

An Assessment of the Drinking Water Supply System in Islamabad, Pakistan [†]

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Abstract: Presently, the provision of safe drinking water is becoming a big challenge all over the world. In developing countries like Pakistan, many technical, financial and policy-related issues are hindering clean drinking water supply to communities. This study evaluates the performance of the drinking water supply system in Islamabad, starting from the Khanpur Dam to the consumer end via the Sangjani water treatment plant (SG-WTP). For this purpose, different physicochemical and biological parameters of water quality were analyzed and compared at four different locations in the Islamabad water supply network (also called the Khanpur Dam water supply network) for a period of one year. Statistical analyses such as the *t*-test, principal component analysis (PCA) and cluster analysis (CA) were performed to observe the variations in water quality parameters at the four locations. The results illustrate that the water quality upstream of the SG-WTP is declining due to various anthropogenic activities adding a variety of organic and inorganic pollutants into the water channel coming from the Khanpur Dam to the Sangjani plant. The water quality at the consumer end is deteriorating mainly due to algal growth and cracks in the water distribution network. As far as the performance of the SG-WTP is concerned, it is currently in good working condition and treating most of the water pollution coming from the Khanpur Dam water. Proper repair, maintenance and regular monitoring are necessary for sustainable operation of the Islamabad water supply system.

Keywords: Khanpur Dam; Sangjani water treatment plant; water quality; consumer end; statistical analysis



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1. Introduction

Presently, drinking water quality is an emerging challenge all over the world. Poor quality drinking water undermines the economic growth and environmental and physical health of billions of people [1]. At present, approximately two billion people (about 26% of the global population) do not have access to safe drinking water, and around 771 million people do not have access to basic drinking water facilities [2]. Similar to the rest of the developing world, Pakistan is also currently facing severe water crises in terms of quality and quantity. Demand for drinking water is rapidly increasing in Pakistan mainly due to population increase and lifestyle changes [3].

It is estimated that nearly 80% of the population of Pakistan is compelled to drink contaminated water, leading to various health issues, including waterborne diseases and malnourishment [4]. About 40% of the population of Pakistan meets their drinking water needs from surface water, including rivers, streams and canals, whereas underground water reserves contribute about 60% of the total drinking water supply [5,6]. The major extraction

of groundwater in Pakistan is through private tube wells and pumps [7]. Drinking water quality in Pakistan is deteriorating at a rapid pace. The contaminants with high influence on water quality in Pakistan include toxic metals (lead, arsenic, cadmium, iron), pesticides, bacterial contaminants (*Escherichia coli*, Total coliforms and Fecal coliforms) and in some parts of the country, nutrients (fluorides, nitrates) are also in abundance [8]. Research reports that microbial contamination including coliforms (fecal coliform, total coliform, *Escherichia coli*) and heavy metals such as iron, arsenic, nickel, mercury and pesticides are abundantly found in drinking water supplies in Pakistan including surface as well as groundwater [9]. In recent years, the outbreak of waterborne diseases (particularly in children) such as diarrhea, typhoid, hepatitis, dysentery, intestinal worms and giardiasis has significantly increased in the country [10].

Islamabad, the capital city of Pakistan, is facing serious issues of water quality and deficiency and many parts of the city do not have enough water for all citizens [11]. The literature reveals that about 60 to 70% of drinking water sources in Islamabad have been polluted with various types of chemical and biological contaminants [12]. A study reports that currently, most of the drinking water resources in Islamabad have been contaminated with heavy metals such as arsenic and lead and fecal coliform bacteria [13]. Improper disposal and leakage of sewage, industrial effluents, agricultural runoff, improper solid waste disposal and leaking pipes and infrastructure are among the major reasons for drinking water contamination in Islamabad [14].

At present, the Simly Dam and the Khanpur Dam are the major sources of water supply in Islamabad [15]. The Khanpur Dam is on the Haro River, located about 50 km from Islamabad in the village of Khanpur, Khyber Pakhtunkhwa province of Pakistan. The designed storage capacity of the dam reservoir is 26,062 million gallons (MG). Currently, the total amount of water supplied annually from the dam is about 57,885 MG, of which about 17,011 MG is provided for municipal use, including drinking water, and 21,323 MG for irrigation purposes [16]. Prior to supplying Islamabad city, the water from the Khanpur Dam is treated at the Sangjani water treatment plant (SG-WTP). The Sangjani treatment plant is being operated on a conventional treatment process with a design capacity of 51 MG per day. Conventional water treatment at the Sangjani plant is done by coagulation, flocculation and sedimentation processes. The raw water coming from the Khanpur Dam is received in a well and then sent to an alum mixing tank. From the alum basin, the water goes to the coagulation chamber. After that, flocculation is carried out through the baffles by providing a zig-zag track to the water for proper mixing of the alum and accumulation of particles. Subsequently, water filtration is conducted with the help of sand filters. As the last step of the treatment process, chlorination is performed prior to water distribution [17]. Water from the Khanpur Dam is supplied to the SG-WTP through intermittent underground pipelines and open channels. The treated water from the Sangjani plant is transported to Islamabad and Rawalpindi through water supply lines and temporary storage facilities (overhead tanks) [18].

The present study has been designed to evaluate the performance of the drinking water supply system in Islamabad, starting from the Khanpur Dam to the consumer end via the SG-WTP. The study is intended to highlight the problems in the drinking water supply system by analyzing and comparing various bio-physical and chemical parameters of drinking water quality at selected locations. The study provides a comprehensive insight for municipal authorities to realize the water supply issues in Islamabad.

2. Materials and Methods

For the purpose of this study, the Khanpur water supply network was divided into three sections: (i) Khanpur Dam to SG-WTP inlet (ii) SG-WTP inlet to SG-WTP outlet and (iii) SG-WTP outlet to the consumer end. Key parameters of drinking water quality were analyzed and compared at four locations: (i) River water at the Khanpur Dam, (ii) inlet of SG-WTP, (iii) outlet of SG-WTP and, (iv) consumer end in Islamabad. Figure 1 shows the sampling locations and their inter-distances.

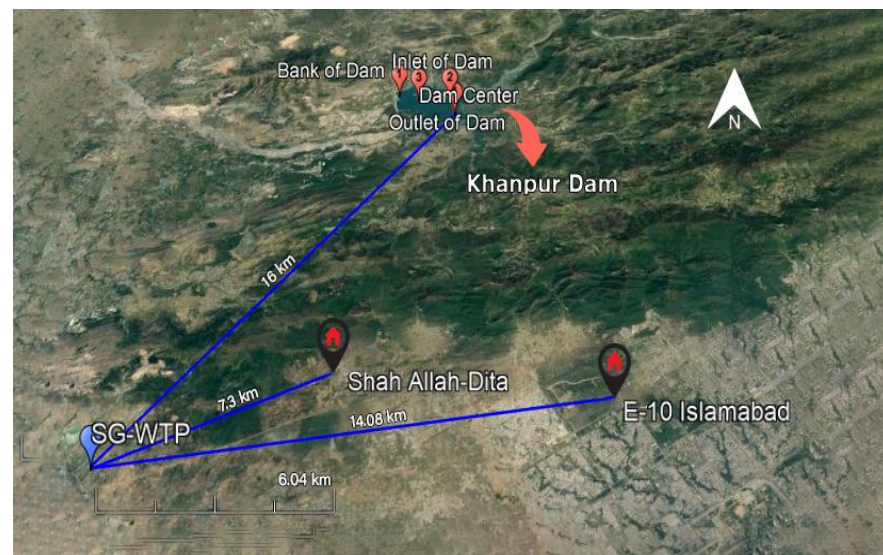


Figure 1. Locations of water quality sampling and their inter-distances.

2.1. Sample Collection

From each location, water samples were collected on a monthly basis for a period of one year. For sample collection, one liter sterilized sampling bottles were used. From each point, temporal-based sampling was conducted in triplicate at predefined locations between 10:00 and 16:00 h. From the Khanpur Dam, samples were collected at a depth of 10 cm. All samples were preserved by adding sodium thiosulphate and stored at 4 °C in ice boxes for further analysis [19].

2.2. Sample Analysis

Water quality analysis was performed in the water testing laboratory at the University of Engineering and Technology (UET), Taxila. All analyses were performed using standard methods of the American Public Health Association (APHA) and the United States Environmental Protection Agency [20,21]. Table 1 provides the details of the water quality parameters tested and the instrument/technique used for each test.

Table 1. Analytical instruments and techniques used for water quality analysis during the Khanpur Dam water supply network study.

S. No.	Parameters	Unit	Method Used
1.	Temperature	°C	Thermometer
2.	Turbidity	NTU	Nephelometric Method using Turbidity Meter (HACH 2100N)
3.	pH	-	pH meter (Senso Direct pH 110)
4.	TDS	mg/L	Gravimetric Method
5.	Alkalinity	mg/L as CaCO ₃	Titrimetric Method
6.	Residual Chlorine	mg/L	Iodometric Titrimetric Method
7.	Total Hardness	mg/L as CaCO ₃	EDTA Titrimetric Method
8.	Nitrates	mg/L	using UV Spectrophotometer (HACH DR 6000)
9.	Orthophosphate	mg/L	using UV Spectrophotometer (HACH DR 6000)
10.	<i>E. coli</i>	MPN/100 mL	Membrane Filtration Method
11.	Fecal Coliform	MPN/100 mL	Membrane Filtration Method
12.	Total Coliform	MPN/100 mL	Membrane Filtration Method

2.3. Statistical Analysis

To study the variations in physicochemical and biological parameters at four locations in the Khanpur water supply system, statistical techniques such as *t*-test, PCA and CA were performed. Independent samples *t*-test technique using a significance level = 0.05 was applied for comparison of data collected from selected locations. PCA was used to reduce the large number of variables into a smaller set of variables and to find the correlation between them. The inputs for PCA are the mean values of the entire data collected from the four sampling sites. CA was used to identify the relationship between the four sites based on their similar water qualities. Statistical Package for the Social Sciences (SPSS; v.25) and XLSTAT (5.03) software applications were used to perform the statistical analyses.

3. Results and Discussion

Table 2 provides the one-year mean values of the tested water quality parameters at selected locations in comparison with guideline values from the World Health Organization (WHO) and/or US EPA. It can be seen in Table 2 that the water temperature at all the locations is significantly higher than the WHO limit value of 12 °C. The pH of the water at all the locations, except the Khanpur Dam, is within the acceptable limit of the WHO (6.5–8.5), whereas the pH value at the Khanpur Dam (8.53 ± 0.48) is slightly higher than the WHO standard. The turbidity of water at the inlet of the SG-WTP (6.55 ± 2.1 NTU) is also higher than the acceptable limit of the WHO (<5 NTU); the turbidity level at all other locations is below the acceptable limit of the WHO. Orthophosphate contamination in the water at all the locations is significantly higher than the guideline value of the US EPA. It can also be noted that water at all locations (except the SG-WTP outlet) is contaminated with total coliform bacteria. The highest level of total coliforms was observed in the consumer end water where it is 30.25 ± 2.95 MPN/100 mL against the WHO acceptable limit of Nil/100 mL. All other parameters of water quality are within acceptable standards of the WHO/US EPA. It can also be seen in Table 2 that the high concentration of chlorine (1.69 ± 0.18 mgL⁻¹) is also present in water at the SG-WTP outlet; however, the chlorine concentration is significantly decreased at the consumer end. Chlorine is used as a disinfectant at the Sangjani water treatment plant.

Table 2. Water quality parameters at selected location of Khanpur Dam water supply network.

Parameters	Sampling Locations				WHO/US EPA Reference Values [22,23]
	Khanpur Dam	SG-WTP Inlet	SG-WTP Outlet	Consumer End	
Temperature (°C)	27.63 ± 0.41	27.65 ± 1.1	30.00 ± 1.05	26.66 ± 1.07	12
pH	8.53 ± 0.48	8.29 ± 0.55	8.17 ± 0.36	7.71 ± 0.36	6.5–8.5
Turbidity (NTU)	4.12 ± 0.73	6.55 ± 2.1	0.89 ± 0.33	0.93 ± 0.23	<5
TDS (mg/L)	461.57 ± 36.3	482.13 ± 45.25	489.66 ± 44.55	483.09 ± 42.48	<1000
Total Hardness (mg/L)	154.98 ± 7.91	162.50 ± 25.84	156.3 ± 18.04	149.76 ± 18.34	-
Alkalinity (mg/L)	182.2 ± 10.77	179.12 ± 12.86	181.78 ± 20.97	166.02 ± 13.25	-
Nitrates (mg/L)	12.45 ± 0.38	13.56 ± 2.89	8.53 ± 1.6	12.30 ± 2.38	50
Orthophosphates (mg/L)	1.64 ± 0.17	1.99 ± 0.15	1.90 ± 0.14	1.71 ± 0.14	0.1
Total Coliforms (MPN/100 mL)	8.85 ± 0.97	15.50 ± 3.9	Nil	30.25 ± 2.95	Nil
Chlorine (mg/L)	-	-	1.69 ± 0.18	0.11 ± 0.26	0.2–1

3.1. *t*-Test

In order to compare the water quality at three sections of the Khanpur water supply system, a *t*-test analysis was performed. The *t*-test uses a *p*-value to describe the significance

of the results. A p -value $\leq$ alpha (significance level) shows that the means of two groups are statistically significant, and the null hypothesis is rejected. Similarly, a value of $p >$ alpha shows that two groups are not statistically significant, and the alternate hypothesis is rejected. The t -test for this study was performed at an alpha level of 0.05. Table 3 provides the p -values for three groups selected for this study i.e., Khanpur Dam vs. SG-WTP inlet, SG-WTP inlet vs. SG-WTP outlet and SG-WTP outlet vs. consumer end.

Table 3. p -values comparing water quality parameters for three groups/sections of the Khanpur water supply system.

Parameter	KHANPUR Dam vs. SG-WTP Inlet p -Value	SG-WTP Inlet vs. SG-WTP Outlet p -Value	SG-WTP Outlet vs. Consumer End p -Value
Temperature ($^{\circ}$ C)	0.963	<0.001	<0.001
pH	0.274	0.539	0.006
Turbidity (NTU)	0.001	<0.001	0.928
TDS (mg/L)	0.233	0.685	0.715
Total Hardness (mg/L)	0.346	0.770	0.386
Alkalinity (mg/L)	0.532	0.712	0.039
Nitrates (mg/L)	0.201	<0.001	<0.001
Chlorine(mg/L)	-	<0.001	<0.001
Orthophosphates (mg/L)	<0.001	0.150	0.004
Total Coliforms (MPN/100 mL)	<0.001	<0.001	<0.001

3.2. Khanpur Dam vs. SG-WTP Inlet

As shown in Table 3, the values of turbidity, orthophosphates and total Coliforms have statistically significant differences between the Khanpur Dam and the SG-WTP inlet (p -value < 0.05). The highest level of water turbidity (6.55 ± 2.1 NTU) at the SG-WTP inlet given in Table 3 is mainly due to soil erosion and stormwater inflow carrying colloidal and suspended particles such as silt, clay and organic and inorganic constituents that mix with water during the course of movement from the Khanpur Dam to the SG-WTP [24]. Turbid water requires more doses of coagulant that produce more sludge and results in the choking of filter beds, lowering the overall efficiency of the water treatment plant. The increase in orthophosphates at the SG-WTP inlet is mainly due to agricultural runoff entering the channel during the monsoon season carrying water from the Khanpur Dam to the SG-WTP. High concentrations of orthophosphates at the outlet resulted in excessive algal growth and aquatic shrubs in the sedimentation pond of the SG-WTP as observed during the site visits. The high level of microbial contamination (total coliforms) at the SG-WTP inlet seems to be due to the inflow of polluted stormwater into the channel. It is noted that recreational and cultural activities upstream of the SG-WTP add a significant amount of pollution in water coming from the Khanpur Dam to the SG-WTP. Higher microbial contamination in water requires a higher amount of disinfectant, raising the water treatment costs.

3.3. SG-WTP Inlet vs. SG-WTP Outlet

In this section, water quality parameters such as temperature, turbidity, nitrates, chlorine and total coliforms were found to be statistically significant (p -value < 0.05). Water entering the SG-WTP has a high value of turbidity, which increases the penetration of sunlight during the sedimentation process and results in a rise in water temperature at the outlet of the SG-WTP. As can be seen in Table 2, the turbidity level at the SG-WTP outlet (0.89 ± 0.33 NTU) was substantially reduced compared to the turbidity level at the inlet of

the plant (6.55 ± 2.1 NTU). This indicates better efficiency of the SG-WTP for settling down the suspended particles in water and lowering the turbidity. The reduction in the amount of nitrates at the SG-WTP outlet is due to the consumption of nutrients by algae, fish and other aquatic shrubs in sedimentation ponds at the treatment plant [25]. The quantity of total coliforms was found to be zero at the SG-WTP outlet. This is mainly due to the chlorination used at the SG-WTP during the treatment process destroying the bacterial contamination in treated water.

3.4. SG-WTP Outlet vs. Consumer End

Comparison of water quality at the SG-WTP outlet and consumer end provides a clear picture of the efficiency of the water supply network from the SG-WTP to residents of Islamabad. In this section, values of temperature, pH, alkalinity, nitrates, chlorine, orthophosphates and total coliforms were found to be statistically significant (p -value < 0.05). As evident from Table 2, the water temperature at the consumer end is decreased mainly due to less exposure to direct sunlight in the underground water supply network. Low pH at the consumer end also resulted in a decrease in alkalinity. Water pH at the consumer end is decreased due to many reasons, including seasonal temperature variations, microbial activity and algal growth. The nitrate concentration at the consumer end is increased due to cracks in the distribution network that allow soil particles and domestic effluent to enter the system [26]. The rise in nitrate concentration at the consumer end indicates the poor performance of the water supply network from the SG-WTP to the consumer end in Islamabad.

The decrease in orthophosphate concentrations at the consumer end is mainly due to its consumption by algae and microbes in the water distribution network. Despite the decrease at the consumer end, the concentration of orthophosphates is still beyond permissible limits. Consumption of drinking water with high orthophosphate concentrations leads to muscle damage, breathing problems and kidney failure [27]. As seen in Table 2, the total coliform concentration at the consumer end changes drastically to an unacceptable level that can cause many water-related diseases, including diarrhea, typhoid, hepatitis, dysentery, intestinal worms and giardiasis [28].

3.5. Principal Component Analysis

Principal component analysis (PCA) was used to simplify our data by reducing the dimensionality of the data set and preserving the variance up to the maximum possible extent. Through PCA, the original variables were transformed into principal components. Principal component analysis showed that three factors from ten parameters are affected the most. The first factor (F1) shows a maximum variance of approximately 45.26%, with the parameter's temperature, chlorine and total coliforms showing the highest loading value (>0.8). The second factor (F2) shows a maximum variance of approximately 35.79%, with the parameters pH and turbidity showing the highest loading value (>0.8). The third factor (F3) shows a maximum variance of approximately 18.9%, with the parameter orthophosphate showing the highest loading value (>0.8).

In PCA, the loading plot describes the relationship between the parameters and how strongly each parameter affects the principal component as shown in (Figure 2). To avoid the complexity of the relationship and to draw a clear conclusion, we ignored factor F3, which had a low value of variance in comparison to parameters [29]. The parameter lines closer to each other show a positive relationship, as the smaller the angle the more positive the relationship between them. Similarly, opposite lines show a negative relationship, as the greater the angle the more negative the relationship. The parameters with perpendicular lines show small correlations with each other.

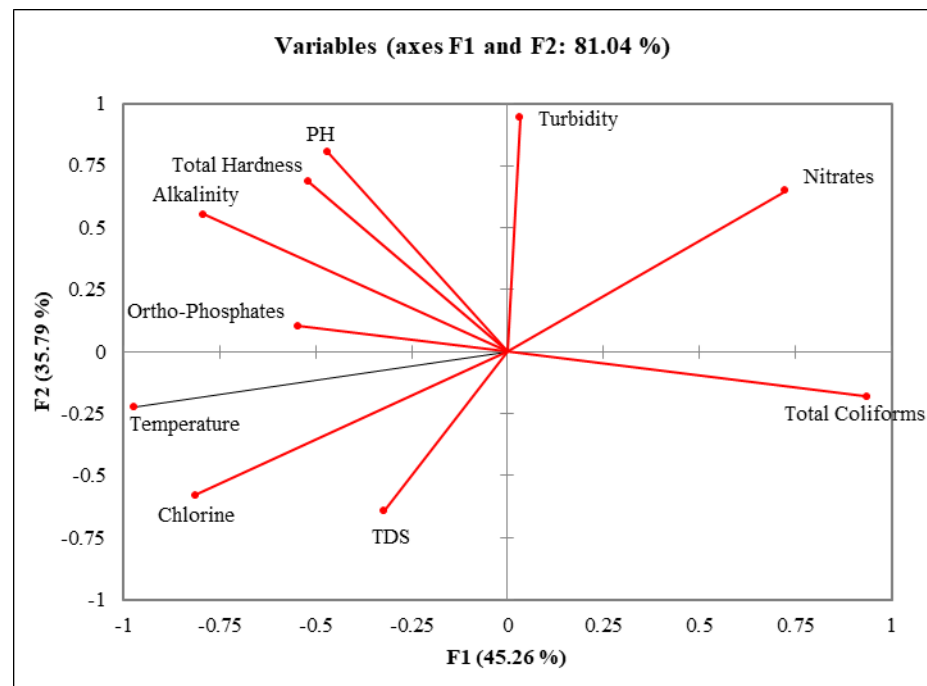


Figure 2. Loading plot showing the influence of each parameter on the principal components and the correlation between them.

3.6. Cluster Analysis

The dendrogram (Figure 3) shows the results of cluster analysis, indicating that water quality at the Khanpur Dam correlates more with the SG-WTP inlet, while water quality at the consumer end correlates too much with the Khanpur Dam and the SG-WTP inlet. There is a minor similarity between the SG-WTP inlet and the SG-WTP outlet. This shows that the SG-WTP is working efficiently; however, the water supply network from the SG-WTP to Islamabad is currently working at less efficiency and has poor performance.

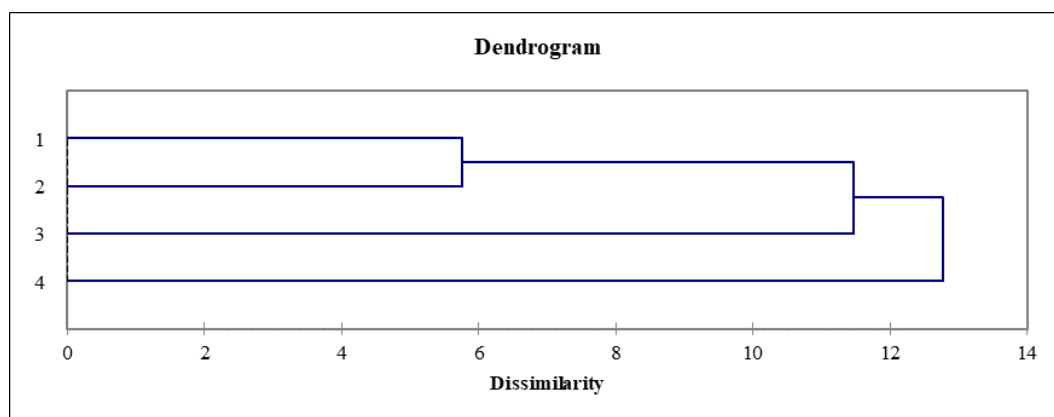


Figure 3. Cluster analysis of four sites under study: (1) = SG-WTP Inlet, (2) = Khanpur Dam, (3) = Consumer End, (4) = SG-WTP Outlet.

4. Conclusions

The Khanpur Dam water supply network efficiently provides clean drinking water to Islamabad following treatment and disinfection at the SG-WTP. However, there exist some water quality issues, which are mainly due to defects in the water supply network from the SG-WTP to the consumer end. As far as the performance of the SG-WTP is concerned, it is currently in good working condition and sufficiently reducing turbidity, hardness

and microbial contamination levels in treated water. High values of certain water quality parameters at the consumer end are due to many factors such as soil erosion, surface runoff, recreational and cultural activities upstream of the SG-WTP, algal growth, cracks in the water distribution network, and above all, poor maintenance and repair of the water supply network. The quality of drinking water from the Khanpur Dam water supply network can be improved by properly covering the water channel from the Khanpur Dam to the SG-WTP, installing chlorine booster pumps and proper maintenance and repair of the water supply network.

Author Contributions: J.I.: Overall supervision and design of the study; H.J.: Conceptualization, data collection and drafting of the manuscript; M.T.S.: Field data collection, data processing and analysis and assisting with manuscript compilation. All authors have read and agreed to the published version of the manuscript.

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