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Model of Base Saturation Flow to Improve Indonesia Highway Capacity Manual at Signalized Intersection

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Abstract. The intersection is a critical component of the urban traffic network, signalized intersection are often analyzed to evaluate their effectiveness. However, one issue with signalized intersection analysis is that the results may not align with the actual field conditions. In Indonesia, the 1997 Indonesia Highway Capacity Manual (IHCM) is commonly used for analyzing signalized intersections. However, traffic conditions have significantly changed since 1997, including changes in vehicle types, land use patterns, driving behavior, road geometry, and technical complexity. Therefore, the 1997 IHCM needs to be updated to reflect current traffic conditions. One important parameter in signalized intersection analysis is the base saturation flow (So). This study aims to improve the IHCM by creating a more accurate base saturation flow (So) parameter. The current So parameter in the 1997 IHCM is 600 x We. After modeling and conducting a chi-variance test with a ρ value of <0.05, the new So value was determined to be in the range of 675 x We to 1000 x We^85. The result of this study is a more accurate So parameter that better reflects actual field conditions and can improve the effectiveness of signalized intersection analysis in Indonesia.

Keywords: base saturation flow, IHCM, signalized intersection, queue length, traffic flow

INTRODUCTION

The urban transportation system is composed of various segments and sections. Traffic management has become a primary focus of many countries due to urbanization [1]. According to [2], signalized intersections are widely used in modern times across the world. The intersection is an essential node of urban roads. Traffic management in terms of security can be done by controlling the cycle time at intersections [3]. Signalized intersections significantly impact the capacity and operation of urban road networks [4]. The capacity of signalized intersections limits the road network's operation so that signalized intersections are designed to regulate traffic [5]. Signalized intersections have different characteristics. The intersection's operational characteristics are determined by its unique pattern [6]. Policymakers, practitioners, and transportation professionals need to consider traffic control when managing the urban road network [7]. Operational characteristics are affected by traffic flow characteristics. In the flow of traffic, several components play a role, namely, vehicles and users [8]. Traffic flow has a significant impact on traffic characteristics [9]. Traffic characteristics in developing countries are heterogeneous, characterized by various vehicle types and a lack of discipline in behavior [10]. Vehicle prosecution and maneuvering are two fundamental behaviors that shape traffic flow [11]. Changing lanes' movement significantly impacts traffic, both efficiency and safety [12].

Indonesia is one of the developing countries with the highest number of motorcycles compared to other vehicles, i.e., 76% [13]. The composition of the motorcycle population affects traffic flow. One crucial parameter in analyzing signalized intersections is saturation flow, which is the maximum flow in the green phase [14]. Saturation flow is fundamental in evaluating service levels, computing capacity, and planning cycle time optimization [15]. Saturation flow is an essential parameter in geometric design, intersection control, and level of service [16]. Saturation flow is the maximum flow in the green phase [17]. Cycle time in signalized intersection operations, the primary parameter used is saturation flow[18]. Travel time at signalized intersections is governed by the signal and saturation flow conditions, as vehicles enter the intersection in one cycle until vehicles cannot pass through the intersection in the final cycle [19]. The procedure for calculating saturation flow is based on the assumption that the vehicle is in lane discipline (Highway Capacity Manual, 2010). In heterogeneous traffic, vehicle discipline on lanes is not easily maintained. For 1985 and HCM 2000, the average saturation flow per lane is 1800 and 1900 per lane per hour. However, the saturation flow will also change with various changes in traffic conditions. In 1997 IHCM, the formula of saturation flow (S) = So x F_{cs} x F_{sf} x F_g x F_{rt} x F_{lt} xF_{p}. So based on 600 x We (entry approach width). 1997 IHCM is the product of data processing in which traffic conditions in 1994 that different from current conditions. Traffic characteristics in 1997 were very different from the current situation [20]. Since the release of 1997 IHCM, the experienced conditions, road traffic infrastructure and facilities and their users are no longer quantitatively and qualitatively in line with the then traffic characteristics and infrastructure conditions. More than two decades after its release, the IHCM has never been updated, despite changes in traffic characteristics due to year-to-year increases in the number of vehicles. Major changes in the traffic flow compared to 1997, when IHCM was created, include: changes in the number and composition of motor cycle (119,288,370,000 vehicles between 1987 and 1994, compared to 136,137,451 between 1995 and National Bureau of Statistics, 2022); changes in the length of national roads; vehicle technology impacts better vehicle mobility; changes in land use functions and changes in driver behavior. One of the important components needs to be in the form of saturation flow in signalized intersection for updating to analysis results close to the field.

MATERIAL AND METHODS

A survey was conducted at six signalized intersections located in Surabaya, Semarang, Jakarta, and Bandung. Collected data included intersection geometry, vehicle counts for left, right, and straight directions, cycle time, side friction, city size, and queue lengths. The update of saturation flow was formulated by comparing actual queue lengths with analysis results using the 1997 IHCM method, and the results were verified using chi-square analysis. The methodology used for signalized intersection analysis in the 1997 IHCM is presented in Figure 1.

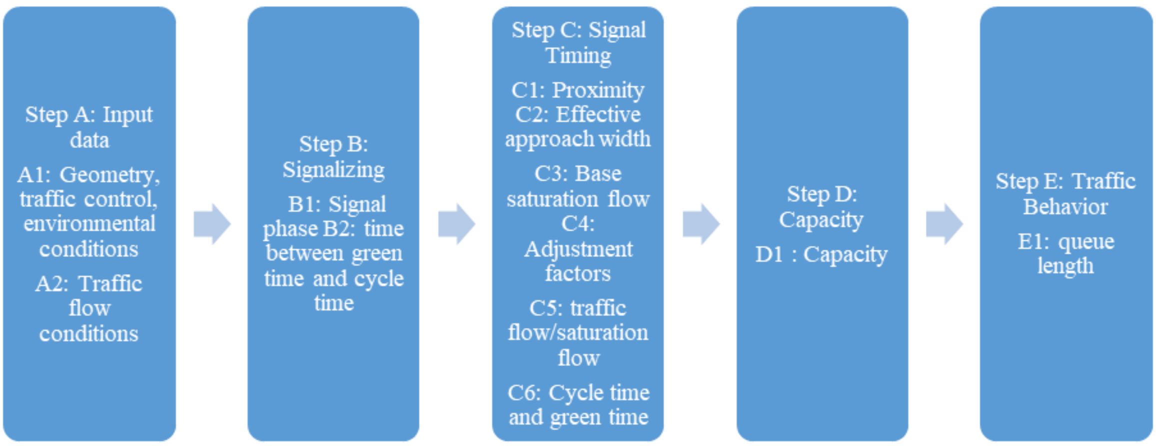

FIGURE 1. The Method of 1997 IHCM in Signalized Intersection

From Figure 1, it can be seen that the traffic behavior is determined according to the queue length. The length of the traffic jam is determined by the intersection capacity, taking into account the traffic flow (Q), degree of saturation (DS), and signal time (c and g). DS is derived from the comparison of traffic flow and capacity = Q/C. A basic model of the signal capacity is obtained by multiplying the saturation flow by the green ratio (g/c) of each batch, as shown in Formula 1.

C = S x g/c..1

S = So x F_{cs} x F_{sf} x F_g x F_{rt} x F_{lt} xF_p...2

Where

C = capacity

S = saturation flow (passenger car unit/hour or pcu/hour)

g = green time (second)

c = cycle time (second)

So = base saturation flow (pcu/hour) = 600 x We

We = entry approach width (meter)

F_{cs} = city size factor

F_{sf} = side friction factor

F_g = gradient factor
F_{rt} = right turning factor
F_{lt} = left turning factor
F_p = parking factor
From formula 1, queue length calculate :
NQ = NQ1 + NQ2
Where

$$NQ1 = 0{,}25 \text{ x } C \text{ x } [(DS - 1) \text{ x } \sqrt{(DS-1)2 + \frac{8 \, x \, (DS-0{,}5)}{C}}$$

If DS > 0,5 and NQ =0

$$NQ2 = c \text{ x } \frac{1-GR}{1-GR \, x \, DS} \text{ x } \frac{Q}{3600}$$

Where :

NQ1 = the number of pcu that remain from the previous green phase
NQ2 = the number of pcu that arrive during phase
DS = Degree of Saturation
GR = green ratio (second)
c = cycle time
C = capacity (pcu/hour)
Q = traffic flow (pcu/hour)

The queue length of the analysis results with 1997 IHCM was compared with the length of the field queue graphically and with the chi-square difference test. If graphically, the distribution of queue length points away from the trendline with ρ value > 0.05, it shows a significant difference between the length of the field queue and the analysis results, so it is necessary to improve the saturated current. One of the parameters of saturation flow is base saturation flow (So)—improvements in updating So using a large trial. The results of the So magnitude test are then analyzed graphically, and chi-square and selected with points of queue length distribution close to the trendline and ρ value <0.05.

RESULTS AND DISCUSSION

According to the 1997 IHCM method to calculate the results of 6 signal intersections with PCE_{LV} = 1; PCE_{MC} = 0.2, PCE_{HV} = 1.3, for the protection flow, the obtained queue length is shown in Table 1 (intersection 3) and Table 2 (intersection 4). Comparison of actual queue length and 1997 IHCM, as shown in Figure 2 and Figure 3.

TABLE 1. Actual Queue Lengths and 1997 IHCM Method at Intersection 3

Cilamaya Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Diponegoro from Gedung Sate	54	43,2
Jalan Cilamaya	52	42,5
Jalan Diponegoro to Gedung Sate	54	36,4
Kalibata Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Raya Pasar Minggu to Cikarang	130,36	128
Jalan TMP Kalibata	118,77	109,5
Jalan Raya Pasar Minggu from Cawang	116,94	112,4
Supriyadi Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Majapahit ke arah Simpang Lima	85	74,2
Jalan Supriyadi	63	50,8
Jalan Majapahit dari arah Simpang Lima	54	44,2

Source: Results of Measurements by Researchers, 2022

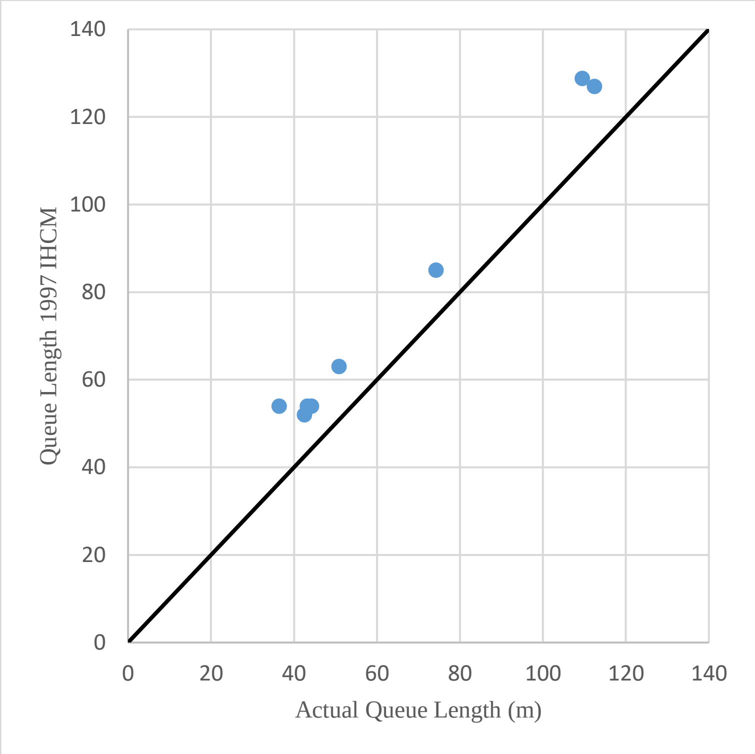

FIGURE 2. A Comparison of Actual Queue Length and Results of Analysis with 1997 IHCM Method at Intersection 3
Source: Results of Measurements by Researchers, 2022

TABLE 2. Actual Queue Lengths and 1997 IHCM Method at Intersection 4

Medoho Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Gajah (to Masjid Agung)	169	100
Jalan Gajah (from Lamper)	151	86
Jalan Medoho Raya	145	65
Jalan Medoho Permai	76	14,5
Kebayoran Lama Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Gandaria III (from Blok M)	200	154
Jalan Gandaria III (fromKebayoran)	329	178
Jalan Gandaria III (from Pondok Indah)	186	156
Jalan Gandaria III (from Tanah Kusir)	200	168
Dr. Soetomo Intersection		
Approach	Queue Length (meter)	
	1997 IHCM	Actual
Jalan Diponegoro (dari selatan ke utara)	202	158
Jalan Diponegoro (dari utara ke selatan)	205	168
Jalan Diponegoro (dari timur ke barat)	186	136
Jalan Dr. Soetomo (dari barat ke timur)	204	165

Source: Results of Measurements by Researchers, 2022

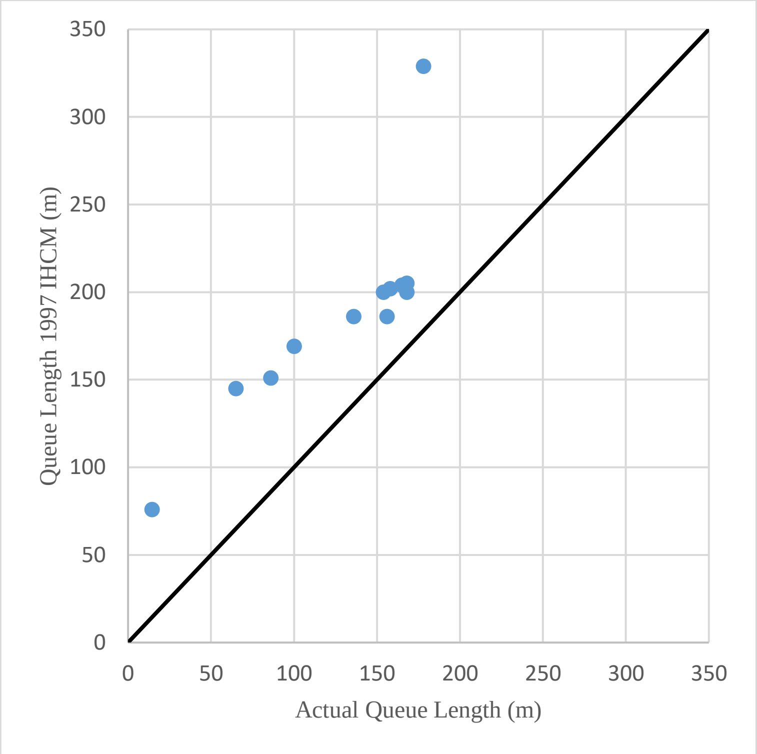

FIGURE 3. Actual Queue Length and Results of Analysis with 1997 IHCM Method at Intersection 4
Source: Results of Measurements by Researchers, 2022

From Table 1, 2 actual queue lengths with the analysis results were tested differently from chi-square. From the analysis of the difference test, it was found that there was a significant difference between the length of the actual queue and the analysis results using the 1997 IHCM method. ρ value > 0.05. Graphically, the actual queue length with 1997 IHCM is compared, and Figures 2 and 3 showing the points in the form of queue length are far above the trendline. This indicates the need to modify the parameters forming capabilities of the signalized intersection, one of which is base saturation flow (So), which is initially 600 x We. The difference is caused by differences in traffic conditions when IHCM 1997 was made, and after 1997 IHCM was made. Where traffic conditions are influenced by various factors, such as the population of vehicles, vehicle technology, infrastructure (roads), land use, and driver behavior. Changes in the vehicle population with the high number of private vehicle owners are caused by urbanization, industrialization, and population growth, which certainly affect traffic flow [21]. Based on the Indonesian Central Bureau of Statistics, from 1987 to 1994, the population of motor vehicles was 11928837 million. The years 1995 – 2021 are 136137451. From 1994 to 2021, there was a 91.24% increase in 124208614 vehicles. In this day, the sophistication of vehicle technology has shown efficiency in facilitating human life [22]. Travel time is influenced by vehicle technology [23]. The impact of vehicle technology is the driver's behavior in the form of maneuverability [24]. Improved driver performance due to the aromatic system in motor vehicle technology [25].

Today's vehicles have more capabilities than the 1994 vehicles, with more responsiveness, reliable brakes, and easier operational systems that make it easier to maneuver the vehicle. The facts show that with the sophistication of vehicle maneuvering technology, it is increasingly agile and affects traffic flow patterns so that motorcycles enter gaps or gaps when red time and cause traffic density to increase with the distance between vehicles that do not pay attention to safe limits. Accessibility is the basis of policies in the sustainable development of transportation in urban areas [26]. Therefore, infrastructure (road) construction is developing rapidly in today's era. Infrastructure performance needs to be improved with improvements [27]. Traffic conditions can be described by infrastructure performance conditions [28]. From 1990 to 1994, the length of the National Road was 327,000 km. In 2011 the length of the National Road was 437 700 km. Based on this, it shows that the development of National roads is now 34% compared to the previous year. Overall, the road length according to the type of pavement in 1994 was 165368 km (asphalt) and 182066 km (not asphalt). In 2020 it was 319787 km (asphalt) and 228579 km (not asphalt); there was an increase in the length of the National Road from 1994 to 2020, namely 154419 km (asphalt) and 46513 km (not asphalt)—sustainable development related to land use.

Land use in its function provides a comprehensive overview of the concept of sustainable development [29]. The pull and rise of a land use system affect the movement of the area. Transportation and land use are two inseparable things. In urban developing countries, there is a lot of declining road capacity. This is due to inappropriate land use arrangements and the high activity of the roadside with the improvement of land use functions. If previously there were many lands, now there are many potential areas. The flow of traffic flow is influenced also by the parameters of the driver's behavior. One of the indicators is the aggressiveness of the way of driving. The form of aggressiveness is in the form of vehicle prosecution and lane movement that does not pay attention to safe distances. Maneuvering on the movement of changing lanes is a potential traffic accident. BPS data for 2014 shows that the number of accidents from 1992 to 1994 was 17,469. From 1995 to 2019, it was a significant 98,942.

With these changes, 1997 IHCM must be initiated by adjusting the base saturation flow (So) at the signalized intersection. So updating was performed with a trial and error from 675 x We to 1000 x We^85. The model analysis results are the next queue length compared to the actual through the chi-square difference test. From the test results of the difference in the length of actual queue length with the model, the amount of So was obtained, which gave the result of the queue length approaching actual with ρ value <0.05, namely at intersections 3 (So = 1000 x We) and 4 (So = 1000 x We). Graphs of the distribution of queue lengths at intersections 3 and 4 can be seen in Figures 4 and 5.

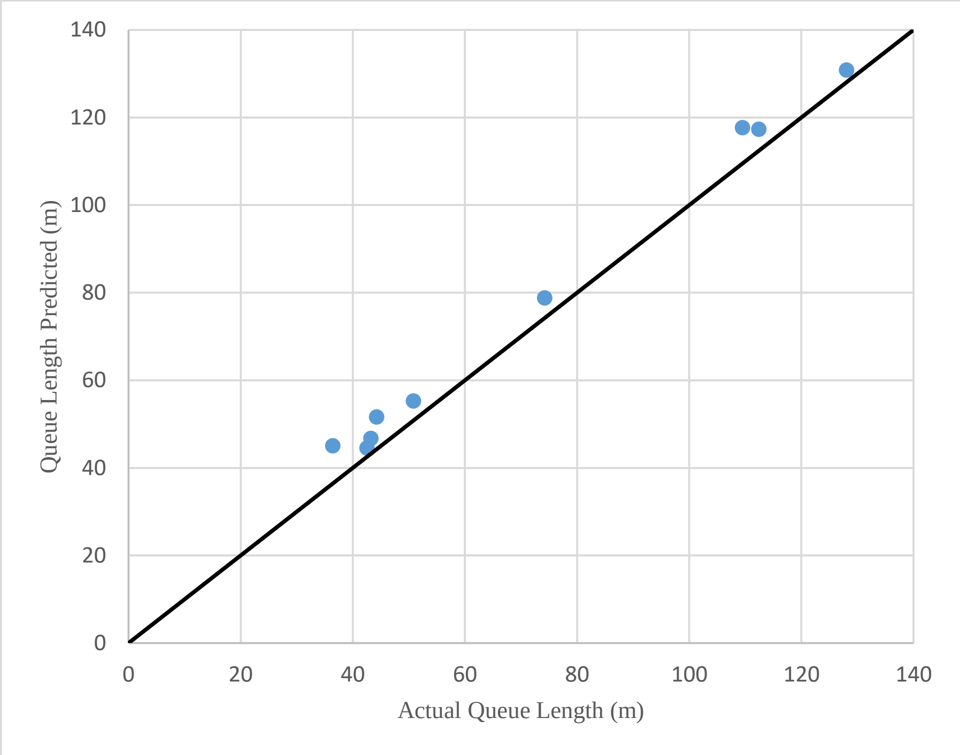

FIGURE 4. Actual Queue Length and Predicted with So = 1000 x We at Intersection 3
Source: Results of Measurements by Researchers, 2022

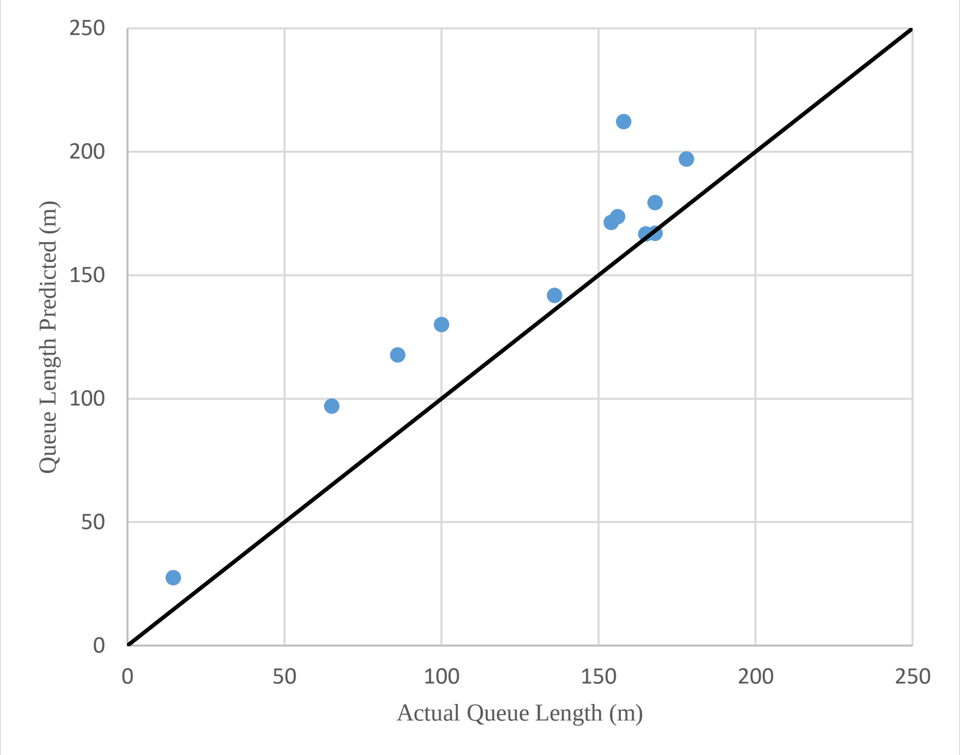

FIGURE 5. Actual Queue Length and Predicted with So = 1000 x We at Intersection 4
Source: Results of Measurements by Researchers, 2022

Figures 4 and 5 show a different pattern compared to before there was an improvement to So. The queue length distribution resulting from the modeling shows that the model queue length distribution (ordinate) is close to the trendline and close to the actual queue length. Because the So model or prediction result is the same, 1000 x We, the amount is an update of the So for IHCM, which is adjusted to current conditions. A so of 1000 x We can be applied to intersections 3 and 4 with the same intersection characteristics.

CONCLUSION

Signalized intersections play a crucial role in managing traffic in urban areas by regulating the movement of vehicles. To ensure efficient intersection management, it is essential to have up-to-date guidelines that reflect current traffic conditions. However, the manual or guideline still in use for intersection management is the 1997 IHCM, which is no longer relevant given the changing traffic conditions since its inception. Our modeling results demonstrate the need for updating the IHCM, specifically its base saturation flow (So) parameter, which is critical for analyzing intersection capacity. The 1997 IHCM specifies a base saturation flow (So) of 600 x We, which was found to differ significantly from field observations. Therefore, we propose an improved base saturation flow (So) of 1000 x We to enhance the IHCM's predictive accuracy.

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