Proposal of a new formula for the calculation of the Hazen-Williams coefficient

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Abstract:

The calculation of the head losses in pipes is done by several formulas, like, Darcy (1875), Manning-Strickler (1885), Scobey (1920), or Hazen-Williams (1906); these formulas have the same calculation principle.

They compute the hydraulic gradient as a function of the flow rate Q, the diameter D and the coefficients indicating the roughness of the pipes (•, C_{HW} and Ks, which are generally from tables).

The choice of Hazen-Williams coefficient C_{HW} is very complex, but this is not the case for the roughness, which a simple use of a roughness tester can accurately know.

The objective of this paper is to propose a relationship giving the Hazen-Williams coefficient taking into consideration all the parameters governing the flow, which are: the absolute roughness of the pipe e, the diameter D, the flow rate Q, the Reynolds number R, the kinematic viscosity •), using two methods (analytical and graphic).

Keywords: Hazen-Williams coefficient, Flow rate, Diameter, Reynolds Number, RMM, Roughness, Hydraulic Gradient.

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1. INTRODUCTION

Calculating the head losses in pipes and canals is very important to implement hydraulic works such as water storage tanks or calculating drinking water distribution networks.

The relationships used to calculate the load losses in pressure lines such: as Darcy (1875), Manning-Strickler (1885), Scobey (1920) or Hazen-Williams (1906), Achour-Bedjaoui (2006), (2012). These formulas have the same calculation principle; they define the gradient of head loss according to the flow Q, diameter D and coefficients indicating the roughness of the pipes (C_{HW} for Hazen-Williams, Ks for Manning-Strickler and ks for Scobey, and absolute roughness).

The resulting coefficients have constant values that can be selected from tables proposed by several authors and developed according to the nature of the pipe material. The values of these coefficients vary inversely in proportion to the absolute roughness of the tubes.

The relationship of Hazen-Williams gives the hydraulic gradient or the head loss according to parameters: the flow rate, the diameter, and a coefficient bearing the name of the author of this relationship. It gives a direct result, without required iterations or a friction factor f.

However, it It presents an inconvenient in the choice of the value of the C_{HW} coefficient, limitation of this relationship is that the parameter C_{HW} does not depend directly on pipe roughness; it is defined as a constant value, depending only on the pipe material, as shown in Table 1[1].

Many authors have discussed the limits of the applicability of this relationship: Vennard (1961), Streeter and Wylie (1985), Streeter et al. (1996), Potter and Wiggert (1997), Liou (1998), Locher (2000), Travis and al (2007), Sharp and Walski (1988), Jaćimović and al. (2014), Adams (2016), Achour and Amara (2022), and they asserted that C_{HW} must depend on both the pipe's relative roughness and the Reynolds number [2].

Table 1. Values of Hazen-Williams constant [1].

Materialial	C_{HW} **factor**		
Asbestos Cement	-	140÷150	140
Brass	-	120÷150	-
Black steel (dry systems)	130	100	100
Black steel (wet systems)	130	120	120
Cast iron - New unlined	130	120÷130	100
Cast iron - 10 years old	100	105÷75	-

Cast iron - 15 years old	100	100÷60	-
Cast iron - 20 years old	80	95÷55	-
Cast iron - 30 years old	80	85÷45	-
Cast iron - 50 years old	80	75÷40	-
Cast iron - Bitumen-lined	-	140	-
Cast iron - Cement-lined	140	140	140
Concrete	120	85÷150	140
Copper	-	120÷150	150
Fibre glass pipe	-	150÷160	-
Fire hose (rubber)	-	135	-
Galvanized steel	-	120	120
Lead	-	130÷150	-
Polyethylene	-	150	-
PVC and plastic pipe	150	150	150
Stainless steel	-	150	150
Steel new and unlined	-	140÷150	-
Steel, welded and seamless	130	100	-
Vitrified clays	-	110	-
Wood	120	-	-

Clay, new riveted steel	110	-	

Several researchers have tried to express it using flow parameters, such as relative roughness, diameter and Reynolds number, or as a function of the friction factor, instead of taking it as a constant value from tables.

When the hydraulic gradient is calculated by Darcy's relationship with Colebrook-white's (friction factor f) and Hazen-Williams's relationship, a significant difference in the results will be obtained because the correspondence between Hazen-Williams coefficient and the absolute roughness is not adequate.

This work is concerned with proposing a general relationship giving the Hazen-Williams coefficient according to a significant number of parameters (flow rate, diameter, absolute roughness, kinematic viscosity, and implicitly the number of Reynolds), with the aim of:

- Avoiding the use of proposed tables to select Hazen-Williams coefficient values.

- Checking the usage or validity limits of the Hazen-Williams relationship because, According to M.H. DISKEN (1960), The Hazen-Williams formula applies only to pipes having a coefficient C in the range of (100-160). For each pipe, the formula should be used only in the range of Reynolds numbers given in table 2. [2].

Table 2. Limits of applicability of the Hazen-Williams formula. [2]

ε/D	R_{min}	R_{max}	Approx. C_{HW}
2×10^{-2}	2×10^{3}	5×10^{3}	100
$1{,}5 \times 10^{-2}$	2×10^{3}	$7{,}5 \times 10^{3}$	110
2×10^{-2}	2×10^{3}	10^{4}	110
6×10^{-3}	4×10^{3}	2×10^{4}	120
4×10^{-3}	8×10^{3}	8×10^{3}	120
2×10^{-3}	10^{4}	$2{,}5 \times 10^{4}$	130
10^{-3}	2×10^{4}	4×10^{4}	130
6×10^{-4}	3×10^{4}	10^{5}	140

4×10^{-4}	4×10^{4}	2×10^{5}	140
2×10^{-4}	6×10^{4}	4×10^{5}	140
10^{-4}	8×10^{4}	8×10^{5}	150
5×10^{-5}	10^{5}	10^{6}	150
10^{-5}	4×10^{5}	4×10^{6}	160
5×10^{-6}	6×10^{6}	2×10^{7}	160

- Making the results of calculating the hydraulic gradient more accurate and converging towards the same results that could be obtained by applying the relationship of Darcy or Achour-Bedjaoui.

A comprehensive overview of the most commonly used equations for the friction factor calculation is given in [3].

2. EVALUATION OF THE WILLIAMS-HAZEN COEFFICIENT

2.1 ANALYTICALLY

The Williams-Hazen relationship gives the hydraulic gradient as a function of the parameters governing a flow, which are the volume flow rate Q (m^3/s), the diameter D (m) of the pipe, and a coefficient called the Williams-Hazen coefficient (C_{HW}), which is given by equation (01), [1].

$$J = \frac{10.675}{C_{HW}^{1.852} D^{.4,87}} Q^{1.852} \quad (01)$$

Where: J is the hydraulic gradient, Q is the flow (m^3/s), D is the pipe diameter (m), and C_{HW} is the Williams-Hazen coefficient.

According to Achour-Bedjaoui (2006), [5], [6] the hydraulic gradient can be represented by the relation (02), which associates the hydraulic gradient with the parameters of the flow, which are: the volume flow Q (m^3/s), the diameter D (m) of the pipe and the absolute roughness ε(m) of the internal wall of the pipe as well as a parameter representing the Reynolds number of the reference pipe, this relation is expressed by:

$$J = \frac{2Q^2}{\pi^2 g D^5} \left[-\log\left(\frac{\varepsilon/D}{3.7} + \frac{10.04}{\bar{R}}\right)\right]^{-2}$$

(02)

With:

J: Hydraulic gradient or slope of the energy grade line;

Q: Volume flow (m3/s);

D: Pipe diameter (m);

ε: Absolute roughness of the internal wall of the pipe (m) ;

$\overline{R}$: Reynolds number of the reference pipe given by the relation (03):

$$\overline{R} = 2R\left[-\log\left(\frac{\varepsilon}{3.7D} + \frac{5.5}{R^{0.9}}\right)\right]^{-1} \qquad (03)$$

Where: R is the Reynolds number.

The relation (02) is obtained by substituting in the Darcy relation the relation of Achour-Bedjaoui (2012) given by the equation (04) expressing the friction factor f. It should be noted that the relation (04) is more accurate and more precise than the one of Colebrook-white (1939); moreover, it is explicit and does not require iterations or software; after conducting 2897 experimental points to compare 46 explicit equations and the Colebrook equation for the evaluation of the friction coefficient, the researchers concluded that the estimates of the Achour-Bedjaoui (2012) equation were the most accurate and stood out from the others [7].

$$f = \left[-2\log\left(\frac{\varepsilon/D}{3.7} + \frac{10.04}{\overline{R}}\right)\right]^{-2} \qquad (04)$$

By equalizing relations (01) and (02), and after an arrangement and simplification, the relation giving the Williams-Hazen coefficient can be represented by relation (05) in the form:

$$\frac{10.675}{C_{HW}^{1.852} D^{4.87}} Q^{1.852} = \frac{2Q^2}{\pi^2 g D^5}\left[-\log\left(\frac{\varepsilon/D}{3.7} + \frac{10.04}{\overline{R}}\right)\right]^{-2} \qquad (05)$$

We get:

$$C_{WH} = 29.16\, Q^{-0.08}\, D^{0.07}\left[-\log\left(\frac{\varepsilon/D}{3.7} + \frac{10.04}{\overline{R}}\right)\right]^{1.08} \qquad (06)$$

Relationship (06) gives the Williams-Hazen coefficient (C_{HW}) as a function of the absolute roughness of the internal wall of the pipe ε(m), the flow rate through the pipe Q (m^3/s), the geometric diameter of the pipe D (m) and the Reynolds number of the reference pipe $\overline{R}$.

Equation (06) can be used for the exact evaluation of the hydraulic gradient through relation (01).

NUMERICAL EXAMPLE 1

Let us consider a PVC pipe with the following characteristics: $\varepsilon = 0.0000015$ m, D = 0.30 m, C =145, T =20 °C ($\nu = 0.0000010023$ m^2/s for water). This pipe will carry the following flows: $Q_1 = 0.05$ m^3/s, $Q_2 = 0.1$ m^3/s, $Q_3 = 0.15$ m^3/s, Q4 = 0.20 m^3/s, /Q_5= 0.25 m^3/s , $Q_6 = 0.30$ m^3/s, $Q_7 = 0.35$ m^3/s and Q_8=0.40 m^3/s.

The objective is to determine the relative error committed in the hydraulic gradient computation when one considers the Hazen-Williams and Achour-Bedjaoui equations, i.e. equation (01) and equation (02). The relative error can be expressed as $(J_{HW} - J_{AB})/ J_{AB}$ and varies with the Reynolds number Re. J_{HW} is computed using equation (01) for C_{HW} =145; in equation (2), $\overline{R}$ will be calculated according to equation (03) in which $R=4Q/(\pi D)$. This is done for all discharges.

As for J_{AB}, it is calculated according to equation (02). The Colebrook-White relation gave the friction factor f for the known values of ε/D and R.

We recall that the Darcy relationship is given by:

$$J = \frac{fV^2}{2gD} \qquad (07)$$

This equation, which has excellent dimensional consistency, is considered to be the “correct” expression of the hydraulic parameter to be determined (Heurich et al., 2005) [8].

Where:

J: Hydraulic gradient or slope energy;

V: The average flow velocity (m/s);

D: Diameter of the pipe (m);

g: Acceleration due to gravity (m/s^2);

f: Friction Coefficient (dimensionless) is given by the Colebrook-White relation equation (08).

$$f = \left[-2\log\left(\frac{\varepsilon}{3.7D} + \frac{2.51}{R\sqrt{f}}\right)\right]^{-2} \qquad (08)$$

Knowing that ε represents the absolute roughness of the pipe's inner wall (m), and Re represents the Reynolds number that defines the flow regime.

The result derived from these calculation steps is shown in Table 3 and Figure 1.

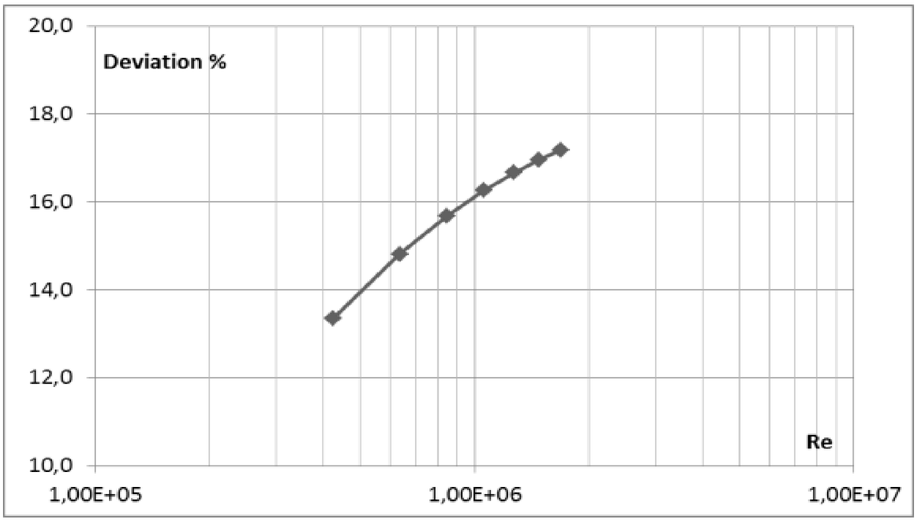

Figure 1. Relative Errors between J_{HW}, J_{AB} and J_{DW}

Figure 1 clearly shows a significant error on the energy slope J, varying between 13.3% and 17.2%, when using the Hazen-Williams relationship instead of the Darcy-Weisbach equation or Achour-Bedjaoui which is considered as a rational reference equation (Table 4).

In order that the Hazen-Williams equation gives almost the same value for the hydraulic slope as Achour-Bedjaoui and Darcy-Weisbach equations, the following C_{HW} values must be adopted for each considered Reynolds number.

These values : (C1=155.2 , C2= 156.3 , C3 = 156.9 , C4= 157.4 , C5= 157.6 , C6 =157.9 and C8 =158) were calculated according to equation (5), (See Table 5.).

The relative deviation between the above C values and C_{HW} =145 then varies between 6.6% and 8.2%.

Thus, applying the Hazen-Williams equation will result in a relative error of 0.1% on calculating the hydraulic gradient for the new corrected C_{HW} values using equation (6).

2.2 GRAPHICALLY

This part of the present work aims to present another method for evaluating the Hazen-Williams coefficient, which will be evaluated according to the relative roughness /D and the Reynolds number Re.

For this purpose, a transformation of the Moody diagram has been made according to the following steps:

1- Evaluation of the friction coefficient f for each value of the Reynolds number R and each value of the relative roughness /D.

2- Determining the relationship between the two coefficients of friction f and Hazen-Williams C_{HW}, respectively.

Starting from the Darcy relation given by equation (06) and equalizing relations (01) and (06) with each other, it follows that:

$$\frac{16fQ^2}{2g\pi^2D^5} = \frac{10.674\,Q^{1.852}}{C_{HW}{}^{1.852}D^{4.871}} \qquad (09)$$

Or else:

$$J = \frac{8fQ^2}{\pi^2gD^5} = 0.0826\frac{fQ^2}{D^5} = \frac{10.675}{C_{HW}^{1.852}D^{4.87}}Q^{1.852} \qquad (10)$$

After arrangement and simplification, equation (10) becomes:

$$f = \frac{10.675}{0.0826}\frac{D^5}{D^{4.87}}\frac{Q^{1.852}}{Q^2}\frac{1}{C_{HW}^{1.852}} \qquad (11)$$

Thus:

$$f = 129.24\,D^{0.13}Q^{-0.148}\frac{1}{C_{HW}^{1.852}} \qquad (12)$$

The Reynolds number is written as:

$$R = \frac{4Q}{\pi D\vartheta} \qquad (13)$$

From Eq.13, the flow rate is given by:

$$Q = \frac{1}{4}\pi D\vartheta R \qquad (14)$$

For: ν=0.00000114 m/s^2 at 15 °C ordinary water temperature, and replacing (14) in (12), it comes that :

$$f = 129.24\,D^{0.13}\left(\frac{1}{4}\pi D\vartheta R\right)^{-0.148}\frac{1}{C_{HW}^{1.852}} \qquad (15)$$

After rearrangement, equation (15) can be written as:

$$f = 1015\,D^{0.13}D^{-0.148}R^{-0.148}\frac{1}{C_{HW}^{1.852}} \qquad (16)$$

Therefore:

$$f = 1015\,D^{-0,018}R^{-0.148}\frac{1}{C_{HW}^{1.852}} \qquad (17)$$

In relation (17), the value of $D^{-0.018} \cong 1$ whatever D is.

Hence, the relation (17) becomes:

$$f = 1015\,R^{-0.148}\frac{1}{C_{HW}^{1.852}} \qquad (18)$$

The expression of Williams-Hazen coefficient can be deduced from equation (18).

$$C_{HW} = \left(1015 \frac{1}{Re^{0.148}} \frac{1}{f}\right)^{1/1.852} \quad (19)$$

From the Moody diagram, for each couple (Re, ε/D), the values of the friction coefficient f are read, whose values will be used in equation (19) to calculate the Hazen-Williams coefficient.

The values in Table 03 are used to draw the graph in Figure 1, which will be used for a pre-calculation of the Hazen-Williams coefficient as a function of Reynolds number (R) for any value of the relative roughness (ε/D).

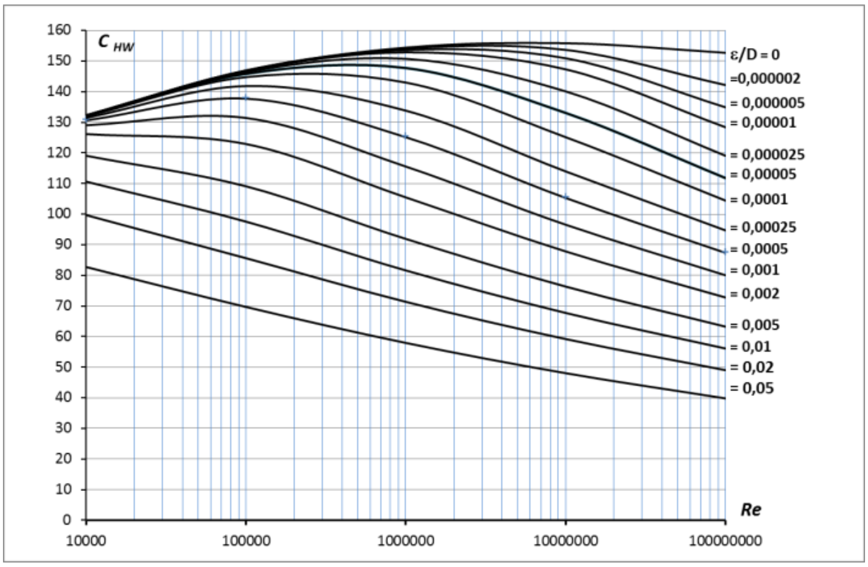

Figure 1. Diagram giving C_{HW} (Established by the authors according to the equation (19)).

NUMERICAL EXAMPLE 2

1-Calculate the Hazen-Williams coefficient for the following data: D=1.0 m, Q= 0.5 m^3/s, ν = 10^{-6} $m.s^{-2}$ and ε= 0.025 mm.

2-Calculate the hydraulic gradient J:

a) According to the Darcy relation.

b) According to the Hazen-Williams relation.

SOLUTION

1- Evaluation of the Hazen-Williams coefficient C_{HW}.

The Reynolds number is: R= 4Q/π/D/ν = 6.37×10^5

The relative roughness is: ε/D = 0.000025

Referring to the graph in Figure 1, the Hazen-Williams coefficient is:

C_{HW}= f (R, ε/D) = f (6.37x10^5, 0.000025) = 150.5

Analytically and according to relation (19), we obtain the following:

$$C_{HW} = \left(1015\ \frac{1}{R^{0.148}}\frac{1}{f}\right)^{1/1.852} = 150.5$$

According to Colebrook-white the coefficient of friction is: f = 0.0130166

Hence the hydraulic slope is:

According to Darcy: $J = \frac{8fQ^2}{\pi^2 g D^5} = 0.000269 = 0.00027$

According to Hazen-Williams, for C_{HW}=150.5

$$J = \frac{10.675}{C_{HW}^{1.852} D^{4,87}} Q^{1.852} = 0.00027$$

Using graph 01, and after direct determination of the Hazen-Williams coefficient, we find almost the same result of the hydraulic gradient without using the tables to select C_{HW} coefficient.

Therefore, the graphical method is a fast and explicit method that does not require an iterative evaluation of the friction coefficient when determining the hydraulic gradient if we want to use Darcy's relation, which usualy uses the Colebrook-White relation.

The above result can be verified by using equation (06), and we obtain the same data: D=1.0 m, Q= 0.5 m^3/s, ν = 10^{-6} m.s^{-2} and ε = 0.025 mm.

$$C_{WH} = 29.16\, Q^{-0.08}\, D^{0.07} \left[-\log\left(\frac{\varepsilon/D}{3.7} + \frac{10.04}{\bar{R}}\right)\right]^{1.08} = 152$$

This value (C_{HW} =152) differs very little from the one obtained graphically (C_{HW} =150.5) with a difference of 0.99=1 %.

3. CONCLUSION

Two methods have been proposed for the evaluation of the Hazen-Williams coefficient for a reasonable calculation of the hydraulic gradient, which are:

Equation (06) to calculate this coefficient directly. This relationship depends on the parameters of the flow (geometrical diameter of the pipe D(m), the flow rate Q(m ^{3}/s), the roughness ε(m) of the pipe and the kinematic viscosity ν (m^2.s^{-1}).

The proposed graphical method (Figure 1) will quickly evaluate the Hazen-Williams coefficient as a function of the Reynolds number Re and the relative roughness ε/D. This graph is obtained after a transformation of the Moody diagram, where the Hazen-Williams coefficient values are read directly on the ordinates axis.

The proposed relation (06) presents the best solution for the choice of the value of the Hazen-Williams coefficient without taking into account the values proposed by some authors and considered as being constant for the same pipe material and without taking into account the flow rate or the diameter.

The two proposed approaches show that the value of the Williams-Hazen coefficient is not constant but varies with flow rate, pipe diameter, absolute roughness and Reynolds number for the same pipe.

We conclude that the Hazen-Williams coefficient is not constant for the same pipe material and varies with flow rate, relative roughness and pipe diameter.

Relationship (01) can be used for $2300 \leq R \leq 10^8$ and for $0 \leq \varepsilon/d \leq 0.5$, covering the entire range of commercial pipes.

The values of C_{HW} range from 49 to 160, but this is only obtained if the Hazen-Williams coefficient is calculated according to the proposed relationship (06).

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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NOMENCLATURE

C_{HW}	Coefficient of Hazen-Williams.
D, m	Pipe diameter
g, m/s^2	Acceleration of gravity
f	Friction coefficient.
J	Hydraulic gradient.
Ks, $m^{1/3}/s$	Manning-Strickler coefficient
L, m	Length of the pipe
Q	Flow rate (m^3/s).
R	Reynolds number.
$\overline{R}$	Reynolds number of the reference pipe.
ε	Absolute roughness (m)
ε /D	Relative roughness.
ν	Kinematic viscosity m^2/s

Table 3. Values used to evaluate the CHW coefficient by using (19).

ε/D	R	f	C_{HW} (19)	ε/D	R	f	C_{HW} (19)
0	10^4	0.0309	135.9	0.000002	10^4	0.0309	135.9
	10^5	0.0180	151.0		10^5	0.0180	150.9
	10^6	0.0117	158.6		10^6	0.0117	158.3
	10^7	0.0081	160.1		10^7	0.0083	157.9
	10^8	0.0059	156.9		10^8	0.0068	146.1

0.000005	10^4	0.0309	135.9	0.00001	10^4	0.0309	135.9
	10^5	0.0181	150.9		10^5	0.0181	150.7
	10^6	0.0118	157.8		10^6	0.0119	157.0
	10^7	0.0086	155.0		10^7	0.0090	151.3
	10^8	0.0075	138.6		10^8	0.0082	131.9
0.000025	10^4	0.0310	135.8	0.00005	10^4	0.0310	135.7
	10^5	0.0182	150.4		10^5	0.0183	149.8
	10^6	0.0122	154.9		10^6	0.0127	151.8
	10^7	0.0099	143,9		10^7	0,0109	136,7
	10^8	0,0094	122,3		10^8	0,0106	114,8
0,0001	10^4	0,0311	135,6	0.00025	10^4	0,0313	135,0
	10^5	0,0185	148,7		10^5	0,0193	145,7
	10^6	0,0134	146,9		10^6	0,0152	137,5
	10^7	0,0122	128,6		10^7	0,0145	117,1
	10^8	0,0120	107,3		10^8	0,0144	97,3
0.0005	10^4	0,0317	134,2	0.001	10^4	0,0324	132,6
	10^5	0,0203	141,5		10^5	0,0222	135,0
	10^6	0,0172	128,5		10^6	0.0199	118.7
	10^7	0.0168	108.2		10^7	0.0197	99.2
	10^8	0.0167	89.7		10^8	0.0196	82.2
0.002	10^4	0.0338	129.6	0.005	10^4	0.0376	122.3
	10^5	0.0251	126.3		10^5	0.0313	112.1
	10^6	0.0236	108.4		10^6	0.0305	94.4
	10^7	0.0234	90.2		10^7	0.0304	78.4
	10^8	0.0234	74.8		10^8	0.0304	65.0
0.01	10^4	0.0431	113.6	0.02	10^4	0.0522	102.4
	10^5	0.0385	100.2		10^5	0.0490	88.0
	10^6	0.0380	83.8		10^6	0.0487	73.3
	10^7	0.0379	69,6		10^7	0,0486	60,8
	10^8	0,0379	57,7		10^8	0,0486	50,4
0.05	10^4	0,0738	83,6				
	10^5	0,0718	71,6				
	10^6	0,0716	59,5				
	10^7	0,0716	49,4				
	10^8	0,0716	40,9				

Table 4. The relative error between J_{HW}, J_{AB} and J_{DW} for C_{HW}= 145.

DN (m)	Q (m³/s)	C_{HW}	R x 10^5	$\overline{R}$ x 10^5	f	J_{HW}	J_{AB}	J_{DW}	Error %	
				(03)	(08)	(01)	(02)	(07)	(J_{HW}-J_{AB}) /J_{AB}	(J_{DW}-J_{AB}) /J_{AB}
0.3	0.1	145	4.24	1.96	0.0136	0.0052	0.0046	0.0046	13.3	0.0
0.3	0.15	145	6.35	2.84	0.0126	0.0111	0.0097	0.0097	14.8	0.0
0.3	0.2	145	8.47	3.69	0.0120	0.0189	0.0164	0.0164	15.7	0.0
0.3	0.25	145	10.6	4.53	0.0116	0.0286	0.0246	0.0246	16.3	0.0
0.3	0.3	145	12.7	5.36	0.0112	0.0401	0.0344	0.0344	16.7	0.0
0.3	0.35	145	14.8	6.18	0.0109	0.0534	0.0457	0.0457	17.0	0.0
0.3	0.4	145	16.9	6.98	0.0107	0.0684	0.0584	0.0584	17.2	0.0

Table 5. The relative error between J_{HW}. J_{AB} and J_{DW} for values of C_{HW} calculated with (06).

DN (m)	Q (m³/s)	R x 10^5	$\overline{R}$ x 10^5	C_{HW}	J_{HW}	J_{AB}	Error %	
			(03)	(6)	(01)	(02)	(J_{HW}-J_{AB}) /J_{AB}	(J_{HW}-J_{DW}) /J_{DW}
0.300	0.1	4.24	1.96	155.2	0.0046	0.0046	0.1	0.1
0.300	0.2	6.35	2.84	156.3	0.0097	0.0097	0.1	0.1
0.300	0.25	8.47	3.69	156.9	0.0164	0.0164	0.1	0.1
0.300	0.3	10.6	4.53	157.4	0.0246	0.0246	0.1	0.1
0.300	0.35	12.7	5.36	157.6	0.0344	0.0344	0.1	0.1
0.300	0.4	14.8	6.18	157.9	0.0456	0.0457	0.1	0.1
0.300	0.45	16.9	6.98	158.0	0.0583	0.0584	0.1	0.1