Settlement performance evaluation of longitudinal settling basins - A case study on Golfaraj and Iry-Siah Rud pump stations, Iran

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Abstract: One of the most important elements of river intake is settling basins for water sediment removal. Settling basins play an important role in supplying appropriate water for irrigation networks and power plants. Therefore, it is necessary to design them carefully based on the local conditions. Our objectives were to determine the properties of sediments entering into the intake systems of two pump stations (Golfaraj and Iry-Siah Rud) by sampling the water suspended load in different points of the systems and to investigate the performance of settling basins in Iran. The suspended load samples were taken from sections before and after the settling basins at three depths of 0.2 y, 0.6 y, and 0.8 y (y is the depth of the cross section from the water surface). Evaluating the characteristics of sediments entering into the stations showed that the mean diameter of the sediment particles is 0.0035 mm and 0.002 mm at the transmission canal and suction basins, respectively. Approximately 90% of the sediments entering into the stations have a diameter smaller than 0.03 mm. In high sediment conditions, statistical analyses revealed that there is a significant difference ($p<0.05$) between the mean cross sectional suspended concentrations, before and after the settling basins. The results indicated that the Golfaraj settling basin, by removing 22.75% of sediments did not have proper performance, as well as the Iry-Siah Rud station. Based on the condition of the stations, we recommend the use of the additional structures such as guide walls with sluiceway, doubled sills, and pre-settling basins and proper designing operation to reduce the problems related to sediment particles.

Keywords: Concentration, Intake, Sampler, Sediment diameter, Suspended load

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1 Introduction

There are several methods of diverting river flow and they include dams, infiltration galleries and wells, pipe intake, bottom outlet, and consolidated diversions. One of the methods of diverting water directly from rivers is using pump stations and intake structures. The direct water harvesting projects has lower costs than the diversion dam method (Razvan, 1989). Separating sediment particles from the river water is one of the most important issues in diverting water by pumping method. Sediment particles existing in the river water cause damage to the station, especially mechanical devices such as pumps and turbines. Therefore, if the sediment problems related to intake system are solved, it will be useful for irrigation networks and power plants. In this case, the sediments must be removed from the flow before entering into the pump station (Ettema and Nakato, 1998). For this purpose, strainers and settlement structures are usually used at the entrance of intake systems (Raudkivi, 1990; Van Rijn, 1993). In these systems, suspended load and a portion of bed load entering into the station are separated from the flow by curative methods. Using the longitudinal settling basin is one of the most important curative methods (Raudkivi, 1990). These basins often have rectangular cross section and sometimes trapezoidal cross section.

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Sediment particles reduce the efficiency of the downstream canals and other facilities. The allowable diameter of sediment particles entering into systems must be determined in designing the settling basins. In agricultural facilities and urban water supply, the maximum allowable diameter of sediment particles is recommended to be equal to 0.25 and 0.05 mm, respectively (Novak et al., 1990). The coarse sediments deposited in the canal can damage the turbines and must be separated; the fine sediment particles are useful for soil fertilizer and do not seem necessary to separate. However, if the volume of the diverted water and the concentration of fine sediments are too high, separation of particles must be done. Settling basins separate the sediments of diverted water and play an important role in supplementing water for the irrigation networks and power plants projects. The designing of settling basins should be performed based on the local conditions. The first stage of designing hydraulic structures of settling basins is to collect complete information about the characteristics and the amount of sediments entering into the system, accumulation capacity of canals and the percentage of sediments must be removed (Ekama et al., 1997).

Limited field studies related to evaluating the settlement performance of longitudinal settling basins have been conducted. Humphreys et al. (1974) studied the flow characteristics in a hydraulic model of the sixteen settling basins in the Central Water Filtration Plant (CWFP). The original model and several modifications were tested. Some recommendations were proposed in prototype basins including turning vanes at abrupt channel bends, training walls in wide basins, and reduction of open area in the slotted baffle. Yoon and Lee (2000) investigated the performance of a rectangular settling basin using hydraulic laboratory experiments. The results show that the overflow rate, the installation of baffle, and the location of effluent are crucial influential factors on removal efficiency. Zahiri et al. (2010) evaluated the problems of the Benehbasht pump station (Behbahan, Iran) related to accumulation in the suction basin and its dredging. They suggested short-term practical solutions including maneuvering the downstream gates of suction basin and designing the sluiceway.

Bleything (2012) summarized the design and construction of the settling basins and indicated a methodology to perform efficiency tests. The flow was sampled for suspended sediments upstream and downstream of the basins, in order to reach a percentage of suspended sediments removed by the basins. Based on the results, the settling basins reduced the amount of suspended sediments in the flow by 53%. Recently, some other studies have focused on experimental and numerical studies and evaluated the performance and efficiency of the settling basins (Yeb and Lin, 2002; Ahmadi et al., 2007; Athanasia et al., 2008; Sammarraee et al., 2009; Liu et al., 2010; Rostami et al., 2011; Shrestha, 2012).

Aras River and the surrounding fertile agricultural lands are located in the north of East Azarbaijan Province (in Iran). The region has been used for many water projects as direct water diverting systems. In those projects, there are numerous problems related to sedimentation and abrasion in the pump station instruments and downstream network components, due to the high sediment load of the river and its temporal variations. Settling basins are one of the fundamental components of the projects used to remove the sediment. Evaluating the performance of settling basins during operation period, recognition of the weaknesses and providing appropriate solutions to sediment issues are very important in properly operating the projects.

Our objectives were to determine the properties of sediments entering into the intake systems of two pump stations (Golfaraj and Iry-Siah Rud) by sampling the water suspended load in different points of the systems and to investigate the performance of settling basins.

2 Materials and methods

Golfaraj and Iry-Siah Rud pump stations have been constructed on the Aras River in Jolfa city, state of East Azarbaijan, north-western part of Iran, to supply water required for agriculture and industry. The stations are located between 45˚36’18” and 46˚26’07” E longitude and between 38˚57’13” and 38˚53’41” N latitude. The location of the intake structures of the stations are shown in Figure 1 (Figure 1a, Golfaraj and Figure 1b, Iry-Siah Rud). The layouts of both stations (intake, settling basins, and pump station) are similar and their intake structure is as tangential-gates. There are two stages of pumping including primary and main pumping in each station. The intake structure of these stations includes a sill, harvest galleries and the gates. Primary pumping is done by spur pumps and water is pumped into the transmission canal. A transmission canal is connected to the settling basins. After the removal of sediment, water enters into the suction basin. In the suction basin, water is pumped to the upstream lands, using the main pump station (East Azarbaijan Regional Water Company, 2007).

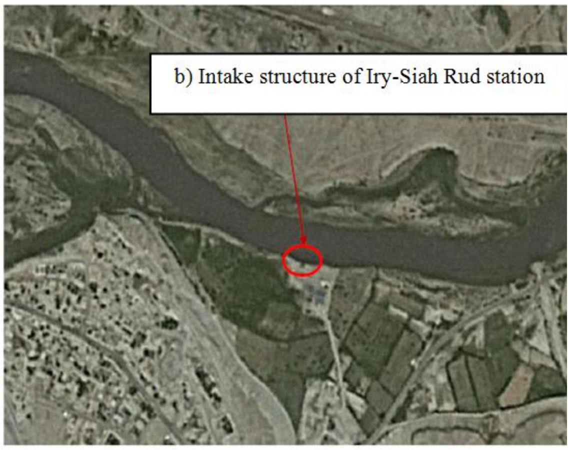
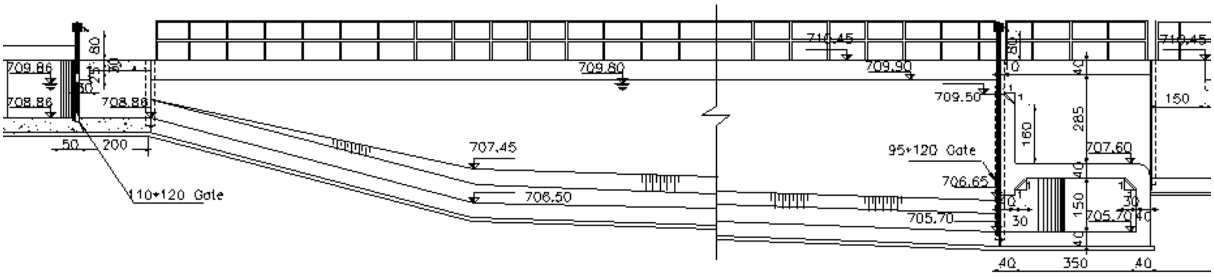


Figure 1. Layout and location of intake structure of Golfaraj (a) and Iry-Siah Rud (b) stations

Settling basin of the Golfaraj station is a longitudinal basin and consists of five galleries with 4.8 m width × 40 m length. Also, its height ranges from 2.45 to 3.25 m according to the basin bottom slope (Figure 2a). There is a sluice gate (1.1 × 1.2 m) at the beginning of each gallery. After the flow of water through the gate and settling basin, the water passes over the spillway at the end of basin and enters into the suction basin of the main pump station. Bottom slope in the transition part of the settling basin is 15° and after the transition, the bottom slope reduces to 1.15°. At the bottom end of each gallery, a sluiceway (1.2 × 0.95 m) is provided to divert sediment into the river (East Azarbaijan Regional Water Company, 2007).

a) Golfaraj station



b) Iry-Siah Rud station

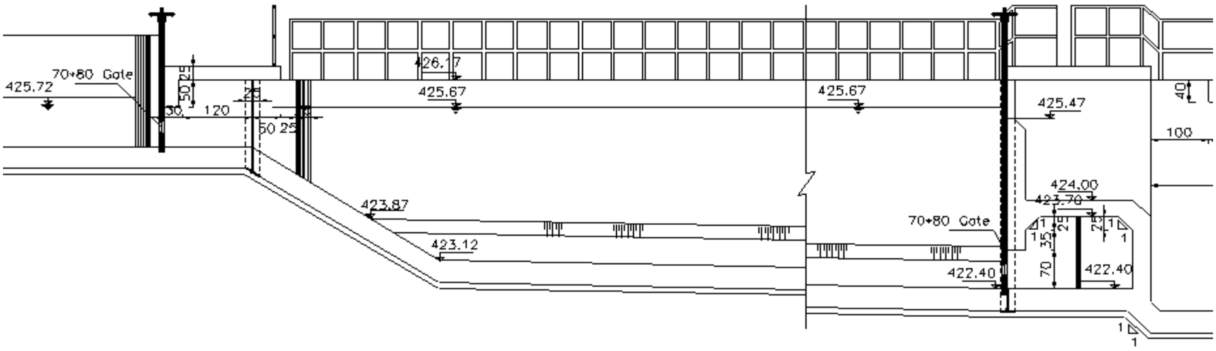


Figure 2 Longitudinal profile of the settling basin of Golfaraj (a) and Iry-Siah Rud (b) stations

The settling basin of Iry-Siah Rud station is also a longitudinal basin and consists of two galleries with 4.8 m width × 40 m length × 3.2 m height (Figure 2b). There are two sluice gates (0.7 × 0.8 m) at the beginning of each gallery. The bottom slope in the transition part of the basin is 33° and after the transition, the bottom slope reduces to 1.15°. At the bottom end of each gallery, a sluiceway (0.7 × 0.8 m) is provided to divert sediment into the river (East Azarbaijan Regional Water Company, 2007).

Sampling of the suspended load was done to determine the characteristics of sediments entering into the system and to evaluate the performance of settling basins during one season of operation (April-September, 2013). The sampling was performed using a suspended load sampler that had been made by Adak (Tabriz, Iran) (Figure 3). The sampler (US P-61) was made based on the standards of the US series of point-integrating samplers (Inter-Agency Committee on Water Resources, 1963). The sampler has a 0.48 cm nozzle that points directly into the stream flow, and an air exhaust permits air to leave the sample container as the sample enters. The exhaust passages are controlled by a valve. The inner volume of the sampler is approximately 1 L.

Figure 3 Point-integrating suspended load sampler (US P-61) made by Adak (Tabriz, Iran)

The sampling was done at two cross sections. These two cross sections were placed in the transmission canal (before the settling basin) and the suction basin (after the settling basin). Sampling as a point integrating method, was carried out at three depths of 0.2 y, 0.6 y, and 0.8 y (y is the depth of the cross section from the water surface) in the cross sections simultaneously. A total of ninety-six (96) samples were taken in various discharges of the Aras River including high and low sediment flows. Concentrations of suspended load and sediment gradation curve were determined using filtration method and hydrometer analysis according to Guy (1973). The samples with higher concentrations were selected for hydrometer analysis. Results of two periods including high and low sediment concentration samples were analyzed for each station. Statistical analyses of the data were made using SPSS v. 22 (IBM, New York, USA). Differences between means were determined by paired-samples T test at a significance level of 0.05.

3 Results and discussion

Sediment gradation curves in sampling sections of Golfaraj and Iry-Siah Rud pump stations are presented in Figure 4. The sediment gradation curves of Golfaraj pump station (Figure 4a) were almost similar to the Iry-Siah Rud pump station (Figure 4b). The figure shows that the mean diameters of sediment particles in the transmission canal and the suction basin are 0.0035 and 0.002 mm, respectively. It means that sediment particle size reduces by 43% in the suction basin. The sediment particles in different locations of the stations are very fine. On the other hand, almost 90% of sediment particles have a diameter smaller than 0.03 mm.

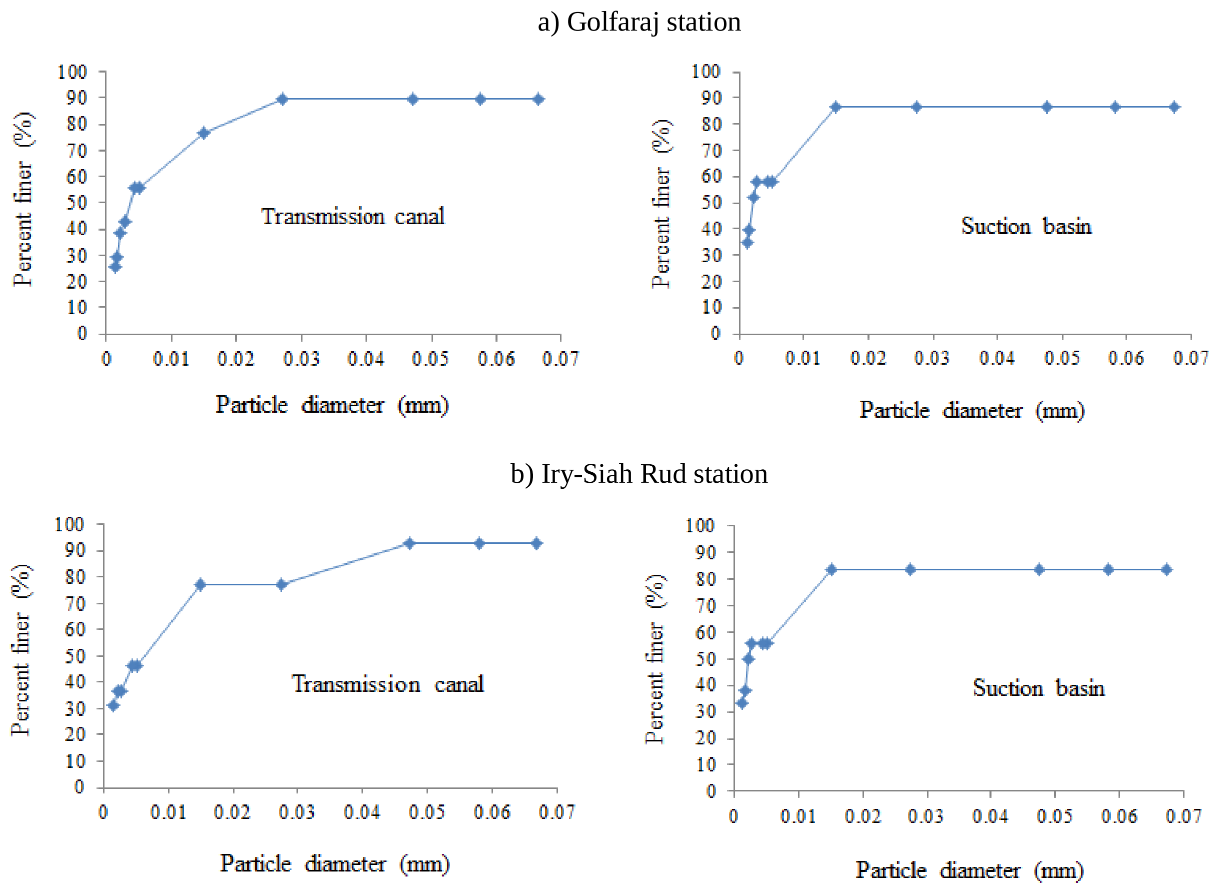


Figure 4 Particle distribution curves of Golfaraj (a) and Iry-Siah Rud (b) stations in transmission canal and suction basin

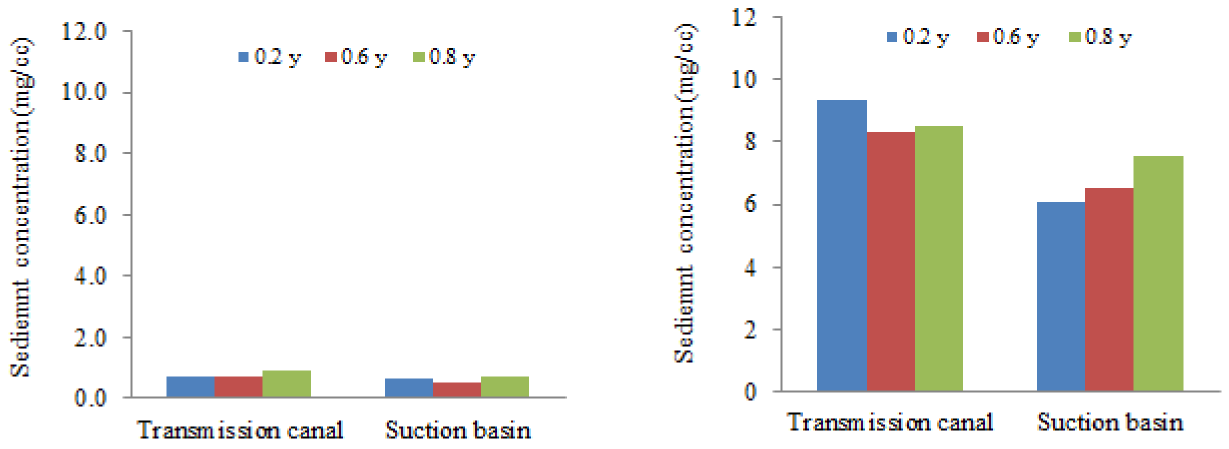
Statistical analysis of the mean cross sectional suspended concentrations of Golfaraj and Iry-Siah Rud stations are shown in Table 1. In the low sediment condition, there were no significant differences between the suspended concentrations of both sections of the transmission canal and suction basin ($p<0.05$). Otherwise, sediment concentration is approximately the same before and after the settling basins. These results indicate that settling basins do not have any noticeable effect on sediment removal in low sediment condition. In high sediment condition, results show a significant difference between the suspended concentrations of both sections before and after the settling basins ($p<0.05$). It means that Golfaraj and Iry-Siah Rud settling basins could remove approximately 22.75% and 42% of the sediment particles respectively, but Iry-Siah Rud settling basin has higher performance than the one at Golfaraj. Figure 5 shows the mean point suspended concentrations in the sections of Golfaraj and Iry-Siah Rud stations.

Table 1 Statistical analysis of the mean cross sectional suspended concentrations of Golfaraj and Iry-Siah Rud stations

Stations	Sediment condition	Cross section	Mean ± Std. deviation (mg/cc)	t	p-value
Golfaraj	Low sediment	Transmission canal	0.76±0.12	1.81	0.107
		Suction basin	0.67±0.09		
	High sediment	Transmission canal	8.74±0.57	6.65^{**}	<0.0001
		Suction basin	6.70±0.74		
Iry-Siah Rud	Low sediment	Transmission canal	0.85±0.12	0.345	0.739
		Suction basin	0.82±0.13		
	High sediment	Transmission canal	6.64±1.04	13.22^{**}	<0.0001
		Suction basin	3.83±0.60		

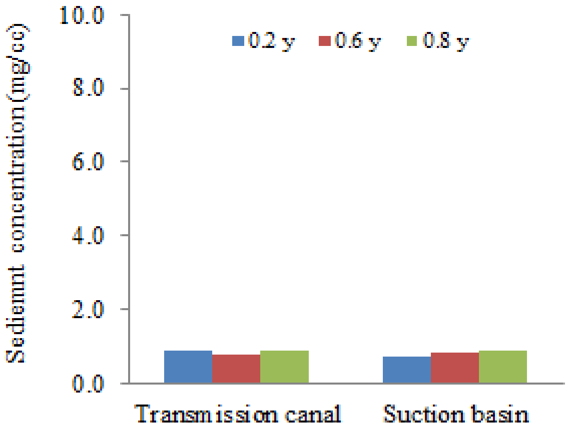
Note: $^{**}p<0.05$

a) Golfaraj station

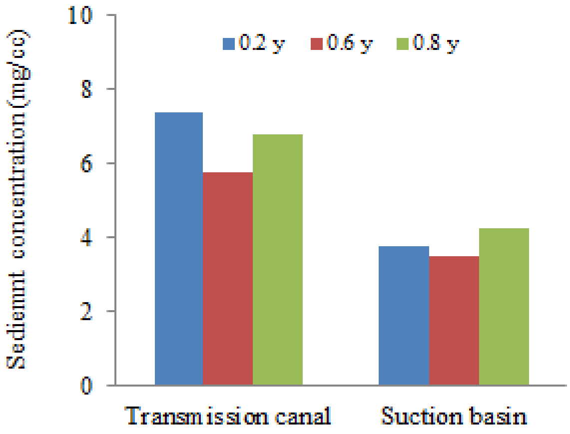


A) Low sediment condition B) High sediment condition

b) Iry-Siah Rud station



A) Low sediment condition



B) High sediment condition

Figure 5 Mean point suspended concentration in the sections of Golfaraj (a) and Iry-Siah Rud (b) stations

Analysis of the layout and location of the stations indicated that the poor performance of Golfaraj settling basin resulted from inappropriate location of the station's intake. Golfaraj station is located at the outer bank of a bend with 63° central angle. Intake of the station was placed approximately at the 29° angle of the bend (Hoseinzadeh, 2014). Considering the hydraulic design criteria of the river intake (Razavan, 1989), the station intake should have been located at the 50° angle of the bend (Hoseinzadeh, 2014). Based on sediments analyses and the performance of the settling basins, the maximum diameter criterion of the allowable sediment particle (equal to 0.25 mm) must not be used in designing the settling basins of Aras River projects. Otherwise, sediment particles criterion equal to 0.25 mm is not suitable to design the settling basins of this river and the sediment analysis of the river water must be done before designing the station. It was proposed that the possibility of using other types of settling basins was evaluated especially in the vortex basin.

Analysis of the input flows of upstream sub-basins into Aras River showed that fine sediments of Aras River are entering from seasonal and torrential rivers of the Marakan Chaye Basin (Figure 6). Considering that most of the sediments entering into the pump stations are fine suspended load, it is essential that the Marakan Chay Basin be analyzed based on vegetation, land use and soil characteristics (Hoseinzadeh, 2014). Otherwise, watershed management must be carried out at the Marakan Chay Basin. Results indicated that sediment-hydraulic conditions in both stations are nearly the same. Therefore, similar engineering (additional structures) and management methods could be provided to reduce both station sediment problems. Additional structures such as guide walls with sluiceway, doubled sills, and pre-settling basins can be used in front of the intake. In addition, it could reduce damage to facilities and networks resulting from the sediments, if proper planning operation is used based on the river sediment conditions.

Figure 6. Sediment condition of Aras River after connection of Marakan Chay River

4 Conclusions

Determining the properties of suspended sediments entering into the Golfaraj and Iry-Siah Rud pump stations showed that almost 90% of the particles have diameter smaller than 0.03 mm. This condition is mainly resulted from the torrential sub-basins of the Aras River, especially Marakan Chaye basin. The settling basins design based on the sediment particles criterion equal to 0.25 mm is not technically suitable for the station. Settlement performance evaluation of the settling basins in high sediment condition indicated differences between the suspended concentrations of both sections before and after the settling basins. Golfaraj settling basin has not performed as well as the one at Iry-Siah Rud due to the inappropriate location of the station's intake. It would be beneficial to investigate effect of the recommended engineering and management solutions on sediment problems of the stations using physical model to develop a more complete understanding of the effect of the solutions.

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