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A Review of Different Approaches of Water Quality Indices

Abhilasha Mehra[1], Prof. R. K Bhatia[2], Prof. Dr. Shailza Verma[3]

[1]ME Environmental Engineering, Department of Civil Engineering, Jabalpur Engineering College, Jabalpur, Madhya Pradesh Pin 482011, India

[2]Associate Professor, Department of Civil Engineering, Jabalpur Engineering College, Jabalpur, Madhya Pradesh Pin 482011, India

[3]Assistant Professor, Department of Civil Engineering, Jabalpur Engineering College, Jabalpur, Madhya Pradesh Pin 482011, India

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Abstract

Water is a precious gift to all human beings. Water quality of sources affects its demand, supply and management. So its rapid quality assessment becomes important in these days. A Water quality index provides a convenient means of summarizing complex water quality data and facilitating its communication to a general audience and to managers. To express water qualities in significant way different water quality indices are used depend on purpose. WQI reduce great amount of parameters into simple numeric value which indicates its quality which make easy interpretation of monitoring data. In this review paper, various WQI indices are discussed which are used for assessing surface water quality. Several national and international agencies involved in water quality assessing and pollution control defines water quality criterion for different uses of water considering different indicator parameters .There are number of WQI specific to any region or area.

Key Words: WQI, ecology, Coliforms, DO, BOD

INTRODUCTION

Water is the one of the nature's precious gifts to mankinds and life on earth is impossible without it. The surfaces water bodies like rivers, reservoir, lake, ponds etc, which are the important sources are unfortunately under severe environmental stress due to anthropogenic activities, industrialization, intense agricultural activities, urbanization, and discharge of untreated waste directly or indirectly into it [1].Water allows us to live but it could be harmful to our bodies when polluted [2]. Therefore, assessment of water quality is important research topic in these days [3].

In traditional practice, evaluation of water quality is based on the comparison of experimental data with guidelines provided by several international and national agencies [4] [5]. This makes difficulty in understanding by mass public hence not popular [6].

Whereas, WQI provides a convenient means of summarizing vast water quality data into a single numeric value that indicates its overall quality of water [7].Due to its capacity of reducing the bulk water quality information, and that is easy to understand the water quality, thus this method gains more popularity worldwide [7][8].

WQI enables us to classify the water sources according to its WQI values that indicates its quality status at a glance and helps in comparison, management, treatment etc. [7]

Various scientists, agencies, experts formulated numerous of WQIs all over the world. For example weighted arithmetic water quality index, National sanitation foundation water quality index, bhargava's index, the river ganga index etc [9].

In this review paper, various water quality index are discussed and their approaches to calculate WQI value.

1. WATER QUALITY INDICES

The concept of WQI was firstly introduced by Horton in 1965 in United states using 10 common water quality parameters like DO, Ph, coliforms, specific conductance, alkalinity and chloride etc and has been widely used and accepted in European, African and Asian countries [10]. Then in 1970 brown developed very similar WQI to Horton WQI based on weights to individual parameters. Further various experts and scientist came and apply different concept on WQI [11].

2. WQI APPROACH PROCEDURE

A. Variable Selections: - For raw data generation water quality parameters selections is must.

B. Determination of quality function for each variable considered as sub-index:- various variables have different units as well as range. By transformation process all the selected parameters are transformed into common scale and sub-indices generated. Weight ages are assigned to each variable according to potential impacts.

C. Aggregation Mathematical function of subindices:-Generally, arithmetic or geometric averages are considered to generate cumulative index value. And finally, assessment and classification of water quality is done.

3. A REVIEW OVER DIFFERENT APPROCHES TO CALCULATE WQI

Weighted Arithmetic Water Quality Index:

Weighted Arithmetic Water Quality Index method classified the water quality according to the degree of purity by using the most commonly measured water quality variables [12].

The calculation of the WQI was done using weighted arithmetic water quality index which was originally proposed by Horton (1965) and developed by Brown et al (1972).[10][11]

The weighted arithmetic WQI method was applied to assess water suitability for drinking purpose. In this method, water quality rating scale, relative weight and overall WQI were calculated by following formulae [11]:

$$WQI = \frac{\sum_{n=1}^{n} q_n w_n}{\sum_{n=1}^{n} w_n}$$

q_n values are given by the relationship.

q_n=100 (v_n-v_i) / (v_s-v_i)

v_s = Standard value, v_n = observed value v_i = ideal value

In most cases v_i =0 except in certain parameters like pH, dissolved Oxygen etc,

Calculation of quality rating for pH & DO ($v_i \neq 0$)

q_{pH} = 100 (v_{pH} – 7.0) / (8.5 – 1.0)

q_{DO} = 100 (V_{DO} – 14.6) / (5.0-14.6).

Calculation of unit weight: The Unit weight (W_n) to various water Quality parameters are inversely proportional to the recommended standards for the corresponding parameters.

W_n = k/s_n.

Where,

w_n = unit weight for nth parameter,

s_n = standard permissible value for nth parameter,

k = proportionality constant and can also be calculated by using the following equations:

$$k = \frac{1}{\sum \frac{1}{Sn}}$$

Table 1: Water Quality Rating as per Weight Arithmetic Water Quality Index Method [12]

WQI Value	Rating of Water Quality Bottom
0-25	Excellent water quality
26-50	Good
51-75	Bad
76-100	Very Bad
100 & above	Unsuitable for drinking purpose

National Sanitization Foundation Water Quality Index [13]:

A commonly-used water quality index (WQI) was developed by the National Sanitation Foundation (NSF) in 1970 (Brown and others, 1970). [11]The NSF WQI was developed to provide a standardized method for comparing the water quality of various bodies of water. 142 water quality scientists were surveyed about 35 water quality tests and asked to consider which tests should be included in an index (Brown and others, 1970; Mitchell and Stapp, 2000).[11] Nine water quality parameters were selected to include in the index. These parameters are: dissolved oxygen (DO), fecal coliform, pH, biochemical oxygen demand (BOD) (5-day), temperature change (from 1 mile upstream), total phosphate, nitrate, turbidity, total solids. The scientists were then asked to graph the level of water quality ranging from 0 (worst) to 100 (best) from the raw data (e.g., pH values 2-12). The curves drawn were then averaged to obtain a weighting curve for each parameter. After the Q-value is obtained, it is multiplied by a "weighting factor," based on that test’s importance in water quality [11][14]. The nine resulting values are then added to arrive at an overall water quality index (WQI). [13]

The mathematical expression for NSF WQI is given by,

$$WQI = \sum_{i=1}^{n} Q_i W_i$$

Where,
Q_i= sub-index for i_{th} water quality parameter;
W_i= weight associated with i_{th} water quality parameter;
n = number of water quality parameters.

Table 2: Water Quality Rating as per different Water Quality Index methods National Sanitation Foundation Water Quality Index (NSFWQI)[12]

WQI Value	Rating of Water Quality
91-100	Excellent water quality
71-90	Good water quality
51-70	Medium water quality
26-50	Bad water quality
0-25	Very bad water quality

Canadian Council of Ministers of the Environment Water Quality Index (CCME WQI):

CCMEWQI is based on a formula develop by the British Columbia Ministry of Environment, Lands and parks and modified by Alberta Environment [8][15]. The index incorporates three elements:
Scope:-the number of variables not meeting water quality objectives;
Frequency:-the number of times these objectives are not met;
Amplitude:-the amount by which the objectives are not met.
The index gives a number between 0(worst water quality) and 100(best water quality).These number are divided into 5 descriptive categories to simplify presentation [8][15][16][17].
It is recommended that at a minimum, four calculations of index values. This index is useful tool for describing the state of the water column, sediments and aquatic life and for ranking the suitability of water for use by humans, aquatic life, wildlife etc.
Once the CCME WQI value has been determined, water quality is ranked by relating it to one of the following categories [8]:

Table 3: Water Quality Grading as per CCMEWQI [12]

Grading	CCME WQI	Water Quality Status
Excellent	95-100	Water quality is protected with a virtual absence of threat or impairment; conditions very close to natural or pristine levels.
Good	80-94	Water quality is protected with only a minor degree of threat or impairment; conditions rarely depart from natural or desirable levels.
Fair	65-79	Water quality is usually protected but occasionally threatened or impaired; conditions sometimes depart from natural or desirable levels.
Marginal	45-64	Water quality is frequently threatened or impaired; conditions often depart from natural or desirable levels.
Poor	0-44	Water quality is protected almost always threatened or impaired; airment; conditions rarely depart from natural or desirable levels.

The calculation of index scores in CCME WQI method can be obtained by using the following relation:

$$WQI = 100 - \frac{\sqrt{F_1^2 + F_2^2 + F_3^2}}{1.732}$$

Scope (F1) = [No. of failed variables /Total no. of variables]*100
Frequency (F2) = [No. of failed tests/Total no. of tests]*100
Amplitude (F3)
(a) excursioni = [Objectivej /failed test valuei]-1
(b) Normalized sum of excursions (nse) = excursionsi /No of tests
(c) F3 = [nse/ (0.01nse+0.01]

Oregon Water quality index (OWQI):

The Oregon Water Quality Index (OWQI) is a single number that expresses water quality by integrating measurements of eight water quality variables (temperature, dissolved oxygen, biochemical oxygen demand, pH, ammonia+nitrate nitrogen, total phosphorus, total solids, and fecal coliform [9][4][12]. Its purpose is to provide a simple and concise method for expressing the ambient water quality of Oregon's streams for general recreational use, including fishing and swimming [18][19][20].

The index employs the concept of harmonic averaging. The mathematical expression of this WQI method is given by-

$$WQI=\sqrt{\frac{n}{\sum_{i=1}^{n}\frac{1}{{SI_i}^2}}},$$

Where,
n = number of sub indices
SI = sub index of ith parameter.
Furthermore, the rating scale of this OWQI has also been categorized in various classes, which are given under Table-

Table 4: Oregon Water Quality Index (OWQI)[12]

WQI Value	Rating of Water Quality
91-100	Excellent water quality
85-89	Good water quality
80-84	Fair water quality
60-79	Poor water quality
0-59	Very poor water quality

British Columbia Water quality index (BCWQI):

This index is very similar to Canadian council of ministers of the environment water Quality Index (CCMEWQI) where water quality parameters are measured and their violation is determined by comparison with a predefined limit[4][9][21]. To calculate final index value the following equation is used:

$$WQI=100-\frac{\sqrt{F_1^2+F_2^2+F_3^2}}{1.453}$$

This number 1.453 was selected to give assurance to the scale index number from zero to 100[12].Disadvantage of this index does not indicate the water quality trend until it deviates from standard limit and due to usage of maximum percentage of deviation, it cannot determine the number of withdrawals above the maximum limit of standard.[4][9][12][]

Bhargava's Index (1983, 1985):

First time an Asian author introduced WQI and addresses the drinking water supply. To develop the index; Bhargava identified 4 groups of parameters. Each group contained one set type parameters [4] [9][22]. The First group included the concentrations of coliform organisms to represent bacteriological parameters [9] [23]. The second group represent toxicants, heavy metals etc. The third group indicates physical effects like odour, turbidity, colour etc. The fourth group represents inorganic, organics nontoxic substances like TDS, sulphate, copper, zinc etc [9][22][23]

The Sub indices Si were calculated and WQI formulation:

$$WQI=\prod_{i=1}^{n} fi\ Pi^{1/n}$$

Where,
n = number of variables parameter; $f_iP_i^{1/n}$
f_iP_i is the sensitivity function of the i_{th} parameters which includes the effect of weighting of the i_{th} variable in use.

Smith's Index:

Smith (1989) designed another kind of WQI called Smith's Index [9]. The index is a hybrid of the two common index types and is based on expert opinion as well as water quality standards [4][9]. The index addresses four types of water uses: general, regular public bathing, water supply and fish spawning [4][9]. The selection of parameters was done using Delphi technique for each water class, developing sub indices, and assigning weightage. Besides the usual Delphi steps, additional rounds of questionnaire were employed to arrive at greater convergence of opinion. To obtain the sub index values, the panel members were provided with the expected values of parameters likely to be encountered and mutually agreed set of descriptors for the range of sub index values[13][][].
The minimum operator technique was used to obtain the final index score [12][13]:
$I_{min}=\sum \min(Isub1, Isub2, Isubn)$
Where, I_{min} equals the lowest sub index.

The River Ganga Index:

Water Quality of ganga river was evaluated using this Index of Ved Prakash et al. The four important water quality parameters-dissolved oxygen (DO), Biochemical Oxygen Demand (BOD), pH and fecal coliforms[13]. This WQI is based on the weighted multiplication form and is given by the equation:
$WQI=\sum_{i=1}^{p} \mathrm{Wi\ Ii}$
Where, I_i = subindex for the i_{th} quality parameters;
W_i = weight associated with the i_{th} water quality parameters;
P= number of water quality parameters. The developed index was employed to evaluate the water quality profile of river Ganga in its entire stretch and to identify area requiring urgent pollution control measures [14]. Where, P_i=pollution index for i_{th} a parameters.

Overall Index of Pollution Index (OIP):

This index was developed in order to assess the status of surface waters in Indian conditions specifically by Sargoanker et al. at NEERI Nagpur, India[4][9]. Sargaonkar and Deshpande developed OIP for Indian rivers based on measurements and subsequent classification of pH, turbidity, dissolved oxygen, BOD, hardness, total dissolved solids, total coliforms, arsenic, and fluoride [26][27].

According to WQI value classified the water Excellent, Acceptable, Slightly polluted and heavily Polluted, according to Indian Guidelines/WHO standards /Eupropean standards. The mathematical Expression:

OIP = $\frac{\sum Pi}{n}$

Where, P_i = pollution index for i_{th} parameters,

N = number of parameters.

Dinius's Water Quality Index (1972):

This index broke new ground in the sense that through it an attempt was made to design to rudimentary social accounting which would measure the costs and impacts of pollution control efforts [4][9].

Dinius's examined the water quality described by various authorities to different levels of pollution variables, and from this information generated 11 sub index equations [27].

The index was calculated as the weighted sum of the subindices, like Horton's index and the additive version of the NSFWQI:

WQI = $\frac{1}{21}\sum_{i=1}^{11} WiIi$

The weights ranged from 0.5 to 5 on a basic scale of importance. On this scale, 1,2,3,4 and 5 denote, respectively, very little, little, average, great and very great importance. The sum of the weights was 21 which is the denominator in the index equation. The index was applied in several streams Albama, USA by Dinius [4][9][27].

Mcduffie and Haney's River Pollution Index:

It is relatively simple water quality index in which eight pollutant variables are included [9][28]. Most subindices are of the general linear form:

IA Proposed River Pollution Index =$\frac{X}{\mathrm{Xn}}$

Where,

I_i is the subindices of the i_{th} pollutant variable.

X is the observed value of the pollutant variable.

X_n is the natural level of the pollutant variable.

Six out of eight subindices described by Mcduffie and Haney were explicit linear functions, and two (coliform count and temperature) were explicit nonlinear functions [9]. The index does not include Ph and toxic substances [28].

The overall index is computed as the sum of n subindices times a scaling factor 10/n+1:

RPI= $\frac{10}{n+1}(TF + \sum_{i=1}^{n} 10 \text{ X } Ii)$

Here, TF is the temperature factor and n is the number of parameters other than temperature.

Stoner's Index:

This index, aimed for use in public water supply and irrigation, employed a single aggregation function which selects from 2 sets of recommended limits and subindex equations [4][9][29]. Two types of water quality parameters are used in the stoner's index:

Type I parameters normally considered toxic at low concentrations (eg. Lead, Radium-226).

Type II which affects aesthetic and health characteristics (e.g, Chlorides, sulphur, odour, taste).

The type I pollutant variables were treated in a dichotomous manner, giving subindex step functions. Each value of Type 1 assigned value Zero if the concentration is less than or equal to the recommended limit and the value 100 if the recommended limit is exceeded [9].

The Type II pollutant variables are represented by explicit mathematical function.

The overall index was computed by combining the unweighted type I subindices with the weighted type 2 subindices[13]:

WQI=$\sum_{i=1}^{m} Ii + \sum_{j=1}^{n} W$jIj

Where,

I_i is the subindex for the i^{th} type I pollutant variable,

W_j is the weight for j^{th} type II pollutant variable,

I_j is the subindex for j^{th} type II pollutant variable.

Ground Water Quality Index of Soltan (1999):

Soltan proposed a WQI based a WQI based on 9 water quality parameters including heavy metals to assess the water quality from artesian wells located near Dkhala oasis, Egypt [9][30]. The indices for individual parameters were calculated as follows-

WQI= $\sum_{i=1}^{n}(q_n)$

Where, qi= 100 X $\frac{Vi}{Si}$

The average water quality index for n parameters was calculated using the expression

AWQI= $\sum_{i=1}^{n}(q_n)/\mathrm{n}$

Where, n is the parameters and q_i is quality rating of ith parameters.

V_i is the observed value of the i[th] parameters

And S_i is the water quality standard for the i[th] parameters.

The permissible or critical pollution index value was set at 100. The AWQI has a value of 0 when all pollutants reach their permissible limits. AWQI values exceeding 100 indicate that the water sample may suffer from serious pollution problems [9][30].

Deininger and Landwehr's PWS Index-

Deininger and Landwehr (1971) presented an index pertaining to water used for public water supply [9]. It employs 11 parameters for surface water sources [31]. Two aggregation functions were considered: an additive form and a geometric mean [9] [31]. The 11-variable and 13- variables version of indices were computed for each aggregation function:

Additive PWS = $\sum_{i=1}^{n} W_i I_i$

Geometric mean PWS= $(\prod_{i=1}^{n} I_i^{W_i})^{1/n}$

Where n=11, for 11 variable version and n=13, for 13-variables version.

An Index for Surface Water As Well As Ground Water Quality:

An index for Dalmatia Region, Croatia developed by Stambuk-Glijanovik in 1999. They addresses the issues of surface water quality as well ground water quality[9][32]. The quality index is given the equation-

$$WQI= \frac{WQE}{WQE_{MAC}}$$

In it the tested water quality evaluation (WQE) is divided by the water quality evaluation WQE_{MAC} which satisfies the maximum admissible concentration (MAC) of first –class water according to the standard of drinking [9][32].

The Croatian standard consists of four classes. The First one includes underground and surface waters which can be used in a natural state or after being disinfected for drinking water. The second one includes underground and surface water which cannot be used for drinking purpose without first being treated. The third group includes the water which cannot be used in natural sites or after being treated. The fourth class is not used [9][32].

WQE calculated by summing up individual quality ratings (q_i) and weighting these parameters in total quality evaluations (w_i):

$$WQE=\sum_{i=1}^{n} q_i w_i$$

Where, $\sum_{i=1}^{n} q_i w_i$ is the weighed sum.

q_i is the water quality score of parameter i; w_i is the weighing factor of the parameter. Nine water quality parameters were used by the author to determine the WQI. After determining the nine parameters, Temperature, mineralization, corrosion coefficient, K= (SO_4 +Cl)/HCO_3, Total nitrogen, BOD, DO, protein, nitrogen, Total phosphorus, and Total coliforms. The result were recorded and transferred to WQE table which contain possible results of the parameters and their score values. By summing up all parameters the water quality evolution was obtained [9][32].

The score values of each particular parameter as well as its weights were arbitrarily estimated, on the basis of a survey. The grades present the weights, i.e., and the percentage of approximately 100% water quality and do not depend on MAC [9][32].

Groundwater Contamination Index-

A contamination index, (C_d) has been developed to provide general view of the groundwater contamination (Backman et al 1998). The parameters were chosen which are considered potentially harmful [9][33]. Two indices are calculated, one based on those parameters which pose health risks and other based on technical –aesthetics aspects.

For the calculations of the contamination index for health risk aspects, F^-, NO^{3-},UO_2^{2-}, As, B, Ba, Cd, Cr, Ni, Pb, Rn, and Se have been considered. For the other index based on technical –aesthetics aspects, the parameters are TDS, SO_4^{2-}, Cl^- ,F^-, NO^{3-}, NH_4, Al, As, Ba, Cd, Cr, Cu, Fe, Hg, Mn, Pb, Sb, Se, and Zn[9].

Either index is given by,

$$C_d = \sum_{i=1}^{n} C_{fi}$$

$$C_{fi} = \frac{C_{Ai}}{C_{Ni}} - 1$$

Where, C_{fi} is the contamination factor in i[th] component,

C_{Ai} is the analytical value of the i[th] component and

C_{Ni} is the upper permissible concentration for the i[th] component,

N representing the normative value.

Aquatic Toxicity Index (ATI):

This index developed by Wepeneret al. to assess the health of aquatic ecosystems. Since extensive toxicity are available for fishes, the toxic effects of different water quality to fishes have been employed as health indicators of the aquatic ecosystem [9][34].The parameters used were Ph, DO, and turbidity while the chemical parameter included ammonium, total dissolved salts, fluoride, potassium and orthophosphates and the potentially hazardous metals selected were total zinc, manganese, chromium, copper, lead and nickel concentrations. The Solway modified un-weighted additive aggregation function was initially employed to aggregate the values obtained from the rating curves [9] [31].

$$I = \frac{1}{100}\left(\frac{1}{n}\sum_{i=1}^{n} Qi\right)^2$$

Where,

I is the final index score,

Q_i is the quantity of the ith parameter (a value between 0-100)

and n is the number of determinants in the indexing system.

Wepeneret al. did not used the weighted sum system, as too little information is available about the importance of one determinant compared to another under different local conditions and the inherent chemistry of the system as a whole[34].

Recreational Water Quality Index (RWQI)

Ideally, recreational water quality indicators are microorganisms or chemical substances whose concentrations can be quantitatively related to swimming and associated to health hazards. Selection of parameters has great importance to RWQI calculation because rigidity problems exist when additional variables are included in the index to address specific water quality concerns, but the faulty aggregation function might artificially reduce the value of the water quality index so that it does not accurately reflect the true water quality. As the number of water quality variables increases, the magnitude of the aggregated index decreases raising the issue of ambiguity again [35][9].

Numerical scales related to the degree of quality were established for each variable to assess variation in quality water and to convey findings in a comprehensive manner to others.

These rating curves are, in fact, the essence of the development of this index. Rating curves have the ability to reproduce the relationship between swimming-associated illness and water quality indicator. The success or failure of the application of the quality index developed will depend on rating curves.

Once rating curves were established, various computing methods to water quality index are possible. The calculation of the proposed RWQI is (1):

$$RWQI = \prod_{i=1}^{n} Qi^{Wi}$$

Where,

Qi is the rating value of parameter i and Wi is the weighting factors (ΣWi=1).

Therefore, each analytical value is transformed in a non-dimensional value or quality level (Qi) through a mathematical equation or through its corresponding graphic representation. Wi is the influence of each parameter in the total value of the index. To calculate each of them, their individual weight must be considered.

Wi is calculated as (2):

$$W_i = \frac{\frac{1}{ai}}{\sum \frac{1}{ai}}$$

The ai coefficient values vary from 1 (very important parameter) to 4 (less significant parameter) according to the importance assigned to each parameter involved in the index. In this way, the RWQI is calculated by the multiplication of all of the products of the parameter weights and sub index values (Q_i^{Wi}) (Eq. 1). RWQI is a number among 0 to 100, where values close to 100 represent the best quality [4][9][35].

This formulation avoids the problems of ambiguity and eclipsing to the number of water quality variables required to be aggregated in a given index. If the value of a sub-index is zero, RWQI has become zero automatically. Furthermore, weight factor of parameter allows obtain large changes to little variations for each one of different parameters.

Besides, this formulation has great sensitivity to small parameter variations giving greater protection to people [35].

4. CONCLUSION:

After the study of various types of Water quality indices it may be inferred that WQI mainly varies with selection of parameters and mathematical function used for computations.

Drinking water standards varies with the region; time and prevailing condition thus affect WQI value.

WQI are necessary for reducing large, multiple water quality data into single numeric value that makes easy to report to managers, and public. WQI value indicates its quality in simple and understandable manner. This, in turn, is essential for comparing water quality of different sources and helps in monitoring the changes in the water quality of a given source as a function of time and other influencing factors.

The water quality and Index value significantly influenced with time of sampling.

There is no universal WQI which can be applied on every water body of Earth. So, different agencies, scientists, experts give their own WQI based on regional condition, standards, purpose, parameters. So, the selection of WQI should be selected according to purpose like drinking purpose, aquatic life, bathing, industrial purpose, agricultural purpose etc and also according to resources like groundwater, river, aquifer etc.

General WQI is an efficient tool in water quality assessment but parameters should be carefully selected depending on source and time.
There is should be regular monitoring of water quality in order to detect changes in physicochemical parameters concentration and convey to the public. So these indices are useful tools to represent water quality in a simple and understandable manner.

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