Scientific Research Publishing

Open Journal of Fluid Dynamics, 2025, 15(1), 33-45
https://www.scirp.org/journal/ojfd
ISSN Online: 2165-3860
ISSN Print: 2165-3852

A Case Study of Infiltration Gallery Water Flowrate to the Bandau Intake

Tony Bin Angang

Faculty of Mechanical Engineering, UMPSA, Kuantan Pahang, Malaysia
Email: angangt@yahoo.com

How to cite this paper: Angang, T.B. (2025) A Case Study of Infiltration Gallery Water Flowrate to the Bandau Intake. *Open Journal of Fluid Dynamics*, **15**, 33-45.
https://doi.org/10.4236/ojfd.2025.151003

Received: November 27, 2024
Accepted: March 15, 2025
Published: March 18, 2025

Abstract

This case study investigates the flow rate of water from an Infiltration Gallery (IG) to the Bandau Intake (BI) and aims to recommend solutions to ensure sufficient water supply. Although the IG effectively supplies raw water to Simpangan Intake (SI), the BI experiences shortages due to design and construction challenges. The study employs fluid mechanics principles, including the Manning and orifice equations, to analyze water flow dynamics over a 30-meter concrete channel. Three cases are examined: the original design, the actual constructed system, and a hypothetical scenario without an orifice. The findings reveal that the actual constructed system achieves 95% of the design flow rate (4.73 m^3/s vs. 4.94 m^3/s), meeting most requirements but falling short of the BI's needs. In contrast, the hypothetical third scenario results in backflow (−3.15 m^3/s), highlighting the significance of proper channel configuration. Limitations arise due to the shallow depth of the BI, necessitating adjustments from the original design. Recommendations include conducting detailed surveys to redesign the system with booster pumps to enhance flow rates and ensure adequate water supply. The study underscores the importance of adaptive engineering in overcoming real-world constraints to optimize water resource management.

Keywords

Infiltration Gallery, Bandau Intake, Simpangan Intake

1. Introduction

The study only focuses on the water flow channel to the Bandau Intake (BI), where all calculations will ignore the junction of the water flow to the Simpangan Intake (SI).

The objective of the study is to analyze the water flow rate in the box drain channel (box culvert) from the Infiltration Gallery to the Bandau Intake by gravity at 30 meter distance and to recommend a better solution based on the findings of case study.

In this case study, we examine the design and construction of an Infiltration Gallery (IG) system aimed at optimizing water intake from a river. Figure 1 shows or presents the initial design of the system, highlighting the dimensions and relative positions of key components, such as the IG and BI. Key metrics include the gallery height above ground level (GL) and the river water level, providing a visual reference for the system's integration into the natural environment [1].

Figure 2 shows the details of actual constructed system, reflecting adjustments made from the design phase and including the implementation of reinforced concrete (RC) culverts of various lengths. These modifications are instrumental in managing the flow and filtration of river water into the system.

Figure 3 explores an alternative setup where the orifice, typically used to control flow rate into the culverts, is omitted. This variation is critical for understanding the impact of structural changes on water flow dynamics and overall system efficiency [2].

Each figure collectively illustrates the iterative nature of engineering design in practical environments, focusing on the adaptability and optimization of water management infrastructures in response to real-world challenges.

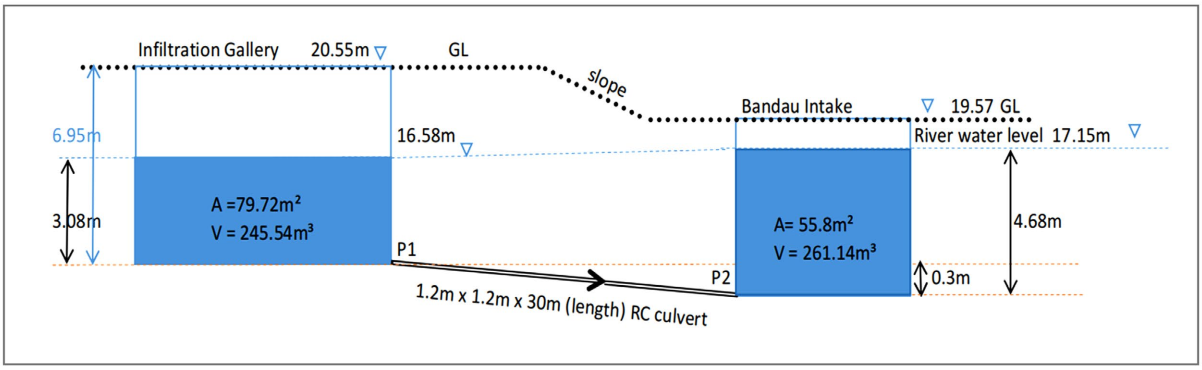

Figure 1. Original design.

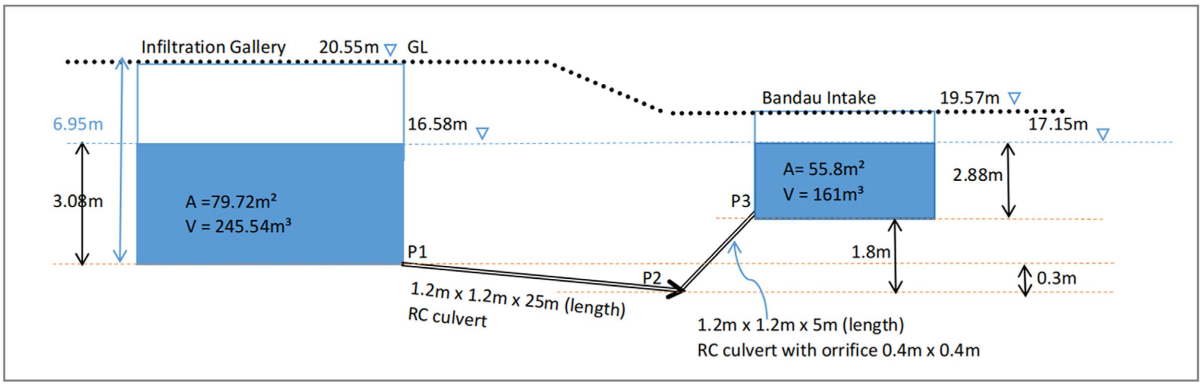

Figure 2. Actual construction.

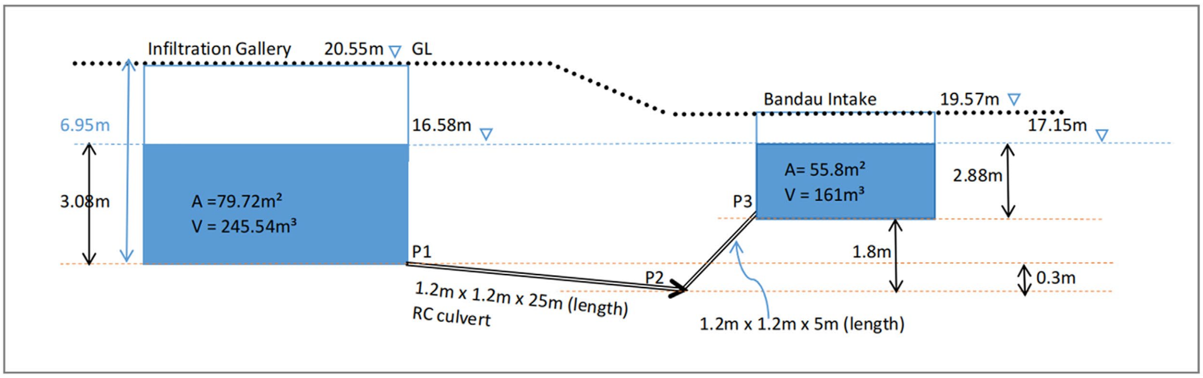

Figure 3. Design without orifice.

The construction of the infiltration gallery has been completed, and raw water has been supplied to the two intakes, namely Simpangan and Bandau.

However, the raw water supplied from the Infiltration Gallery to the Bandau water treatment plant is insufficient due to the lack of raw water in the Bandau intake, whereas the Simpangan Intake does not suffer from water shortage problems. The water flow channel used for Bandau Intake is the same as the Simpangan Intake channel.

Due to this, this study was conducted to find an answer as to why the raw water supplied to Bandau Intake is insufficient [3].

Background Overview

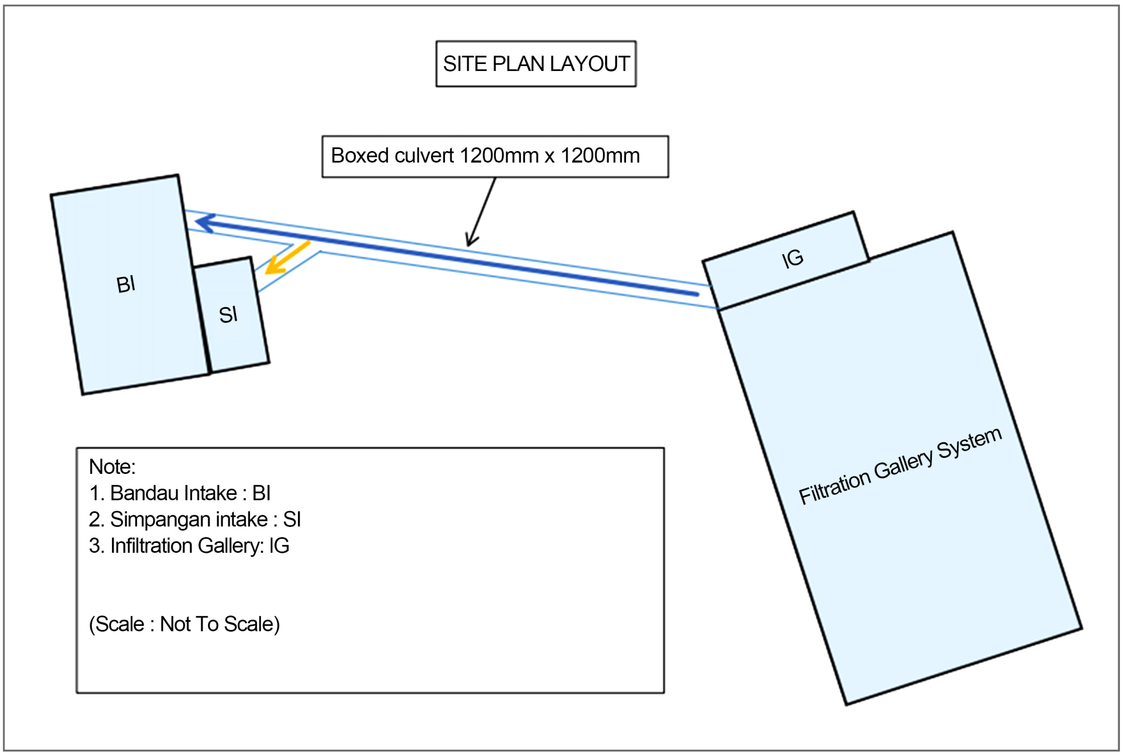

Figure 4. Construction drawing site plan.

Figure 4 shows the construction design drawing (original) of Infiltration Gallery (IG). The blue line shows the flow of water by gravity from the Infiltration gallery to the Bandau intake (BI), and the orange line shows that the water flow is diverted first to the Simpangan Intake (SI) before the flow continues to the BI.

The size of the flow door to the SI is 600 mm^2, while the size of the flow door for the BI is 1100 mm^2. The distance of the water channel from the IG to the BI is 30 meters, but 5 meters before reaching the BI, there is a water flow junction to the SI. It means the water flow was divided in two: firstly, the water will enter the SI through the constructed junction channel and then further to the BI [4].

According to this design, the water flow channel does not have any problems, and water can easily flow from the IG. The cross-sectional area of the concrete water channel or boxed culvert is 1.44 m^2 [1].

However, after the construction work of the IG was completed, and during the construction of the concrete channel, a problem appeared: the depth of the IG exceeded that of the BI, as illustrated in **Figure 1** in the introduction section. With the problem of the shallow BI depth, the construction of the concrete water channel was changed to a slope of 5 meters with a height of 1.8 meters leading to the BI. For a better understanding, please refer to **Figure 1** in the introduction section.

2. Analysis Review

The study considers both uniform and varying depths. Uniform depth applies to the straight sections of the culvert, while varying depth is analyzed near the BI, where slope and orifice effects cause disruptions. The critical slope depends on the channel dimensions and flow conditions. Subcritical flow dominates the studied system, but an in-depth analysis of Froude number and the critical slope is recommended for future studies [5].

The scenarios focus on mild slopes, as seen in the constructed channel. The steep rise near BI disrupts flow efficiency, creating challenges in Case 2. The study primarily examines uniform flow but acknowledges non-uniform flow effects near the BI orifice. These effects could be analyzed further using simulation tools in future studies.

All cases satisfy the Manning equation as the hydraulic radius, slope, and roughness coefficient are used to compute the velocity and flow rate. For instance, Case 2 incorporates the slope and adjustments from construction to calculate the flow rate accurately. The Manning equation is derived from the Chézy equation. The Chézy coefficient can be expressed by linking both equations. The Manning equation refines the Chézy equation by explicitly incorporating channel roughness and is used here for more practical applications [6].

Manning's Equation

Manning's formula describes the flow velocity (v) of a liquid in open channels as a function of channel characteristics and slope [7].

$$v = \frac{1}{n} R^{2/3} S^{1/2} \tag{1}$$

Mathematical Variables:

v: Average flow velocity (m/s)

n: Manning's roughness coefficient (dimensionless)

R: Hydraulic radius (m), defined as:

$$R = \frac{A}{P} \tag{2}$$

where A is the cross-sectional flow area (m^2), and P is the wetted perimeter (m).

S: Channel slope (m/m), representing the energy grade line or bottom slope.

Application:

The flow discharge (Q) in an open channel can be obtained by combining the velocity v with the flow area A:

$$Q = v \cdot A = \frac{1}{n} R^{2/3} S^{1/2} A \tag{3}$$

This formula is widely used in civil engineering, particularly in the design and analysis water systems, as well as in natural rivers and other watercourses. It helps engineers determine flow quantities necessary for various calculations, including flood forecasting, irrigation scheduling, and infrastructure design.

Another fluid mechanic formula to be introduced is orifice equation. The orifice equation is used to calculate the flow rate of fluid passing through an orifice, which is a small hole or opening in a container or barrier. This equation is a fundamental part of fluid dynamics and is especially useful in various engineering applications, including measuring the flow rates in tanks, pipes, and other fluid conveyance systems.

The basic form of the orifice equation can be derived from Bernoulli's principle and the continuity equation, and it is typically expressed as follows:

Orifice Equation

The orifice equation models the discharge (Q) through a small opening, where the velocity of flow is derived from Bernoulli's principle. It is given as:

$$Q = C_d A \sqrt{2gh} \tag{4}$$

Mathematical Variables:

Q: Volume flow rate (m^3/s)

C_d: Discharge coefficient (dimensionless), accounts for energy losses due to friction and geometry

A: Cross-sectional area of the orifice (m^2), where $A = \pi r^2$ for circular openings

g: Gravitational acceleration (9.81 m/s^2)

h: Head or fluid height above the orifice centerline (m).

Application:

The velocity of the fluid (v) through the orifice can be expressed as:

$$v = \sqrt{2gh} \tag{5}$$

Thus, the flow rate becomes:

$$Q = C_d A v = v = \sqrt{2gh} \tag{6}$$

3. Methodology

3.1. Case 1: Design Base on Assumption That Depth of BI Is Deeper than IG

Figure 5 shows the original design where the Bandau Intake (BI) depth is greater than the Infiltration Gallery (IG) depth. Using Manning's equation, the velocity and flow rate are calculated based on the assumed hydraulic radius, slope, and roughness coefficient.

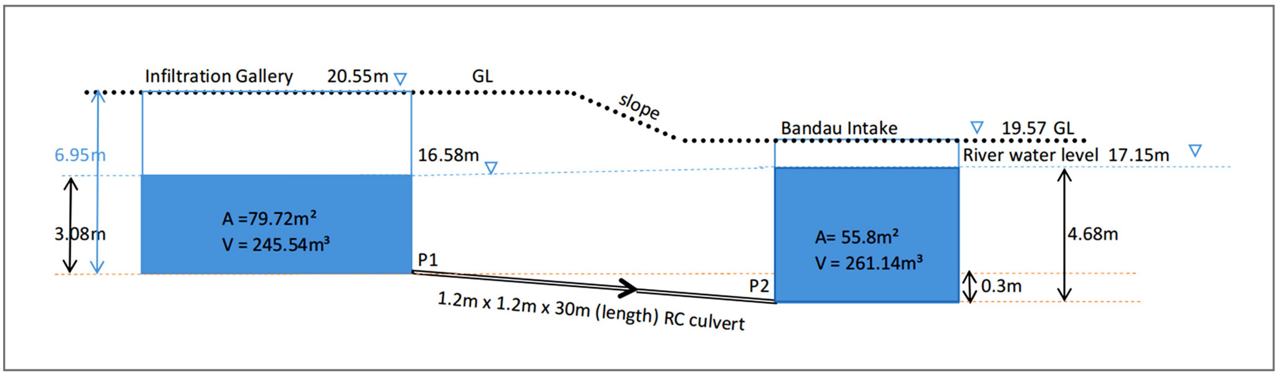

Figure 5. Original design.

<u>Determine the velocity of water along 30 m long of culvert:</u>

Hydraulic Radius, *R*—Assuming full flow in a square culvert, the hydraulic radius can be approximated as:

$$R = \text{Area}/\text{Wetted Perimeter}$$

$$R = (1.2\times1.2)/(1.2\times4) = 1.44/4.8$$

$$R = 0.3$$

Slope Calculation, *S*—Assuming the 0.3 m drop is across the entire length of the culvert

$$S = \text{Gradient}/\text{Distance}$$

$$S = 0.3\text{ m}/30\text{ m}$$

$$S = 0.01$$

Manning's roughness coefficient, *n* for concrete—0.013

By using Manning formula:

$$v = \frac{1}{n}R^{2/3}S^{1/2}$$

Simplified the formula:

$$V = 1/n\times R^{0.67}\times S^{0.5}$$

$$V = 1/0.013\times0.3^{0.67}\times0.01^{0.5}$$

$$V = 3.43\text{ m/s}$$

Determine the water flow rate (*Q*) along 30 m of culvert:

The flow rate (Q) is the product of the velocity and the cross-sectional area.

Culvert cross-sectional area, $A = 1.2\ \text{m} \times 1.2\ \text{m} = 1.44\ \text{m}^2$

$$Q = A \times V$$

$$Q = 1.44\ \text{m}^2 \times 3.43\ \text{m/s}$$

$$Q = 4.94\ \text{m}^3/\text{s}$$

Therefore, the flow rate along the 30 m culvert is 4.94 m^3/s.

3.2. Case 2: Actual Constructed Base as Shown in Following Figure

Figure 6 shows the constructed channel incorporates a slope and an orifice to control flow rate. Adjustments in elevation and slope near the BI were considered, and calculations of flow velocity and rate were performed using the Manning and orifice equations [8].

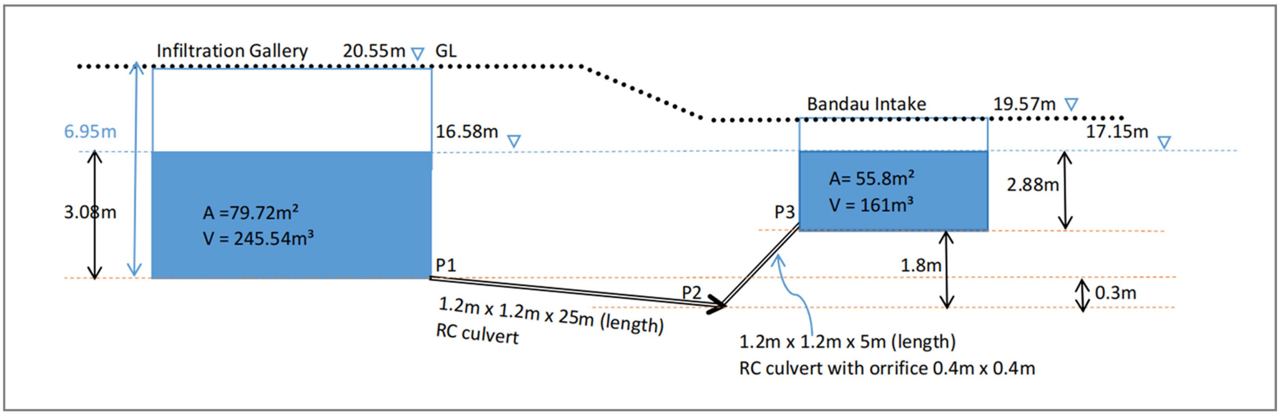

Figure 6. Actual constructed.

Note:

1) The culvert drops by 0.3 meters at the 25-meter mark due to an obstruction.

2) The culvert then rises to 1.8 meters over the last 5 meters to reach Bandau Intake.

3) An orifice or opening with an area A_0 of 0.16 m^2 is installed at Bandau Intake inlet.

4) The cross-sectional area of the 25 m length of culvert is, $A = 1.44\ \text{m}^2$.

Calculate the Velocity at the 25-meter Mark ($V_{25\text{m}}$)

Hydraulic Radius, R—Assuming full flow in a square culvert, the hydraulic radius can be approximated as:

$$R = \text{Area}/\text{Wetted Perimeter}$$

$$R = (1.2 \times 1.2)/(1.2 \times 4) = 1.44/4.8$$

$$R = 0.3$$

Slope Calculation, S—Assuming the 0.3 m drop is across the entire length of the culvert.

$$S = \text{Gradient}/\text{Distance}$$

$$S = 0.3\ \text{m}/25\ \text{m}$$

$$S = 0.012$$

Manning's roughness coefficient, n for concrete—0.013

Manning Formula:

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

Simplified the formula:

$$V_{25\,\text{m}} = 1/n \times R^{0.67} \times S^{0.5}$$

$$V_{25\,\text{m}} = 1/0.013 \times 0.3^{0.67} \times 0.012^{0.5}$$

$$V_{25\,\text{m}} = 3.76\ \text{m/s}$$

Calculate the Flow Rate at the 25-meter Mark ($Q_{25\text{m}}$)

With the velocity, we can determine the flow rate:

$$Q_{25\,\text{m}} = A \times V_{25\,\text{m}}$$

$$Q_{25\,\text{m}} = 1.44\ \text{m}^2 \times 3.76\ \text{m/s}$$

$$Q_{25\,\text{m}} = 5.4\ \text{m}^3/\text{s}$$

Account for Elevation Rise Over the Last 5 Meters

The water rises by 1.8 meters over the last 5 meters to reach Bandau Intake, so the total effective head $h_{\text{eff Bandau Intake}}$ just before the orifice is:

$$h_{\text{eff Bandau Intake}} = h_{\text{eff 25m}} - 1.8\ \text{m}$$

$$h_{\text{eff Bandau Intake}} = 0\ \text{m} - 1.8\ \text{m}$$

$$h_{\text{eff Bandau Intake}} = -1.8\ \text{m}$$

There is a negative value, which means the water has to rise, and we'd expect a reduction in kinetic energy converting to potential energy to overcome the elevation.

Calculate the Velocity and Flow Rate Through the Orifice

Velocity at the Orifice ($V_{orifice}$): The velocity of water through the opening or orifice can be calculated using Bernoulli's equation, but for orifices, we also typically introduce a discharge coefficient C_d to account for the reduction in velocity due to the vena contracta effect where the flow streamlines converge, causing the actual jet area to be less than the orifice area.

$$V_{\text{oriffice}} = C_d \sqrt{2 \times g \times h_{\text{eff}}}$$

The discharge coefficient C_d is for sharp-edged orifices, and it typically ranges from 0.6 to 0.7. Will use the maximum value of 0.7.

We would then calculate the velocity through the orifice, assuming there's enough head to drive the flow:

$$V_{\text{oriffice}} = C_d \sqrt{2 \times g \times h_{\text{eff}}}$$

$$V_{\text{oriffice}} = 0.7\sqrt{2\times 9.81\times 1.8}$$

$$V_{\text{oriffice}} = 4.16\ \text{m/s}$$

Due to the effective head is −1.8 m, therefore the $V_{\text{orifice(opening)}}$ is −4.16 m/s.

$$Q_{\text{orrifice}} = A_{\text{orrifice}} \times V_{\text{orrifice}}$$

$$Q_{\text{orrifice}} = 0.16\ \text{m}^2 \times \left(-4.16\ \text{m/s}\right)$$

$$Q_{\text{orrifice}} = -0.67\ \text{m}^3/\text{s}$$

Hence,

$$\text{Total Flowrate } (Q_{25\text{m}} + Q_{\text{orrifice 5m}})$$

$$Q_{\text{total}} = 5.4\ \text{m}^3/\text{s} + \left(-0.67\ \text{m}^3/\text{s}\right)$$

$$Q_{\text{total}} = 4.73\ \text{m}^3/\text{s}$$

Therefore, the flow rate along the 30 m (25 m + 5 m rise) culvert is 4.73 m^3/s.

3.3. Case 3 (If No Orifice Installed or BI Opening Cross-Section 1.2 m × 1.2 m)

Figure 7 shows the scenario of case 3. This hypothetical scenario assumes the BI opening has unrestricted flow. Without an orifice, significant inefficiencies and backflow were observed. Flow rate and velocity were calculated using Bernoulli's principle and Manning's equation to illustrate the impact of unregulated flow [9].

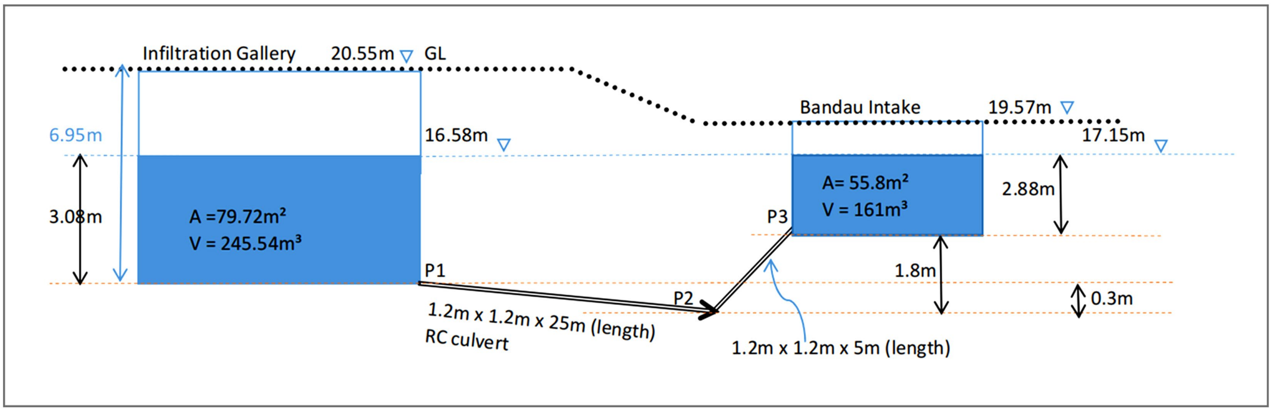

Figure 7. Design without orifice.

Note:

1) The culvert drops by 0.3 meters at the 25-meter mark due to an obstruction.

2) The culvert then rises to 1.8 meters over the last 5 meters to reach Bandau Intake.

3) The cross-sectional area of the culvert is 1.44 m^2.

Calculate the Velocity at the 25-meter Mark ($V_{25\text{m}}$)

Hydraulic Radius, R—Assuming full flow in a square culvert, the hydraulic radius can be approximated as:

$$R = \text{Area}/\text{Wetted Perimeter}$$

$$R = (1.2 \times 1.2)/(1.2 \times 4) = 1.44/4.8$$

$$R = 0.3$$

Slope Calculation, S—Assuming the 0.3m drop is across the entire length of the culvert

$$S = \text{Gradient}/\text{Distance}$$

$$S = 0.3\ \text{m}/25\ \text{m}$$

$$S = 0.012$$

Manning's roughness coefficient, n for concrete—0.013

Manning Formula:

$$v = \frac{1}{n} R^{2/3} S^{1/2}$$

Simplified the formula:

$$V_{25\,\text{m}} = 1/n \times R^{0.67} \times S^{0.5}$$

$$V_{25\,\text{m}} = 1/0.013 \times 0.3^{0.67} \times 0.012^{0.5}$$

$$V_{25\,\text{m}} = 3.76\ \text{m/s}$$

Calculate the Flow Rate at the 25-meter Mark ($Q_{25\text{m}}$)

With the velocity, we can determine the flow rate:

$$Q_{25\,\text{m}} = A \times V_{25\,\text{m}}$$

$$Q_{25\,\text{m}} = 1.44\ \text{m}^2 \times 3.76\ \text{m/s}$$

$$Q_{25\,\text{m}} = 5.4\ \text{m}^3/\text{s}$$

Account for Elevation Rise Over the Last 5 Meters

The water rises by 1.8 meters over the last 5 meters to reach Bandau Intake, so the total effective head $h_{\text{eff Bandau Intake}}$ just before the orifice is:

$$h_{\text{eff Bandau Intake}} = h_{\text{eff 25m}} - 1.8\ \text{m}$$

$$h_{\text{eff Bandau Intake}} = 0\ \text{m} - 1.8\ \text{m}$$

$$h_{\text{eff Bandau Intake}} = -1.8\ \text{m}$$

There is a negative value, which means the water has to rise, and we'd expect a reduction in kinetic energy converting to potential energy to overcome the elevation.

Calculate the Velocity and Flow Rate

The velocity of water rise on slope can be calculated using Bernoulli's equation:

$$V = \sqrt{2 \times g \times h_{eff}}$$

We would then calculate the velocity, assuming there's enough head to drive the flow:

$$V_{\text{rise}} = \sqrt{2 \times g \times h_{\text{eff Bandau intake}}}$$

$$V_{\text{rise}} = \sqrt{2 \times 9.81\ \text{m/s}^2 \times 1.8\ \text{m}}$$

$$V_{\text{rise}} = 5.94\ \text{m/s}$$

Due to the effective head is −1.8 m, therefore the Velocity rises is −5.94 m/s.

$$Q_{5\,\text{m}} = A \times V$$

$$Q_{5\,\text{m}} = 1.44\ \text{m}^2 \times (-5.94\ \text{m/s})$$

$$Q_{5\,\text{m}} = -8.55\ \text{m}^3/\text{s}$$

Hence,

$$\text{Total Flowrate } (Q_{25\,\text{m}} + Q_{5\,\text{m}})$$

$$Q_{\text{total}} = 5.4\ \text{m}^3/\text{s} + (-8.55\ \text{m}^3/\text{s})$$

$$Q_{\text{total}} = -3.15\ \text{m}^3/\text{s}$$

Therefore, flow rate along the 30 m (25 m + 5 m rise) culvert is −3.15 m^3/s.

4. Discussion & Result

Table 1 shows the comparison summary of the three cases, which shows the flow rates and efficiencies of each scenario. The second case study achieves 95% of the design flow rate and is deemed the most suitable for practical implementation [10].

Table 1. Comparisons result.

Case	Description	Flow Rate (Q)	Remarks
Case 1	Ideal design where BI depth > IG depth.	4.94 m^3/s	Aligns with theoretical design assumptions.
Case 2	Actual constructed system with slope and orifice.	4.73 m^3/s	Achieves 95% of design flow rate.
Case 3	No orifice; unrestricted BI opening.	−3.15 m^3/s	Results in backflow; highly inefficient.

The first case study shows the water flow rate (Q = 4.94 m^3/s) that should be produced after the construction work is completed or it is the value of the design flow rate.

The second case study showed the water flow rate (Q = 4.73 m^3/s) produced after the actual construction work was completed. The value of this water flow rate does not reach the design flow rate where the value is less than 5% of the value of the design flow rate. But it is able to channel water as much as 95% of the design flow rate.

The third case study shows the water flow rate (Q = −3.15 m^3/s) produced if the construction work uses this method. The value of the water flow rate is severely reduced by −65% of the design flow rate. It means back flow occurred.

The findings highlight the importance of proper channel configuration, slope adjustments, and the inclusion of an orifice to regulate flow [11].

In order to clarify cases two and three participations, you could try it practically by connecting your hose to the water tap and flowing the water with 300 mm gradient from water tap level at a distance of 30 m, then bending the hose to rise to above the water tap height around 1.8 m and at the same time close half of hose end that shows the velocity of water flow is increasing. Then repeat the same for case 3, where we came to the free end hose feel water flow property.

4.1. Limitation

The construction work could not be carried out according to the original design (refer to figure case 1) because the existing structure (Bandau Intake) is shallow, which is not the same as in the approved design drawing.

4.2. Future Recommendation

i) Construction according to the original design is impossible because the depth of the Bandau Intake does not exceed the depth of the Infiltration Gallery. If construction is to be carried out as well, Bandau Intake will need to be demolished first, and then a new Intake will need to be built.

ii) To ensure sufficient flow of raw water to the Bandau Intake, the appointed consultant needs to do a detailed survey including designing a booster pump system with a pipeline to the Intake Bandau.

iii) To ensure sufficient continuous water flow to the water treatment plant, the Government (Sabah State Water Department) needs to propose installing 2 units or more suitable booster pumps along with a pipe system that is directly connected to the existing pipe or Bandau intake raw water pipeline.

5. Conclusions

The second case study is actually constructed at the construction site. After the calculation, as shown in the previous section methodology, it was found that the flow rate was 5% less than the approved design (case study 1). Although the flow rate did not reach the design requirements, the constructed channel was able to produce a water flow rate of 95% of the designed flow rate compared to the third case (if implemented).

However, as explained in the previous background section, the water flow was divided into two parts: the water channel to Simpangan Intake (SI) and then later continued flow to Bandau Intake (BI). It is known that the opening size of the SI gate is 0.36 m^2 or (600 mm × 600 mm) which is half the size of the cross-section (1200 mm × 1200 mm or 1.44 m^2) of the main concrete channel to BI. It will affect the next flow of water to the BI, where it is considered 25% or ($0.36\ m^2/1.44\ m^2 \times 100\% = 25\%$) of the flow rate affected by the BI. As a result, the water flow to the BI is only 70% of the desired design. Of course, 70% of raw water is not sufficient for Bandau Intake or the water treatment plant to run fully. However, case 2 is still able to supply the raw water to the Intake with less than 30% of the desired design compared to case 3 study.

Therefore, the construction of the channel in the second case is very suitable to be maintained, and there is no need to carry out work like in the third case or enlarge the opening. Case 3 is the proof of flow rate calculation.

Although this second case study only lacks 30% of the flow from the approved design, it is supposed to be very helpful in providing raw water to Bandau Intake.

The study concludes that the second case, representing the actual constructed system, achieves a flow rate of 95% of the design requirement, making it a viable solution for supplying water to the Bandau Intake. Recommendations include conducting detailed surveys and utilizing booster pumps to enhance flow efficiency, ensuring an adequate water supply to the Bandau water treatment plant [12].

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] French, R.H. (1985) Open-Channel Hydraulics. McGraw-Hill.

[2] Sturm, T.W. (2014) Open Channel Hydraulics. McGraw-Hill Education.

[3] Henderson, F.M. (1966) Open Channel Flow. Macmillan.

[4] Mays, L.W. (2005) Water Resources Engineering. John Wiley & Sons.

[5] Brater, E.F. and King, H.W. (1976) Handbook of Hydraulics. McGraw-Hill.

[6] Roberson, J.A. and Chaudhry, C. (1998) Hydraulic Engineering. John Wiley & Sons.

[7] Jain, A.K. (2001) Open Channel Flow. Nem Chand & Bros.

[8] Hager, W.H. (2010) Wastewater Hydraulics: Theory and Practice. Springer.

[9] Crowe, C.T., Elger, D.F. and Williams, B.C. (2020) Engineering Fluid Mechanics. 12th Edition, Wiley.

[10] Chow, V.T. (1959) Open-Channel Hydraulics. McGraw-Hill.

[11] White, F.M. (2020) Fluid Mechanics. 9th Edition, McGraw-Hill Education.

[12] Featherstone, R.E. and Nalluri, C. (2009) Civil Engineering Hydraulics. 5th Edition, Blackwell Publishing.