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IRRIGATION CANAL WATER LOSSES

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Quantifying irrigation water losses in paddy fields is required for good water management. Losses in conveyance canals consist of evaporation and infiltration. A semi-empirical formula for canal infiltration was developed by Moritz and a semi-graphical equation was developed by Bouwer. An analytical method formula was recently developed by Sunjoto and was tested against field data of water losses in the canal of the Sukawati Irrigation Area in Comal, Central Java, Indonesia. Analysis of the results was conducted using a least squares and linear regression methods. The results of the comparison show that the Sunjoto formula has the best fit to field data, followed by the Bouwer and Moritz formulas. Based on the tested Sunjoto formula, this paper proposes formulas for water losses of canals with one side and both sides lined.

INTRODUCTION

The design of an irrigation project requires data on water losses in canals to determine area sizes for paddy fields. Water losses in the canal consist of evaporation on the surface of the canal to the atmosphere and infiltration in the wetted perimeter of the canal, which will become groundwater. The value of evaporation can be found by using standard methods, but this water loss is not the focus of this paper.

Direct measurement of infiltration can only be carried out when the water in the canal goes to irrigate the paddy field, and this data is needed in the design stage or before constructing the canal. For this reason, Moritz (1913) developed a semi-empirical formula of infiltration computation and later Bouwer (1965) proposed a semi-graphical formula. These methods have been widely used.

The aim of this paper is to propose a similar formula to both formulas above, which is developed analytically based on the principle of Forchheimer (1930) to calculate the coefficient of permeability of soil and Sunjoto's (2002) formula which calculates the dimension of a recharge well.

METHODOLOGY

The study carried out direct measurements in irrigation canals of Sukawati, Tegal, Central Java, Indonesia as project cooperation among the Department of Civil Engineering Gadjah Mada University and Sub-Project of Pemali-Comal, Tegal, Department of Public Works the Government of Indonesia. The research project was conducted in 1980 when the author was one of the team members, which handled a plan of study to measure, calculate and analyze the field data. Measurement of water losses on site can be carried out by two methods:

Infiltration method

By this method, the canal has a certain length, usually between two gates that have to be closed simultaneously meaning there is no water inflow no outflow from this section of the canal. Decreasing of the elevation of water surface in the canal is recorded in a certain period, and by those data, the volume of water losses can be calculated. In this test the water losses consist of infiltration and evaporation. Due to the fact that the tests that were carried out in a certain period, the evaporation must be taken into consideration and it can be found by direct measurement or by calculation method. Finally the amount of infiltration is the difference of total water losses and the value of water evaporated.

Inflow-outflow method

The second method is the direct measurement of discharge at the same time of two cross sections in a certain length of the canal. From the difference of upstream and downstream cross section discharge, the water losses in a certain length of the canal can be found. The evaporation is neglected, due to the fact that these measurements are carried out simultaneously.

The measurement on site consists of measurement of inflow and outflow discharge in the upstream and downstream ends from one section of the canal. Water losses can be calculated from the difference of the two discharges. In this research, measurement was applied to 17 sections of the canal, but this research is only using 8 due to complexity of the data. Chosen sections were PA-BCm_1, BCm_2-BCm_3, BPt_1-BPt_2, BPt_4-BPt_5, BPt_5-BPt_6, BPt_7-BPt_8, BPt_9-BRd_1, and BRd_1-BRd.

Besides applying discharge measurements, this study is also using the infiltration rate of the soil around the canal with the assumption that soil is homogenous and isotropic and these data can be used to calculate the soil permeability coefficient.

Discharge measurement

There are many ways to measure discharge flow of a canal, but due to the fact that the flow of the canal cannot be closed and according to equipment adequateness, *the area velocity* method with *mid section procedure* were chosen. The location has to be on a straight canal, have a constant water surface and be free of hydraulic disturbances like turbulence or water jumps. The technique of measurement is follows:

1) The canal surface is divided into several sections. A canal with more than 2 m width is divided into 1 m each and for a canal with less than 2 m width is divided into 0.50 m each.

2) Velocity of flow is measured by using a current meter in the middle of section. The depth of water which is less than 1 m, velocity is measured at one point at 0.6 H_w and for the depth which has more than 1 m, it is measured on 0.20 H_w and 0.80 H_w where H_w is the depth of the water in the canal.

3) The discharge is the average velocity multiplied by average surface area.

4) Water losses are calculated from the difference between upstream and downstream discharge of each of canal. The results of conducting out four measurements with different periods, different seasons, and different discharges is presented in Table 1. Geometric data are also collected consisting of base width of canal (W_b), width of water surface (W_s) and depth of water (H_w).

Coefficient of permeability

A double ring infiltration meter is used for infiltration measurement which is an open a cylinder at the top and bottom. This cylinder is placed on the soil surface and filled by water and the decrease of water level as a function of time is measured. The result is usually a curve in exponential form. These data provide the measured permeability coefficient by the field test method. From the various field tests, the average permeability coefficient is 8.33×10^{-6} m/s. This value becomes the calculation basis for the Moritz (1913), Bouwer (1965) and Sunjoto (2008b) formulas.

Beside the measurement method there are other computational methods. The existing equations to calculate water losses in the conveyance canal are:

Table 1. Step of field measurements.

No	Step	Period	Season	Discharge of canal
1	I.	26 - 30 September 1980	Dry	50 %
2	II.	16 - 27 October 1980	-	50 %
3	III.	07 - 13 November 1980	-	100 %
4	IV.	16 - 22 December 1980	Rainy	100 %

Moritz (1913)

The Moritz (1913) formula is a semi-empirical method, where water losses depend on a layer of the canal, discharge, velocity of flow, depth of the canal, base width and slope of the canal. All data can be measured in the field directly except the daily water losses through layer of the canal, and the equation as follows:

$$S = 0.0116 \times C\left[\frac{Q}{V}\left\{(N+Z)^{0.5} + \frac{2\left(Z^2+1\right)^{0.5} - Z}{(N+Z)^{0.5}}\right\}\right]^{0.5} \qquad (1)$$

where,

S : water losses in the canal ($m^3/s/km$)

C : daily water losses (m/day)

Q : discharge of canal (m^3/s)

V : flow velocity (m/s)

N : ratio between base to depth of canal

Z : slope of bank (Z = *horizontal* when *vertical* = 1)

Based on the field measurement data tabulated on Table 2 with parameters of width of the canal base, width of water surface, depth of water, and coefficient of permeability of soil layer of C = 8.3×10^{-6} m/s or 0.72 m/day, water losses can be calculated by Equation (1) with the assumption that the daily water losses are equal to the permeability of soil layer. The result of water loss calculations along the section of the canal at each measurement step are shown in Table 3, Column 6.

Bouwer (1965)

The formula of Bouwer (1965) is a semi-graphical method, which depends on a coefficient of permeability of soil, position of canal and ratio of water surface elevation to the groundwater table. This formula, which is supported by curves found by electric analog test in three conditions (Figure 1), gives a value of I_s/K from Figure 2. Finally, water losses can be computed by the equation as follows:

$$q = \left(I_s / K\right).k.W_s \qquad (2)$$

where,

q : water losses ($m^3/s/m$)

I_s/K : value from the graph (Fig. 2.)

k : coefficient of permeability of soil (m/s)

W_s : width of water surface (m)

Besides using Equation (2), a diagram must be initially used knowing the water elevation surface of the canal towards the groundwater table, and also layering on permeable and impermeable layers on that canal location which is combined by canal dimensions. From field data of water surface of

Table 2. Water losses and geometric data of each section for 4 steps measurement.

No	Section of canal	Length of section L_c (m)	Water losses Q_c (m^3/s)	Area of cross section A (m^2)	Width of water surface W_s (m)	Wet perimeter of canal P (m)	Width of canal base W_b (m)	Depth of canal H_w (m)
Measurement I								
1	PA - BCm$_1$	1000	0.0587	13.6513	19.625	22.850	18.179	0.723
2	BCm$_2$ -Bcm$_3$	900	0.1639	11.3746	9.625	11.135	6.861	1.382
3	BPt$_1$ - BPt$_2$	650	0.0246	6.0350	8.825	9.335	7.331	0.747
4	BPt$_4$ - BPt$_5$	475	0.0376	5.4206	9.750	10.390	8.565	0.953
5	BPt$_5$ - BPt$_6$	450	0.0977	3.4340	8.650	9.300	7.815	0.418
6	BPt$_7$ - BPt$_8$	500	0.0143	2.8432	7.200	7.840	6.362	0.419
7	BPt$_9$ - BRd$_1$	550	0.0156	1.2195	2.788	3.580	1.706	0.419
8	BRd$_1$ - BRd$_2$	760	0.0628	1.2761	2.975	3.975	1.934	0.520
Measurement II								
1	PA - BCm$_1$	1000	0.0698	11.1544	19.250	20.260	18.053	0.599
2	BCm$_2$ -Bcm$_3$	900	0.0744	9.2663	10.475	10.955	8.519	0.978
3	BPt$_1$ - BPt$_2$	650	0.0437	3.9026	7.125	10.955	5.928	0.599
4	BPt$_4$ - BPt$_5$	475	0.0988	4.1164	11.125	11.625	10.360	0.383
5	BPt$_5$ - BPt$_6$	450	0.0808	2.4264	8.530	9.175	7.941	0.295
6	BPt$_7$ - BPt$_8$	500	0.0441	2.2388	7.010	7.188	6.341	0.334
7	BPt$_9$ - BRd$_1$	550	0.0090	0.9887	2.775	3.090	1.935	0.420
8.	BRd$_1$ - BRd$_2$	760	0.0365	1.1938	2.700	3.160	1.587	0.556
Measurement III								
1	PA - BCm$_1$	1000	0.4200	19.6780	20.375	21.255	18.347	1.014
2	BCm$_2$ -Bcm$_3$	900	0.1880	12.1850	10.500	11.564	7.840	1.330
3	BPt$_1$ - BPt$_2$	650	0.0985	7.7430	9.300	9.871	7.451	0.925
4	BPt$_4$ - BPt$_5$	475	0.0906	6.7133	11.850	12.149	10.344	0.596
5	BPt$_5$ - BPt$_6$	450	0.0334	3.4815	9.250	9.374	6.819	0.478
6	BPt$_7$ - BPt$_8$	500	0.0383	3.4621	7.775	8.024	6.826	0.474
7	BPt$_9$ - BRd$_1$	550	0.0219	0.6992	2.550	2.765	1.925	0.313
8.	BRd$_1$ - BRd$_2$	760	0.0144	1.5869	3.500	2.765	2.428	0.536
Measurement IV								
1	PA - BCm$_1$	1000	0.2741	22.3621	20.750	21.630	18.481	1.135
2	BCm$_2$ -Bcm$_3$	900	-	-	-	-	-	-
3	BPt$_1$ - BPt$_2$	650	0.1995	6.4332	8.310	7.050	6.581	0.864
4	BPt$_4$ - BPt$_5$	475	0.0334	5.8559	11.725	10.525	10.680	0.523
5	BPt$_5$ - BPt$_6$	450	0.0428	4.3804	9.200	9.350	8.191	0.505
6	BPt$_7$ - BPt$_8$	500	0.0746	3.7288	7.750	8.275	6.719	0.515
7	BPt$_9$ - BRd$_1$	550	0.0620	0.8749	2.675	2.585	1.912	0.381
8.	BRd$_1$ - BRd$_2$	760	0.0090	1.4489	3.560	3.697	2.616	0.472

the canal, surface of groundwater and position of soil layer, it can be concluded that this area of study is in accordance with 'A condition' as is being described on Figure 1, then by substituting related geometric data to Figure 2, the value of $I_S/K = 1.90$ is valid for all of the length of the canal tested. Using the real soil permeability's coefficient $k = 8.3\text{x}10^{-6}$ m/s and data from Table 2 then implementing Equation (2) to calculate the loss of water for along each section of the canal gives the result shown in Table 3, Column 8.

Table 3. Discharge of water losses by measurement and result of computation.

No	Section of Canal	Length of Canal (m)	Water Losses (m^3/s) X	X^2	Moritz (1913) (m^3/s) U	X.U	Bouwer (1965) (m^3/s) V	X.V	Sunjoto (2008b) (m^3/s) W	X.W
1	2	3	4	5	6	7	8	9	10	11
Measurement I										
1	PA - BCm$_1$	1000	0.0587	0.003446	0.07221	0.004239	0.31072	0.018239	0.20496	0.012031
2	BCm$_2$ - BCm$_3$	900	0.1639	0.026863	0.04532	0.007428	0.13715	0.022479	0.21542	0.035307
3	BPt$_1$ - BPt$_2$	650	0.0246	0.000605	0.02615	0.000643	0.09082	0.002234	0.08784	0.002161
4	BPt$_4$ - BPt$_5$	475	0.0376	0.001414	0.0231	0.000869	0.07875	0.002961	0.08788	0.003304
5	BPt$_5$ - BPt$_6$	450	0.0977	0.009545	0.01535	0.001500	0.06163	0.006021	0.03578	0.003496
6	BPt$_7$ - BPt$_8$	500	0.0143	0.000204	0.01489	0.000213	0.057	0.000815	0.03562	0.000509
7	BPt$_9$ - BRd$_1$	550	0.0156	0.000243	0.00759	0.000118	0.02215	0.000346	0.02126	0.000332
8	BRd$_1$ - BRd$_2$	760	0.0628	0.003944	0.01245	0.000782	0.0358	0.002248	0.03874	0.002433
Measurement II										
1	PA - BCm$_1$	1000	0.0698	0.004872	0.06785	0.004736	0.30478	0.021274	0.16986	0.011856
2	BCm$_2$ - BCm$_3$	900	0.0743	0.005520	0.04408	0.003275	0.14926	0.011090	0.17032	0.012655
3	BPt$_1$ - BPt$_2$	650	0.0437	0.001910	0.02107	0.000921	0.07334	0.003205	0.06376	0.002786
4	BPt$_4$ - BPt$_5$	475	0.0988	0.009761	0.01911	0.001888	0.08367	0.008267	0.03936	0.003889
5	BPt$_5$ - BPt$_6$	450	0.0808	0.006529	0.0139	0.001123	0.06077	0.004910	0.02524	0.002039
6	BPt$_7$ - BPt$_8$	500	0.0441	0.001945	0.01377	0.000607	0.05549	0.002447	0.0284	0.001252
7	BPt$_9$ - BRd$_1$	550	0.0090	0.000081	0.0081	0.000073	0.02416	0.000217	0.0225	0.000203
8	BRd$_1$ - BRd$_2$	760	0.0365	0.001332	0.01179	0.000430	0.03249	0.001186	0.03826	0.001396
Measurement III										
1	PA - BCm$_1$	1000	0.1290	0.016641	0.08097	0.010445	0.32259	0.041614	0.28628	0.036930
2	BCm$_2$ - BCm$_3$	900	0.1880	0.035344	0.04784	0.008994	0.14962	0.028129	0.2209	0.041529
3	BPt$_1$ - BPt$_2$	650	0.0985	0.009702	0.02874	0.002831	0.09571	0.009427	0.1092	0.010756
4	BPt$_4$ - BPt$_5$	475	0.0906	0.008208	0.02199	0.001992	0.08676	0.007860	0.06084	0.005512
5	BPt$_5$ - BPt$_6$	450	0.0334	0.001116	0.01468	0.000490	0.05539	0.001850	0.03778	0.001262
6	BPt$_7$ - BPt$_8$	500	0.0383	0.001467	0.01628	0.000624	0.06155	0.002357	0.04166	0.001596
7	BPt$_9$ - BRd$_1$	550	0.0219	0.000480	0.00704	0.000154	0.02221	0.000486	0.01662	0.000364
8	BRd$_1$ - BRd$_2$	760	0.0144	0.000207	0.01415	0.000204	0.04211	0.000606	0.0441	0.000635
Measurement IV										
1	PA - BCm$_1$	1000	0.2471	0.061058	0.08449	0.020877	0.32853	0.08117976	0.32048	0.079191
2	BCm$_2$ - BCm$_3$	900	0	0	0	0	0	0	0	0
3	BPt$_1$ - BPt$_2$	650	0.1995	0.039800	0.02597	0.005181	0.08552	0.017061	0.09624	0.019200
4	BPt$_4$ - BPt$_5$	475	0.1334	0.017796	0.02152	0.002871	0.08818	0.011763	0.05436	0.007252
5	BPt$_5$ - BPt$_6$	450	0.0428	0.001832	0.01687	0.000722	0.06555	0.002806	0.04364	0.001868
6	BPt$_7$ - BPt$_8$	500	0.0746	0.005565	0.01659	0.001238	0.06135	0.004577	0.04488	0.003348
7	BPt$_9$ - BRd$_1$	550	0.0620	0.003844	0.00768	0.000476	0.02329	0.001444	0.02026	0.001256
8	BRd$_1$ - BRd$_2$	760	0.0090	0.000081	0.01386	0.000125	0.04284	0.000386	0.04006	0.000361
S			**2.3147**	**0.281356**	**0.8354**	**0.086069**	**3.10918**	**0.319486**	**2.7225**	**0.306709**

Sunjoto (2008b)

Forchheimer (1930) has developed an equation to calculate the permeability coefficient of soil from the field test with the formula as follows:

$$Q = F.K.H \tag{3}$$

where,

Q : discharge of infiltration

K : coefficient of permeability of soil

H : hydraulic head

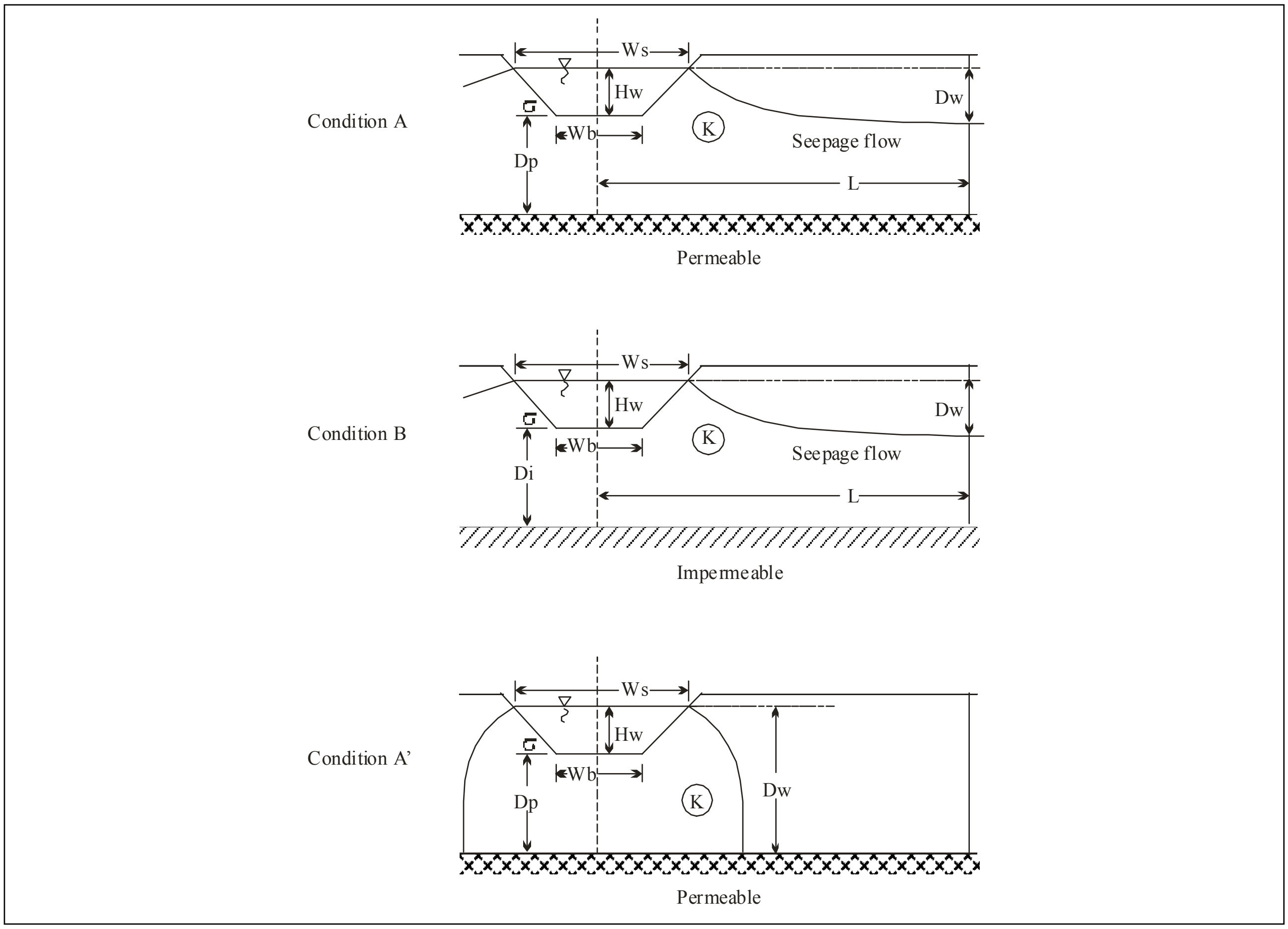

Figure 1. Three conditions of flow by Bouwer, 1965 (*with permission from* ASCE).

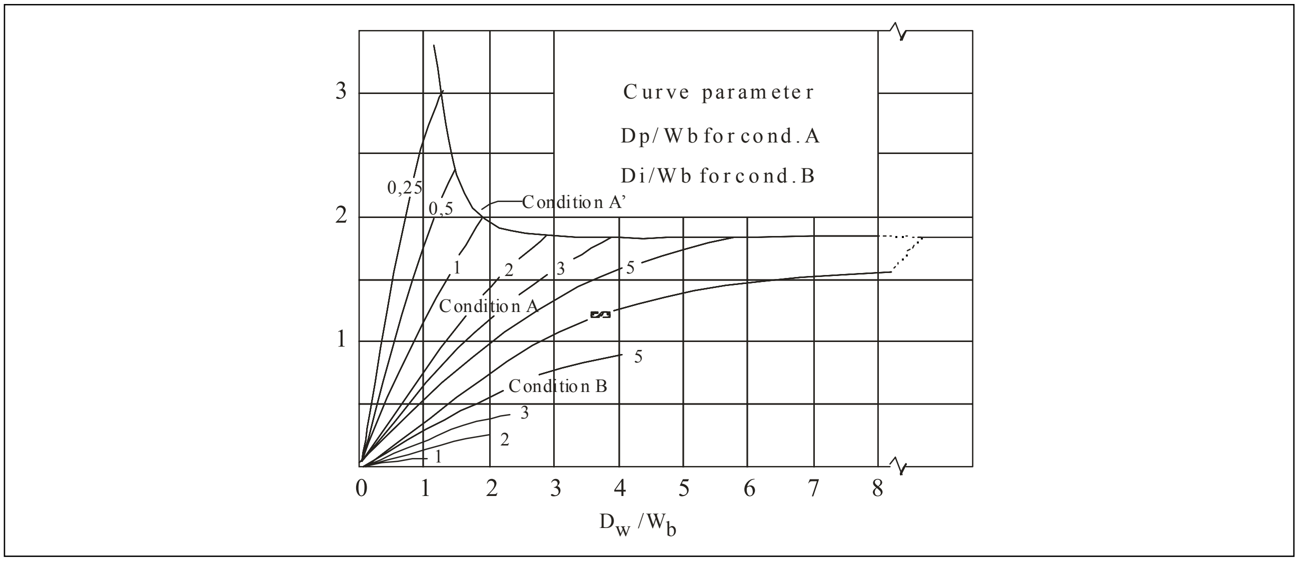

Figure 2. Value of I_s/K by Bouwer, 1965 (with permission from ASCE).

F : shape factor of well

Forchheimer's formula with Equation (3) is designed to calculate the coefficient of permeability of soil from his field test by auger hole methods. For the auger hole with a casing he defined shape factor of well as $F = 4R$ which is developed mathematically where R is radius of casing. For the equal condition with permeable lower casing as long as L, Dahcler (1936) has developed a formula of shape factor as follows:

$$F = \frac{2\pi L}{\ln\left\{\frac{L}{2R} + \sqrt{\left(\frac{L}{2R}\right)^2 + 1}\right\}} \tag{4}$$

where,

L : length of permeable lower casing

R : radius of casing (well)

From this Equation when *L = 0*, Dachler's formula (1936) gives a value of *F = 0/0* or indefinite value but Sunjoto (2002) developed a similar formula to calculate the depth of recharge well and when *L = 0*, the value of $F \neq 0$ is definite value and it means that this formula is in accordance with the physical condition and the formula as follows:

$$F = \frac{2\pi L + 2\pi R \ln 2}{\ln\left\{\frac{L + 2R}{2R} + \sqrt{\left(\frac{L}{2R}\right)^2 + 1}\right\}} \tag{5}$$

For the well with a rectangular cross section and the same condition Sunjoto (2008a) developed a formula:

$$f = \frac{4L + 4\sqrt{bB}\ln 2}{\ln\left(\left(L + 4\sqrt{bB}\right)/4\sqrt{bB} + \sqrt{\left(L/4\sqrt{bB}\right)^2 + 1}\right)} \tag{6}$$

where,

f : shape factor of rectangle

b : width of rectangle

B : length of rectangle

L : length of permeable lower casing

Based on the substitution of Equation (6) to Equation (3), the result is Equation (7) for a canal on natural soil (Figure 3) as follows:

$$q = \frac{4KH_w\sqrt{\lambda(W_b + W_s)}}{\ln\left\{\frac{H_w + 2\sqrt{\lambda(W_b + W_s)}}{2\sqrt{\lambda(W_b + W_s)}} + \sqrt{\left(\frac{H_w}{2\sqrt{\lambda(W_b + W_s)}}\right)^2 + 1}\right\}} \tag{7}$$

Using the canal cross section described in Figure 3, and the data of length of section, water losses, area of cross section, width of water surface, wet perimeter of canal, width base of canal, and depth of water from the direct field measurement tabulated on Table 2 then implementing

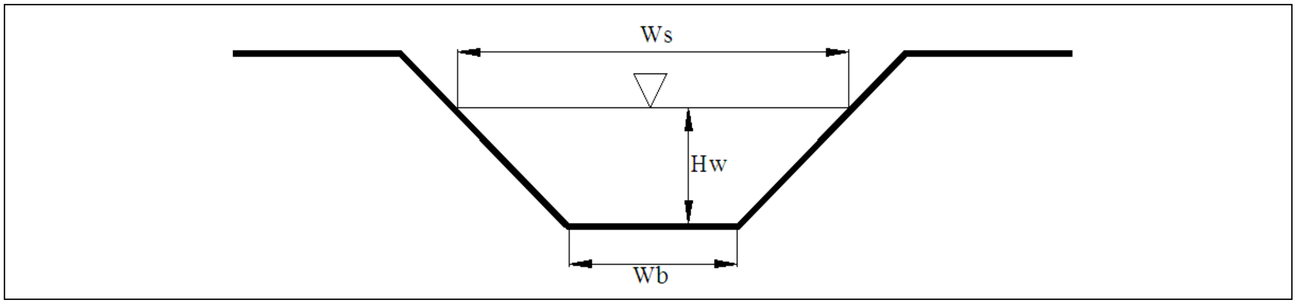

Figure 3. Cross section of canal on natural soil (without linings).

Equation (7) to calculate the loss of water for along each section of the canal gives the result shown in Table 3, Column 10 and Table 4, Columns 7 and 8.

Based on the formula of Sunjoto (2008b) another formula can be developed for water losses of canals with one side lining and a formula for water losses of a canal with two side linings as follows:

Canal with one side lining (Figure 4)

Canal with one side lining is a canal on natural soil with impermeable layer on the one side of the bank, where a part of the water can infiltrate to groundwater through the base of the canal and one side of bank and formula proposed is as follows:

$$q = \frac{4KH_w\sqrt{\lambda(W_b+W_v)}}{\ln\left\{\frac{2H_w+\sqrt{\lambda(W_b+W_v)}}{\sqrt{\lambda(W_b+W_v)}}+\sqrt{\left(\frac{2H_w}{\sqrt{\lambda(W_b+W_v)}}\right)^2+1}\right\}} \tag{8}$$

The implementation of Equation (8) to calculate the loss of water for along each section of the canal gives the result shown in Table 4, Columns 9 and 10.

Canal with two side linings (Figure 5)

A canal with two side linings is a canal on natural soil with impermeable layers on the two sides of the bank, where the water can only infiltrate to groundwater through the base of the canal and the formula proposed is as follows:

$$q = 4KH_w\sqrt{2\lambda W_b} \tag{9}$$

The canal cross section described on Figure 5 and the data of length of section, water losses, width base of canal, and depth of water from the direct field measurement and the result of calculation by Equation (9) are tabulated in Table 4, Column 11.

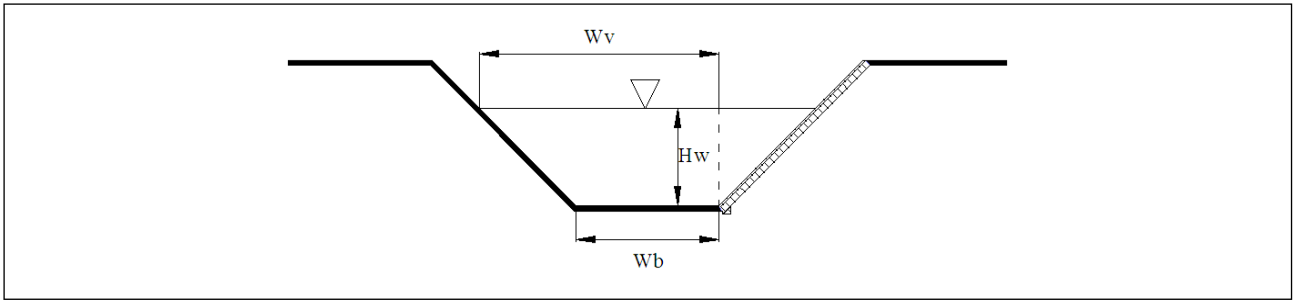

Figure 4. Cross section of canal with one side lining.

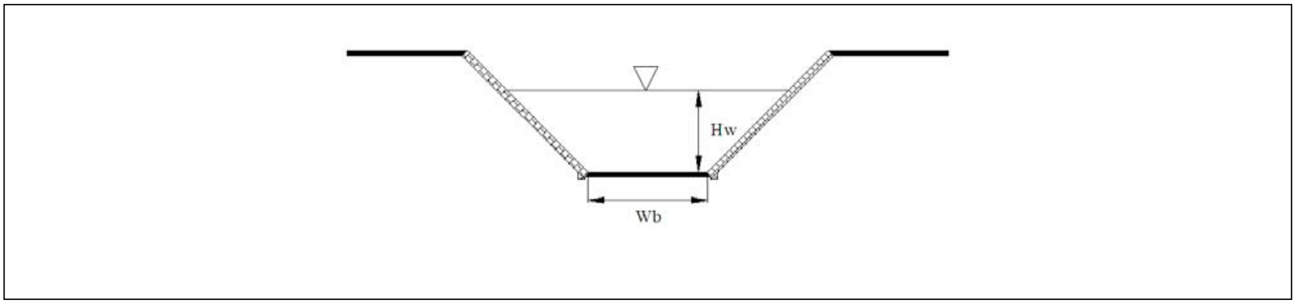

Figure 5. Cross section of canal with two side linings.

where,

q : water losses ($m^3/s/m$)

H_w : canal depth (m)

K : coefficient of permeability of soil (m/s)

W_b : width of canal base (m)

W_s : width of water surface (m)

W_v : width of water surface when the lining is vertical (m), (Figure 4) or $W_v = W_s - Z.H_w$

Z : slope of bank (Z = *horizontal* when *vertical* = 1)

λ: unit length (λ = 1 m when other dimension in *meter*)

Equations (7), (8) and (9) can be used for the elevation of highest groundwater table which is equal to the elevation of the canal base or groundwater table beneath of the bottom of the canal.

RESULTS AND DISCUSSION

Results

From field observation, the area is sandy clay soil and from the field test, the permeability of soil coefficient result is 8.3×10^{-6} m/s. This value is used for calculating the Moritz (1913), Bouwer (1965) and Sunjoto (2008b) formulas. From the measurement for each section profile data is determined for each section. They are: velocity, width of canal base, width of water surface, depth, area and wet perimeter. These data can be used to calculate discharge, based on width and slope of the canal in each section. Then from the discharge of each section water losses along the canal between two sections are determined and the results are shown in Tables 3 and 4.

Discussion

Discussion for the canal on natural soil can be carried out by using a least square method placing the result of measurement as the independent variables and the results of the three formulas as dependent variables (Table 3). The equation of linear regression for each formula of computation is determined. Statistical calculation for the formula of linear regression (Walpole, 1993) can be calculated by Equations (10), (11) and (12) as follows:

$$y = a + bx \qquad (10)$$

$$b = \frac{n\sum xy - \left(\sum x\right)\left(\sum y\right)}{n\sum x^2 - \left(\sum y\right)^2} \qquad (11)$$

Table 4. Comparison of water losses computed by Sunjoto's formula (2008b) to the water losses computed by proposed formulas.

No	Field measurement					Computation				
						Sunjoto (2008b) Eq. (7)		Proposed formulas for canal with:		
	Canal section	L_c	W_b	H_w	Water losses	Z = 1	Z = 0	one side lining Eq. (8)		two side linings Eq. (9)
								Z=1	Z=0	
		m	m	m	Q_c (m^3/s)	Q_c (m^3/s)	Q_c (m^3/s)	Q_c (m^3/s)	Q_c (m^3/s)	Q_c (m^3/s)
1	2	3	4	5	6	7	8	9	10	11
1	PA-BCm$_1$	1000	18.179	0.723	0.0587	0.20496	0.20083	0.17947	0.17743	0.14531
2	BCm$_2$-BCm$_3$	900	6.861	1.382	0.1639	0.21542	0.19436	0.14949	0.14055	0.15358
3	BPt$_1$-BPt	650	7.331	0.747	0.0246	0.08784	0.08340	0.07088	0.06873	0.06197
4	BPt$_4$-BPt$_5$	475	8.565	0.953	0.0376	0.08788	0.08302	0.06871	0.06439	0.06245
5	BPt$_5$-BPT$_6$	450	7.815	0.418	0.0977	0.03537	0.03443	0.03131	0.03085	0.02479
6	BPT$_7$-BP t$_8$	500	6.362	0.419	0.0143	0.03562	0.03446	0.02491	0.03051	0.02491
7	BPt$_9$-BRd$_1$	550	1.706	0.419	0.0156	0.02125	0.01888	0.01630	0.01515	0.01419
8	BRd$_1$-BRd$_2$	760	1.934	0.520	0.0628	0.03873	0.03403	0.02873	0.02648	0.02591
1	PA-BCm$_1$	1000	18.053	0.599	0.0698	0.16985	0.16701	0.15192	0.15051	0.11997
2	BCm$_2$-BCm$_3$	900	8.519	0.978	0.0744	0.17033	0.16062	0.13237	0.12775	0.12110
3	BPt$_1$-BPt	650	5.928	0.599	0.0437	0.06376	0.06059	0.05243	0.05088	0.04469
4	BPt$_4$-BPt$_5$	475	10.360	0.383	0.0988	0.03937	0.03864	0.03573	0.03537	0.02760
5	BPt$_5$-BPT$_6$	450	7.941	0.295	0.0808	0.02524	0.02477	0.02315	0.02291	0.01763
6	BPT$_7$-BP t$_8$	500	6.341	0.334	0.0441	0.02840	0.02765	0.02544	0.02507	0.01982
7	BPt$_9$-BRd$_1$	550	1.935	0.420	0.0090	0.02250	0.02025	0.01752	0.01643	0.01515
8	BRd$_1$-BRd$_2$	760	1.587	0.556	0.0365	0.03825	0.03243	0.02709	0.02435	0.02509
1	PA-BCm$_1$	1000	18.347	1.014	0.4200	0.28628	0.27824	0.23897	0.23506	0.20474
2	BCm$_2$-BCm$_3$	900	7.840	1.330	0.1880	0.22091	0.20249	0.15792	0.14953	0.15799
3	BPt$_1$-BPt	650	7.451	0.925	0.0985	0.10921	0.10251	0.08454	0.08136	0.07736
4	BPt$_4$-BPt$_5$	475	10.344	0.596	0.0906	0.06084	0.05908	0.05251	0.05164	0.04292
5	BPt$_5$-BPT$_6$	450	6.819	0.478	0.0334	0.03778	0.03647	0.03257	0.03193	0.02648
6	BPT$_7$-BP t$_8$	500	6.826	0.474	0.0383	0.04166	0.04022	0.03596	0.03525	0.02919
7	BPt$_9$-BRd$_1$	550	1.925	0.313	0.0219	0.01661	0.01534	0.01368	0.01306	0.01126
8	BRd$_1$-BRd$_2$	760	2.428	0.536	0.0144	0.04410	0.03960	0.03350	0.03133	0.02992
1	PA-BCm$_1$	1000	18.481	1.135	0.2741	0.32047	0.31046	0.26260	0.25776	0.23000
2	BCm$_2$-BCm$_3$	900	-	-	-	-	-	-	-	-
3	BPt$_1$-BPt	650	6.581	0.864	0.1995	0.09624	0.09003	0.07450	0.07154	0.06791
4	BPt$_4$-BPt$_5$	475	10.680	0.523	0.0334	0.05435	0.05302	0.04780	0.04715	0.03827
5	BPt$_5$-BPT$_6$	450	8.191	0.505	0.0428	0.04364	0.04230	0.03786	0.03719	0.03066
6	BPT$_7$-BP t$_8$	500	6.719	0.515	0.0746	0.04487	0.04317	0.03823	0.03739	0.03146
7	BPt$_9$-BRd$_1$	550	1.912	0.381	0.0620	0.02025	0.01838	0.01607	0.01515	0.01366
8	BRd$_1$-BRd$_2$	760	2.616	0.472	0.0090	0.04006	0.03666	0.05137	0.02992	0.02735

where: Z=1 : when slope is 45°, Z=0 : when slope is 90° (vertical), L_c : length of canal section (m), W_b : width of canal base (m), H_w : canal depth (m), Q_c: water losses along the section ($Q_c = q.L$) (m^3/s)

$$a = \bar{y} - b\bar{x} \tag{12}$$

The average value of water losses $\bar{x}$, $\bar{u}$, $\bar{v}$, $\bar{w}$, where $\bar{x}$ represents water losses by data measurement, $\bar{u}$, $\bar{v}$, and $\bar{w}$, represent Moritz's, Bouwer's and Sunjoto's formula of computation respectively and based on data from Table 3 are computed as follows:

$\bar{x} = \Sigma x : n = 2.31470 : 31 = 0.074668$

$\bar{u} = \Sigma u : n = 0.83540 : 31 = 0.026948$

$\bar{v} = \Sigma v : n = 3.10918 : 31 = 0.100296$

$\bar{w} = \Sigma w : n = 2.72250 : 31 = 0.087823$

Using Equations (10), (11) and (12) and based on data from Table 3, the linear equation of each method is presented, related to the data of measurement and the equations as follows:

1) Method of Moritz (1913):

$$b = \frac{31 \times 0.086069 - 2.31470 \times 0.83540}{31 \times 0.281356 - 2.31470^2} = 0.21831$$

a = 0.026948 – 0.074668 x 0.21831 = 0.01065

Equation of Moritz versus measurement

$$u = 0.01065 + 0.21831\ x \tag{13}$$

2) Method of Bouwer (1965):

$$b = \frac{31 \times 0.319486 - 2.31470 \times 3.10918}{31 \times 0.281356 - 2.31470^2} = 0.80472$$

a = 0.100296 – 0.074668 x 0.80472 = 0.04021

Equation of Bouwer versus measurement:

$$v = 0.04021 + 0.80472 \tag{14}$$

3) Method of Sunjoto (2008b):

$$b = \frac{31 \times 0.306709 - 2.31470 \times 2.72250}{31 \times 0.281356 - 2.31470^2} = 0.95304$$

a = 0.087822 – 0.074668 x 0.95304 = 0.01666

Equation of Sunjoto's Formula versus measurement:

$$w = 0.01666 + 0.95304\ x \tag{15}$$

Using the assumption that the field measurement result tends to be close to the real situation, therefore the result of regression equation will become y = x or a gradient line of 45^{o} or b = 1, which means that field measurement will be equal to the result of the calculation. From the three regression equations it can be concluded that Moritz's formula on Equation (13), has the most minimum slope or gradient line with b = 0.21831, Bouwer's formula on Equation (14), has a higher gradient line with b = 0.80472, and the formula of Sunjoto (2008b) on Equation (15) has the largest gradient line with b = 0.95304, and is the closest result to the field measurements.

Discussion of canal with side linings can be carried out by comparing the water losses of this canal to the water losses of the canal on natural soil calculated by the formula proposed by Sunjoto (2008b). The result (Table 4) of each step of calculation of the proposed formula for the canal with one side lining Equation (8) is always smaller than the result of Equation (7) even with a theoretically vertical slope (Z = 0). The result of each step of calculation of the proposed formula for the canal with two side linings Equation (9) is that almost all of the results are smaller than the result of Equation (8) respectively even with a theoretically vertical slope (Z = 0). This means that they are in accordance with logical analysis.

CONCLUSIONS

In designing of irrigation areas where on the field direct measurement cannot be carried out due to an lack of a canal, the computation method using these formulas will be able to show the efficiency of the irrigation canal, and also the contribution of the canal to the increase of groundwater storage distributed along the canal. From the three regression equations, it can be concluded that the formula of Sunjoto (2008b) for the canal on natural soil, Equation (7), has the best result with the water losses on field measurement. This is followed by Bouwer (1965) and finally by Moritz (1913). Besides these three formulas of water losses for canal on natural soil, the two formulas can be used to compute water loses of a canal with one side lining and two side linings.

When the dimensions are width of base canal in length (W_b in L), width of water surface in Length (W_s & W_v in L), depth of water in Length (H_w in L), permeability coefficient of soil in Length per unit Time (K in L/T) and length of canal unit in Length ($\lambda = 1$ meter), the result will be in cubic Length per unit time per meter length of canal (q in L^3/T/meter). Usually these dimensions are L in meter and T in second and the result will be in m^3/s/m. The three formulas of Sunjoto are in accordance with physical condition and it complies with *dimension analyses.* This is not true for the formulas of Moritz and Bouwer.

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