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Groundwater Recharge Potential Using GIS around the Land Development Facilities of Chulalongkorn University at Kaeng Khoi District, Saraburi Province, Thailand

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Abstract

Kaeng Khoi District (Saraburi Province, Thailand) suffers from a surface water shortage due to increasing demand from domestic use and crop production, particularly in the drought season. Groundwater resources are an additional source of freshwater in this area, especially for agricultural purposes, but to be sustainable its usage should not exceed long-term groundwater recharge. Evaluation of the groundwater recharge potential is therefore essential to determine the sustainable use level for groundwater resources. This study aimed to determine the groundwater recharge potential using the geographic information system (GIS) around the Land Development Facilities of Chulalongkorn University at Kaeng Khoi District, Thailand. The hydrologic and geologic features affecting groundwater recharge potential into the groundwater system are the lineaments, drainage density, lithology and land cover/land use. The weighting of these factors were derived from integration of the interrelationship of the major and minor effects of each contributing factor. Then GIS overlay was used to determine the influence of the hydrologic and geologic effects on total groundwater recharge potentiality, classified into five categories: very high, high, moderate, low and very low. The highest recharge potential zone was located in the downstream areas. The map generated revealed that about 50 % of the study area had a medium groundwater recharge potential, mainly located in the eastern upstream part and the central area.

Keywords: Groundwater recharge; Geographic information system; Groundwater; Kaeng Khoi District

Introduction

Groundwater is an essential and optional water resource for many purposes, especially for the agricultural sector in Thailand. However, to ensure sustainable groundwater use, average groundwater recharge into aquifers should be higher than groundwater demand from the groundwater reservoir over a long time period. *Groundwater recharge* is defined as the entry into the saturated zone of water made available at the groundwater table [1]. The groundwater recharge is temporally and spatially distributed and depends upon many contributing factors, including topographic, meteorological, hydrological and geologic characteristics [2].

Many techniques have been used to measure groundwater recharge, including both point-based and lumped areal estimations. Examples of point-based groundwater recharge estimation include the study of applied mass balance of chloride to estimate groundwater recharge in the eastern Mediterranean area [3], and the use of the soil water balance model with groundwater level fluctuations to calculate groundwater recharge in the central Kansas plains [4]. However, point-based estimation methods are time- and cost-demanding to perform the field measurements, and the obtained recharge rates cannot be extrapolated over a wide-range scale. For reliability and accuracy, groundwater recharge estimation on a large-scale and/or complex area should be evaluated by distribution models, which are useful for spatial analysis using the geographic information system (GIS) to provide a better map of groundwater recharge potential that can be used to ensure sustainable groundwater resource management [5]. The GIS technique has been used for assessing groundwater recharge potential and can incorporate multiple factors such as drainage density, lithologic characteristics, hydrologic characteristics, and land use/cover [6-8]. The results can be applied further to develop appropriate guidelines for sustainable groundwater resource management.

The surrounding areas of the Land Development Facilities of Chulalongkorn University, Kaeng Khoi District, Saraburi Province, have long faced a water shortages, particularly in Huai Haeng sub-district and the areas located outside the irrigation areas in the dry season, because of high water demand from the agricultural sector. This has led to excessive consumption of surface water. Hence, an assessment of the secondary water resource (groundwater resource) is essential to ensure sustainable water management in the area. The main aim of this study was to construct a groundwater recharge potential map of the Land Development Facilities of Chulalongkorn University and adjacent areas (Figure 1).

Study area

The study area (Figure 1) comprises the areas surrounding the Land Development Facilities of Chulalongkorn University at Kaeng Khoi District, Saraburi Province, which is approximately 142 km north of Bangkok. This watershed covers an area of approximately 314 km^2. The length of the major stream is about 17.65 km and the area is located in zone 47 in the northern hemisphere at an easting of 708000-734000 and a northing of 1593000 -1613000. Mean annual rainfall over the 30-year period from 1981 to 2010 was 1,253 mm/year.

Methodology

In this study, various types of data (e.g. hydrologic and geographic information) were collected and digitized as thematic layers using GIS. The groundwater recharge potential was evaluated to assess the relationships among the various contributing factors that affect groundwater recharge. The weight and rate of each contributing factor on groundwater recharge were categorized according to those values that gave reliable results [10]. Finally, spatial analysis was used to integrate the GIS multilayer system to obtain a map of groundwater recharge in this area. The factors affecting groundwater recharge potential are shown in Table 1 and are described in the following sections.

Lithology

The geological map, as a shape file, was obtained from the Department of Mineral Resources (DMR) and in the GIS. The area was assigned the percolation values of the lithological units in the field [9]. Based on the known percolation rates of each rock type, the rock types in the present study were classified into three categories [10] as shown in Table 2. The clay content (%) in the quaternary alluvial deposits controls the water infiltration and reduces the permeability among rocks. Joints and fractures in fracturing systems within hard rocks increase the rock permeability and water percolation. A map of the zones of different lithological characteristics with respect to groundwater recharge was then prepared, and is shown in Figure 2 (a).

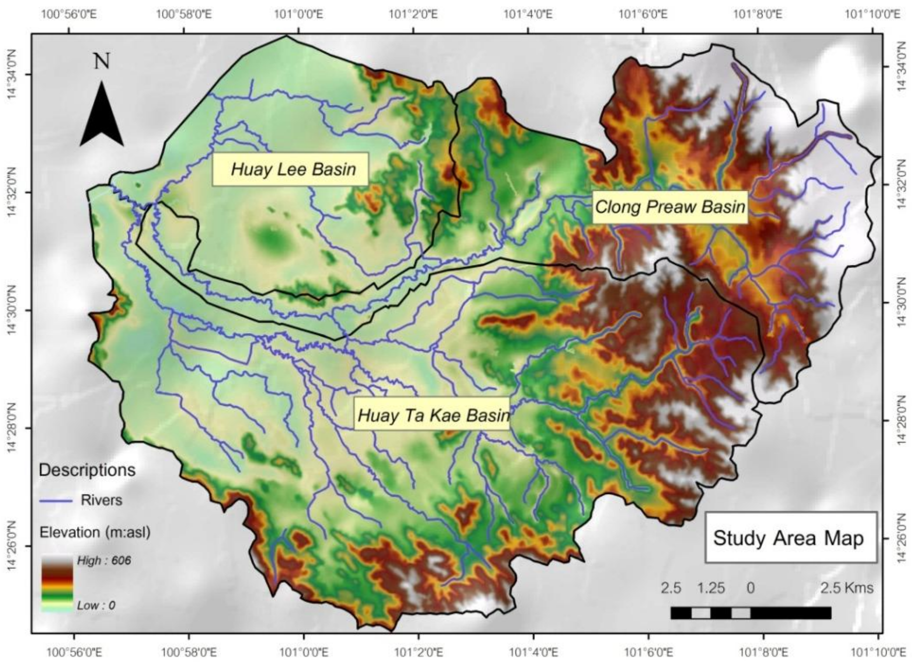

Figure 1 Map showing the study area.

Table 1 Factors that affect the groundwater recharge of the study area (as used in the GIS analysis)

No.	Data	Source[a]	Date	Details
Hydrological data				
1	Rainfall data	TMD	1981–2010	Statistic (.xls)
2	Stream line	DWR	2007	GIS (.shp)
Geological data				
3	Geologic structure	DMR	2005	GIS (.shp)
4	Lithology	DMR	2005	GIS (.shp)
5	Boundary	DMR	2005	GIS (.shp)
Land use/ Land cover data				
6	Land use data	LDD	2009	GIS (.shp)

[a]TMD : Thailand Meteorological Department
DWR: Department of Water Resources
DMR: Department of Mineral Resources
LDD: Land Development Department

Table 2 Factors that affect the groundwater recharge in the present study

Factor	Basis of categorization	Descriptions
Lithology	Rock type Weathering character Joints and fractures	Volcanic rock, Rhyolite and Andesite Volcanic rock and Rhyolitic tuff Quaternary alluvial deposits
Lineament	Lineament-density value	No lineament Lineament in hard rock unit Sediment unit
Land use/ Land cover	Type Areal extent Associated vegetation	Built up and urban area Agricultural area Forest area Water body
Drainage	Drainage-density value	0 - 0.00083 (m/km^2) 0.00083 - 0.00219 (m/km^2) 0.00219 - 0.00545 (m/km^2)

Land use/cover

Based on the shape file obtained from the Land Development Department (LDD), the four land use/cover categories in the study area were water body, forest, agricultural, and urban/built up land. Land use/cover is one of the major factors influencing groundwater recharge estimation. Moreover, the amount of groundwater recharge due to land use/cover changes can be estimated from changes in groundwater levels [11]. A land use/land cover map was produced for the difFerrent groundwater recharge zones and is shown in Figure 2(b).

Drainage density index

The stream data from the Department of Water Resources (DWR) was prepared in order to calculate the drainage density. The drainage system was categorized into three ranges of drainage density value (Table 2 and Figure 2 (c)). The dendrite drainage characteristics had a small sinuosity, indicating the homogeneous nature of the massive bedrock types. The drainage density, defined by the total length of the stream channel in a unit area [12] is spatially different, depending on climatic conditions, lithology, topographic characteristics and land use impacts [13]. The drainage network was determined using Kernel's method to evaluate the possibility of groundwater recharge zone. The surface drainage map was produced from the Digital Elevation Map (DEM) of 30-m resolution (1:50000 scale). The surface drainage map of the area ranged from 0 to 0.00545 m/ km^2 and was classified into three categories: high-moderate (0.00219 to 0.00545 m/km^2); moderate (0.00083 to 0.00219 m/km^2) and low drainage frequency (< 0.00083 m/km^2) and then generated as a thematic layer by ArcGIS 10, as shown in Figure 2(c).

Lineaments

The linear geological features of the study area were obtained from the Department of Mineral Resources (DMR). This study used lineament-length density [12], which shows the total lineament length per unit area, as shown in Equation 1.

$$Ld = \frac{\sum_{i=1}^{i=n} L}{A} \qquad \text{Equation 1}$$

where $\sum_{i=1}^{i=n} L$ represents the summation length of lineament (L) and A represents the unit area (L^2). A high lineament density signifies a high secondary porosity, indicating that the area has a high groundwater recharge potential. From this a lineament density contour map was prepared as shown in Figure 2 (d), and a synoptic classification was made to indicate a moderate-low, low and very low frequency.

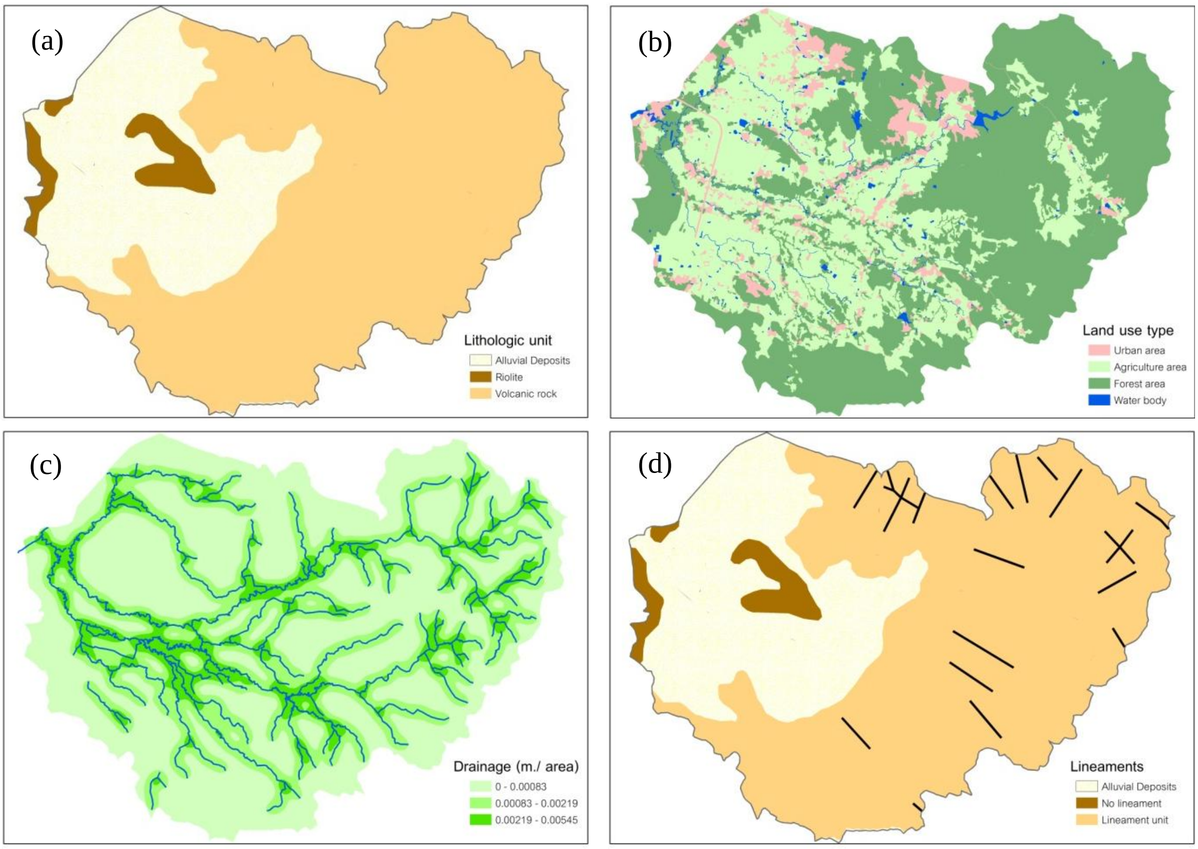

Figure 2 Factors affecting the groundwater recharge: (a) lithology, (b) land use, (c) drainage density (m/km^2) and (d) lineament.

Results and discussion

The four factors (lithology, land use/cover, lineaments and drainage density) influence groundwater recharge and are inter-dependent factors. The evaluation of the interrelationships of the major and minor degree of each factor on groundwater the recharge potentiality followed the study of Adham et al. and Shaban et al. [7, 14].

The major description levels were classified in discrete degrees, ranging from a very high to a very low contribution to the groundwater recharge potential. The weighting of each factor was categorized from very high (10 pt.), high (8 pt.), high-moderate (6.5 pt.), moderate (5 pt.), moderate-low (3.5 pt.), low (2 pt.), or very low (1 pt.). According to Figure 3, which presents the interaction among contributing factors, the factors of main influence were assigned 1 pt, whist the minor influence were assigned 0.5 pt. The relative rates were finally calculated from both main and minor influences as shown in Table 3. The lithology was found to be the main factor affecting the other three major influences, with a derived weight of 3.0, whilst that for land use/cover and lineament were 2.0, and the drainage density weight was 1.5.

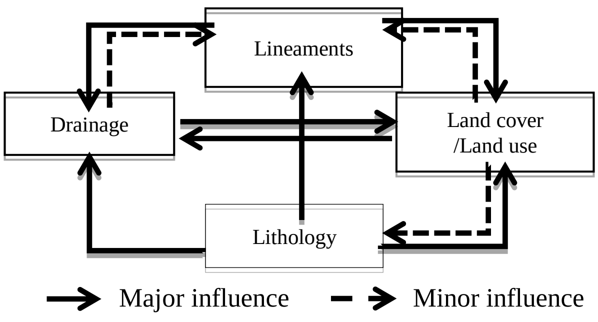

Figure 3 The interactive influence of factors considering groundwater recharge potential [10].

Table 3 Evaluation of the rates and weights of the factors and their contributing classes used for evaluating the groundwater recharge potential in the study area

Factor	Description Scale	Weight (1-10)	Rate (1-3)	Weighted rating	Total	Factor on recharge potential capacity (%)
Lithology	High	8	3	24	45	36.2
	Moderate	5	3	15		
	Low	2	3	6		
Lineament	Moderate	3.5	2	7	13	10.5
	Low	2	2	4		
	Very low	1	2	2		
Land use/ coverage	High	8	2	16	46	37.0
	High-Moderate	6.5	2	13		
	Moderate	5	2	10		
	Moderate-Low	3.5	2	7		
Drainage	High-Moderate	6.5	1.5	9.75	20.25	16.3
	Moderate	5	1.5	7.5		
	Low	2	1.5	3		
			Grand total weight		124.25	100

The rates and weights of each contributing factor were integrated and then the sum of weighted factors used to represent the degree of the groundwater recharge (Tables 2 and 3; Figure 4), which is finally presented as the groundwater recharge potentiality map (Figure 5).

The final map was derived from the sum of all the weighted factors using the overlaying technique in the GIS system. Accordingly, the recharge potential categories and their qualitative estimation in the study area were calculated (Table 4), and the groundwater recharge potentiality map (Figure 5) was prepared with descriptive categorical levels of very high, high, moderate, low and very low (Table 4). The grand total weight of all contributing factors in this case is 124.25, which was further used for calculation of percentage of individual factor effects on the recharge potential capacity. The high potential groundwater recharge zone located in the western downstream areas was found to be due to the quaternary alluvial deposits and intensive agricultural areas, which increase the ratio and level of water infiltration into groundwater aquifers. The moderate potential areas are mainly located in the eastern upstream and central parts of the present study, and cover ~175 km^2 or 55.6% of the total area.

Table 4 Areas of groundwater recharge potentiality (km^2)

Recharge potentiality class	Estimated recharge rates[a]	Average recharge rates[a]	Area (km^2)	Area (% of total)
Very high	45–50%	47.50	25.59	8.15
High	30–35%	32.50	70.58	22.48
Moderate	10–20%	15.00	174.43	55.56
Low	5–10%	7.50	33.37	10.63
Very low	<5%	2.50	9.98	3.17
		TOTAL	313.94	100.00

[a] From [15]

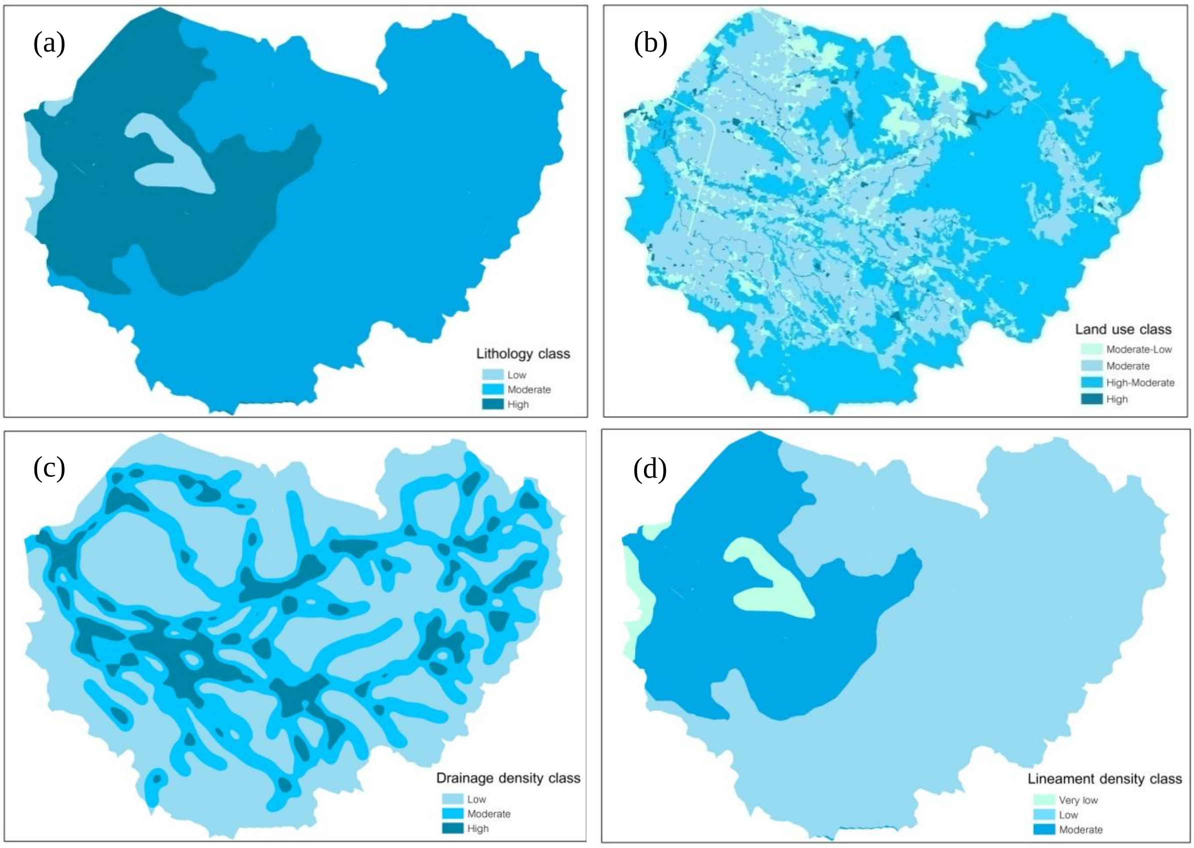

Figure 4 Spatial data weight of the four factors used to assess groundwater recharge. The factors are shown in the six classes of very low, low, moderate-low, moderate, high-moderate and high for the: (a) lithology, (b) land use, (c) drainage density and (d) lineament.

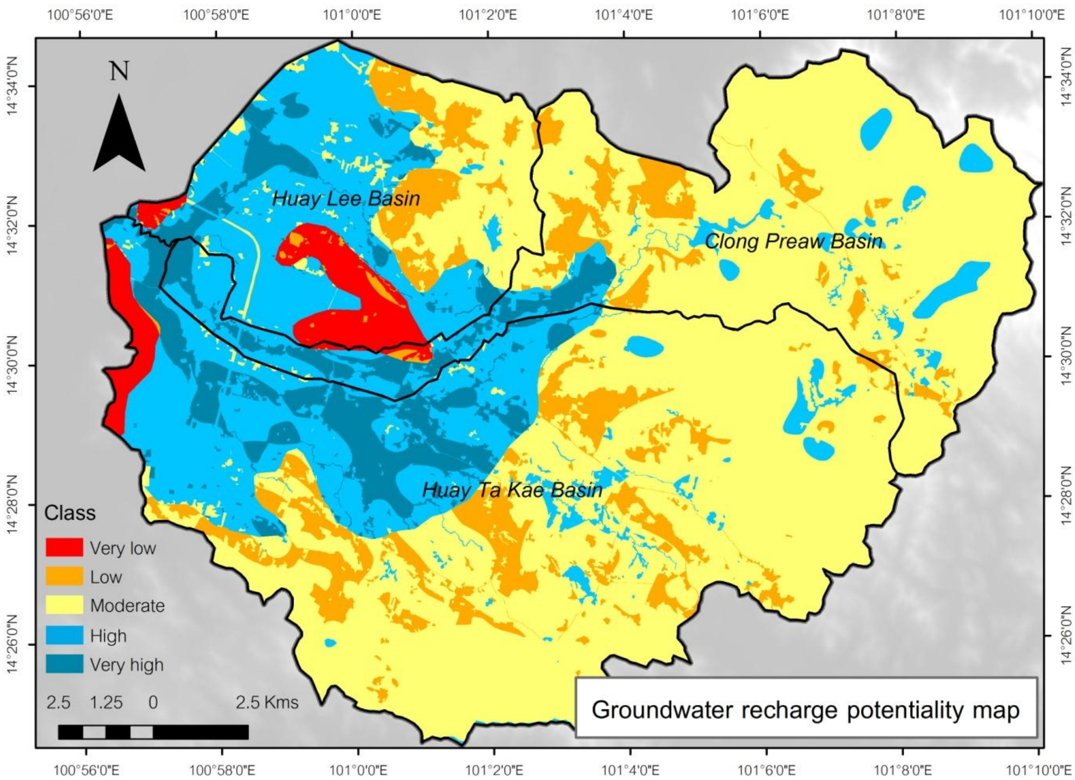

Figure 5 Groundwater recharge potentiality map of the study area.

Conclusion

The present study provides a groundwater recharge potentiality map of the areas surrounding the Land Development Facilities of Chulalongkorn University in Kaeng Khoi District, Saraburi Province, as an example of the application of the methodology that should be applicable elsewhere. The groundwater potentiality was integrated from thematic maps of the main influencing factors (lithology, land use/cover, drainage density and lineament density) and the groundwater recharge potential zones derived from the sum of the respective weights and rates of each contributing factors and their interactions. About 25.59 km^2 (8.15% of the total study area), mostly located in areas in the western downstream regions of the present study, was found to have a high potential groundwater recharge. The main influencing factors were the lithology and land use/ cover. The resultant map of this study provides preliminary groundwater recharge information for effective groundwater exploration to identify appropriate sites for new pumping wells for domestic and agricultural purposes in this area. Moreover, based on the water balance approach, the local government can now recommend suitable pumping rates in order to obtain long-term sustainable groundwater utilization.

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