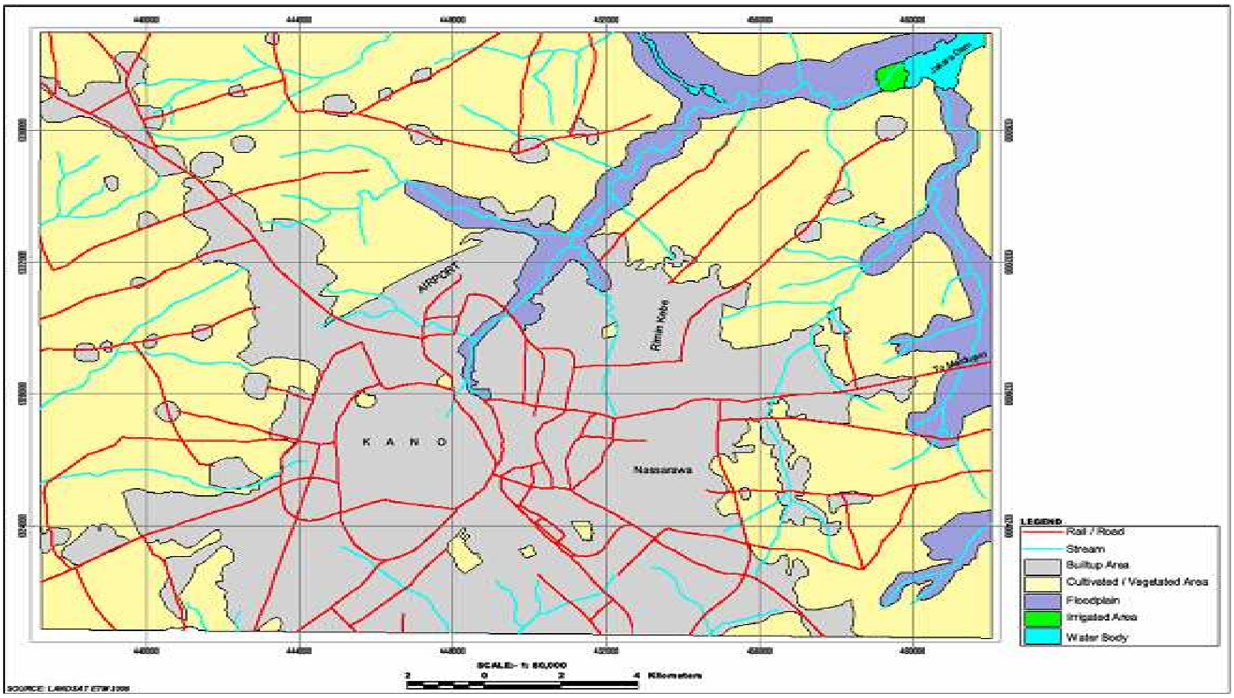

Fig. 4 Land use along the Jakara catchment Kano metropolis, 2006

Analysis of types of urban surfaces in the Jakara channel shown in Table 1 revealed that rooftops alone constitute the major type of surface in the urban and semi urban sites of the Jakara catchment as opposed to the cases reported in Europe and North America, where the transport component exceeds the rooftop component in terms of total impervious area created. For example, transport-related imperviousness comprised 63 to 70% of total impervious cover at the site in 11 residential, multifamily and commercial areas where it had actually been measured (City of Olympia, 1994b).

Table 1 Proportion of Impervious Cover in the Sampled Reaches of Jakara channel.

Characteristics	Rural reach	Semi urban reach	Urban reach
Total area(m^2)	17.5	15.0	17
% Roads	0.01	0.30	0.80
% Flood plain	5.20	6.10	NIL
% Buildings	2.60	28.0	99.0
% Cultivated area	80.0	5.60	NIL
% Irrigated area	11.0	9.00	NIL
% Water body	0.30	0.60	0.20
% Total impervious area	2.61	28.3	99.8

Source: Land use Map of Kano Metropolis, 2000, Land sat Imagery of Kano 1987, 1995, 2006 and Field work, 2008.

4.2. JAKARA CHANNEL FULL MORPHOLOGICAL VARIABLES

Table 2 shows the morphological variables of full channel dimension of the six sampled reaches.The mean channel width is 12.73m with standard deviation of 3.78 and coefficient variation of 29.8 percent and a range of 10.8. The mean cross-sectional area is 24.54m^2 with standard deviation of 17.37, coefficient of variation of 70.8 percent and a range of 6.59. The mean depth is 1.71m, standard deviation of 0.81 and coefficient of variation of 47.4 percent and a range of 2.11. The mean wetted perimeter is 18.43m, standard deviation 2.69, coefficient of variation 14.6 percent and a range of 6.59. The statistics show a high degree of variation in the channel dimension considering that it is a 3rd order stream. This is reflected in the high variation between standard deviation and mean value and the range. However, all the variables of full channel dimension show that the urban reach is larger than the semi-urban and rural reach. The relatively large channel size draining impervious reach could be due to increased peak discharges because, impervious surfaces cause increased storm runoff, flood frequencies, and peak discharges compared to pre-urban conditions. Previous works elsewhere have shown runoff increased by 200–500% as a result of urbanization (Paul and Meyer, 2001, Arnold and Gibbons, 1996, Booth, 1991). Streams adjust to such increased regimes by altering their cross-sectional area to accommodate the higher flows. This is done either through widening of the stream banks, and down cutting of the streambed, or frequently, both.

Table 2. Channel full dimension variables.

Channel reach	Width (m)	Depth (m)	Cross section m2	Welted parameters(m)
Sample point I	18.80	2.81	52.83	16.01
Sample point II	16.70	2.53	42.25	14.97
Sample point III	10.75	1.80	19.35	17.11
Sample point IV	12.11	1.62	19.62	18.97
Sample point V	8.10	0.79	6.34	20.90
Sample point VI	9.90	0.69	6.83	22.60
Mean	12.73	1.71	24.54	18.43
Standard Deviation	3.79	0.81	17.37	2.69
Range	10.80	2.11	46.49	6.59
Coefficient of variation	0.298	0.474	0.708	0.146

Source: Field work, 2008

On the other hand, the relatively smaller channel size of streams draining semi urban and rural reaches could be due to low flow peak discharges brought about by high infiltration capacity. Rural channel reduction could be also due to fluvial deposit and the abandonment of the former summit by running water. Table 3 is a comparative analysis of the reach morphological variables of the six sampled reaches. The data shows first, that there is uniformity in the variables within individual sampled reach. The data also indicate that the width and depth increase in the downstream direction, as do cross-sectional area and wetted perimeter in the rural non-impervious reach. The semi urban reach also shows a similar increase in these variables in a downstream direction. The urban reach however, shows a slightly different trend with mean depth, width and cross-sectional area not showing an increasing trend in the downstream direction.

Generally, reach morphologies are associated with physical processes that limit the range and magnitude of possible channel responses to changes in discharge. Reach-specific response is thus affected by external influences, such as channel confinement, riparian vegetation, the location of the reach within the drainage basin and the sequence of upstream reach types. It has also been shown that channel characteristics do not necessarily take place uniformly because of variations in boundary materials or direct disturbances to river channels. Thus as observed by among others Allen and Narramore, (1985), Booth, (1990), several factors explain the variation in the channel response observed.

Table 4 shows the channel planform characteristics in the urban, semi urban and rural reaches of the Jakara channel.

Table.3 Comparative analysis of Reach dimension variables.

Channel reach	Width (m)	Depth (m)	Cross section m^2	Wetted parameters
Urban Reach				
Sample I	18.80	2.87	52.83	16.01
Sample II	16.70	2.53	42.25	14.97
Mean	17.75	2.67	47.54	15.48
Standard deviation	1.49	0.14	5.29	0.52
Coefficient of variation	8.00	5.20	11.10	3.40
Simi- Urban Reach				
Sample 1	10.75	1.80	19.35	17.11
Sample 11	12.11	1.62	19.62	18.97
Mean	11.43	1.71	19.49	18.04
Standard deviation	0.68	0.09	0.135	0.93
Coefficient of variation	59.50	5.20	6.9	5.20
Rural Reach				
Sample 1	8.10	0.79	6.34	20.90
Sample 1I	9.90	0.69	6.83	22.60
Mean	9.0	0.74	6.59	21.75
Standard deviation	0.90	0.05	0.24	0.85
Coefficient of variation	10.00	7.00	3.70	3.90

Source: Field work, 2008

Width/ depth ratios are higher in the urban reach compared to the semi-urban and rural reach. This can be explained by the fact that increased flooding associated with urbanization often leads to erosion of the stream bank which increases the ability of the channel to convey the increased flood flow. The increased cross sectional area creates reduced velocities, reducing the channel's sediment transport capacity and allowing sediment to settle out. One possible explanation for lower width/depth ratios in the semi urban and rural reaches is that greater sediment yield from erosive land use accreting on the stream bank and floodplain. In the urban reach, the width of the meander belt is lower than that of semi urban (5.95m vs. 11.75m), whereas, rural reach has a wider average width of the meander belt than semi urban and urban reaches (34.55m).

The Jakara channel enlargement variables measured showed a capacity ratio of 2.36, width ratio 1.94, depth ratio 2.25 and enlargement ratio of 7.21. The ratios obtained in this study however, indicate much larger increase compared with what has been reported elsewhere where, typical channel enlargement ratios range from 1.0–4.0 (Gregory, 1987a). Data from humid tropical areas of Nigeria include downstream sections of the Ekulu capacity ratio of 0.79, (Jeje and Ikeazota, 2002), channels along the headwaters of

Elemi River through the village of Igede, capacity ratio of 0.81, (Ebisemiju, 1989a) and in the Ikpoba River in Benin City with capacity ratio of 1.2 (Odemerho, 1992) also indicate that the magnitude of these changes has generally been smaller than the observation in this study.
Several researchers suggest reasons for the likely variations in the increase in channel sizes. Regional variations related to hydro climatic effects have been proffered notably by Ebisemiju, 1(989a,b), Jeje and Ikeazeato (2002) in the humid tropics of Nigeria and southeast Asia Douglas, (1974, 1985b), along with recent work in semi arid regions of Arizona by Chin and Gregory,(2001) and Israel by Laronne and Shulker, (2002).

Table 4 Comparison of Reach Planform Dimension Variables.

Channel characteristics	Urban Reach	Semi-Urban Reach	Rural Reach
Meander length (m) (mean)	5.95	11.75	34.5
Meander width (m) (mean)	2.95	8.57	4.5
Slope	2.05^0	1.8^0	1.05^0
Sinuosity	1.07	1.21	1.56
Width/depth ratio(mean)	12.30	6.70	6.65

Source: Field work, 2008

In this study, the low rainfall in the area (typical of semi arid regions) results in weathering processes dominated by mechanical rather than chemical means. Clay production is thus inhibited and silt-sized fractions are predominant in the soils. The lack of bank-stabilizing clay in a semi-arid region ephemeral stream channels may partially explain why these channels typically have wide, shallow, with low sinuosity geometries. Similar observation was made elsewhere (see, Schumm, 1961).
The sparseness of vegetation along some stream banks in these areas can also contribute to larger channel widening tendencies since vegetation along the bank of the channel has been known to stabilize the channel and restrict bank collapse and erosion as was also observed by among others, Reid and Frostick, (1997) , Merritt and Wohl, (2003).

The large channel observed in this study may also be due in part to several localized factors. Roof tops have been shown to be important medium in conveying runoff speedily to channel enhancing erosion and channel enlargement. This added to absence of lawns, intense modification of the channel, sand mining on the channel, weak soil and intense rainfall events are likely causal factors of the observed widening.
Furthermore, it is pertinent to bear in mind also, that the ultimate base level for fluvial processes in the study area is the mean water level of Lake Chad which at 282m above sea level is only 150m lower than the bed elevation of the channels in the study area. Hence, the capacity of the channels to evacuate the floods generated does not match the rate of generation, leading to channel widening to accommodate the floor water. The storm channel is, therefore, a natural response to the combination of the prevailing environmental factors in the study area (Olofin, 1989b).

It has also been argued that response to land use or environmental change varies for different channel types. Alluvial channels like that of Jakara, in particular, exhibit a wide variety of potential responses. Changes in channel roughness due to alteration of channel sinuosity and bed forms which are pervasive in this area can also explain the large capacity ratio in this area.

5. CONCLUSION AND RECOMMENDATION

The results of this study indicate that the all variables of channel dimension show that the urban reach is larger than the semi-urban and rural reach. The observed variation in channel morphology due to urbanization has serious implication to urban channel management. Effective management requires a clear understanding of the spatial variations in channel changes due to urban development. Recognizing spatial variations in channel characteristics within and between sites is also important to developing appropriate management schemes for changing urban channels. Variations within the channel reaches observed mean that different strategies may be required for different channel segments to handle spatially distributed response mechanisms. Consequently, the selection of a mitigation strategy is dependent upon the extent to which a channel has been impacted by urban development within the catchment, the nature of the stream channel reach under consideration, and the anticipated future conditions required.

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