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Adaptive water management through hybrid infrastructure: Addressing floods and water scarcity in the Sunter River Region

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Abstract

The Sunter River basin faces significant challenges related to flooding and water scarcity, driven by broken embankments and high rainfall intensity. This study aims to design an adaptive water management system that mitigates flood risks during the rainy season while conserving rainwater for use during the dry season. This research employs area calculation using the Polygon Thiessen method to analyze rainfall distribution. Rainfall data with 90% reliability is processed using the F.J. Mock method, while the Mononobe theory is applied to determine rainfall intensity. The study proposes a hybrid infrastructure that integrates rainwater harvesting (RwH), green roofs (GRo), infiltration trenches (ITre), and ground reservoirs to manage and conserve water resources effectively. The analysis indicates that the hybrid infrastructure can harvest approximately 401,345 m^3 of rainwater annually. The infiltration trench system is designed to manage runoff from the Sunter River's drainage channel, with a capacity of 143,259 m^3/s, based on a 5-year return period. The trench dimensions are 2.5 meters in depth and 3 meters in width. Rainwater storage for RwH and GRo employs fiberglass reinforced panel tanks in a modular knock-down system with dimensions of 1m x 1m x 1m, reinforced with slab structures and C-channel plates. This infrastructure is strategically constructed over the Sunter River to optimize land use and mitigate flooding. The proposed system offers a sustainable solution to address water management issues in urban areas, reducing flood risk while enhancing water availability during dry periods. This hybrid infrastructure model can be adapted and replicated in other flood-prone and water-scarce regions, contributing to improved resilience against climate variability. This study presents an innovative approach by integrating multiple water management techniques into a single hybrid infrastructure system. By addressing both flooding and water scarcity through adaptive design, the research provides a novel contribution to sustainable urban water management practices in the Sunter River region.

Keywords: Green roof, Hybrid infrastructure, Infiltration trench, Rainwater harvesting, Water conservation.

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1. Introduction

Flooding occurs when land (which is usually dry) is submerged by an increasing volume of water. There are two types of floods: the first is flooding or inundation, which occurs in urban areas. The second is flooding that occurs in the vicinity of the embankment. It is caused by the overflowing of rivers [1].

Areas in the Sunter River basin are potentially submerged in water. This is due to the broken embankment of the Sunter River and high rainfall. This Sunter stream passes through Cipinang Melayu and Cipinang Muara. No sheet pile wall construction has been done in the Sunter River yet; thus, if rainfall continues to fall with high intensity, it will overflow and inundate [2]. The Sunter area in the Kelapa Gading District, particularly along Yos Sudarso Road, often experiences flooding every rainy season, with the worst flooding occurring in January 2020, where the inundation reached as high as 100 cm [3].

Land cover change detected using Landsat imagery shows that vegetation cover in Jakarta has decreased drastically. In 1999, the built-up land cover in Jakarta was 65.5% and vegetation cover was 35.5%, while in 2019 its composition drastically changed to 93.6% built-up land cover and only 6.4% vegetation cover. The increase in built-up area has increased the surface area that is impermeable. The impermeable layer on built-up land has led to a decrease in infiltration rate and an increase in surface flow or runoff volume, which in turn can cause flooding [4].

Floods in the past were caused by very high rainfall, but catchment areas are still available. The current flood occurs due to blocked river flow from upstream to downstream instead of the heavy precipitation intensity coupled with low water infiltration [5]. The rapid consumption, contamination, and shortage of fresh water resources have led us to develop water demand management policies and to find alternative sources such as desalination.

Systems or rainwater harvesting in sustainable water management studies. Utilization of rainwater is an economic, environmental, public, and environmentally friendly technology. Collecting and storing rainwater with zero emissions can increase the amount of available water resources in the city, reduce city floods, pollution, and improve the urban water issue [6].

Hybridization in water engineering can be achieved by introducing two or more fundamentally different types of elements that work together to achieve a predefined set of design objectives (e.g., flood prevention and stormwater treatment). Many studies thus far have suggested green-blue-grey hybrid infrastructure as the most promising urban water management approach that can simultaneously combine the reliability, robustness, and acceptability of conventional pipe networks with multi-functionality, sustainability, and adaptability [7].

The aim of this research is to control flooding and inundation in the Sunter River Basin between STA 06.250 and STA 07.350 based on a Hybrid Infrastructure system model design that combines two elements, namely green infrastructure in the form of building models to capture, accommodate, absorb, and drain rainwater, and grey infrastructure in the form of existing drainage in runoff water management as an environmentally adaptive solution to raw water needs for urban communities. The proposed hybrid infrastructure design in this research includes rainwater harvesting, roof gardens, and infiltration trenches.

2. Methodology

The location to be studied in this research is in the Sunter River, specifically in the West Kelapa Gading Village area, North Jakarta, while the map of the location is presented as in the Figure 1. The Sunter River Watershed is included in the Ciliwung-Cisadane river basin. Geographically, the Sunter watershed is located at 6°16'32.58" South latitude and 106°53'20.41" East longitude.

Figure 1.
Sunter watershed and its catchment area.

The data used in this study were obtained from field observations and data from several related institutions such as the PU and BMKG. The data obtained are used to calculate the maximum runoff by using the Polygon Thiessen III and Rational Method. Calculating debit using the F.J. Mock Method.

2.1. Data Collection Method

The data used in this study consist of daily rainfall data from three rainfall stations, namely Kemayoran, Tanjung Priok, and Bogor Stations, climatological data in the form of air temperature, relative humidity, solar irradiation, and wind speed from the Meteorological, Climatological, and Geophysical Agency, topographic maps, and discharge data from direct measurement in the field.

2.2. Data Analysis Method

The design and analysis in this study used Microsoft Excel and ArcGIS computer programs. The topographic map was processed to determine the catchment area, and then divided into the area of influence of the three stations from the catchment area. The maximum runoff discharge was calculated using the rational method after using the Polygon Thiessen method to calculate the rainfall plan (X_T) and the Mononobe method to calculate the rainfall intensity (I). The mainstay discharge uses the method of F.J. Mock after calculating evapotranspiration with the Penman Modification method and provides recommendations for a hybrid infrastructure system.

3. Results and Discussions

3.1. Maximum Runoff Discharge

3.1.1. Rainfall Analysis Plan

Analysis of planned flood flows in a catchment area considers the potential rainfall that may occur in the area. This rainfall estimate is obtained through statistical analysis of recorded historical rainfall data. The measurement and recording of this rainfall data are carried out by rain gauging stations located throughout the catchment area.

The calculation uses the Thiessen method. Thiessen is a method in which polygons are drawn between stations in an area, and then the average rain height is calculated from the number of multiplications between each polygon area and the rain height, which is divided by the total area. The Thiessen polygon method is usually used to determine the average rainfall when the rain stations are not evenly distributed [8].

The north latitude and south latitude coordinates of the three rainfall stations in the Sunter watershed area are shown in Figure 2 and the average rainfall calculation is shown in Table 1.

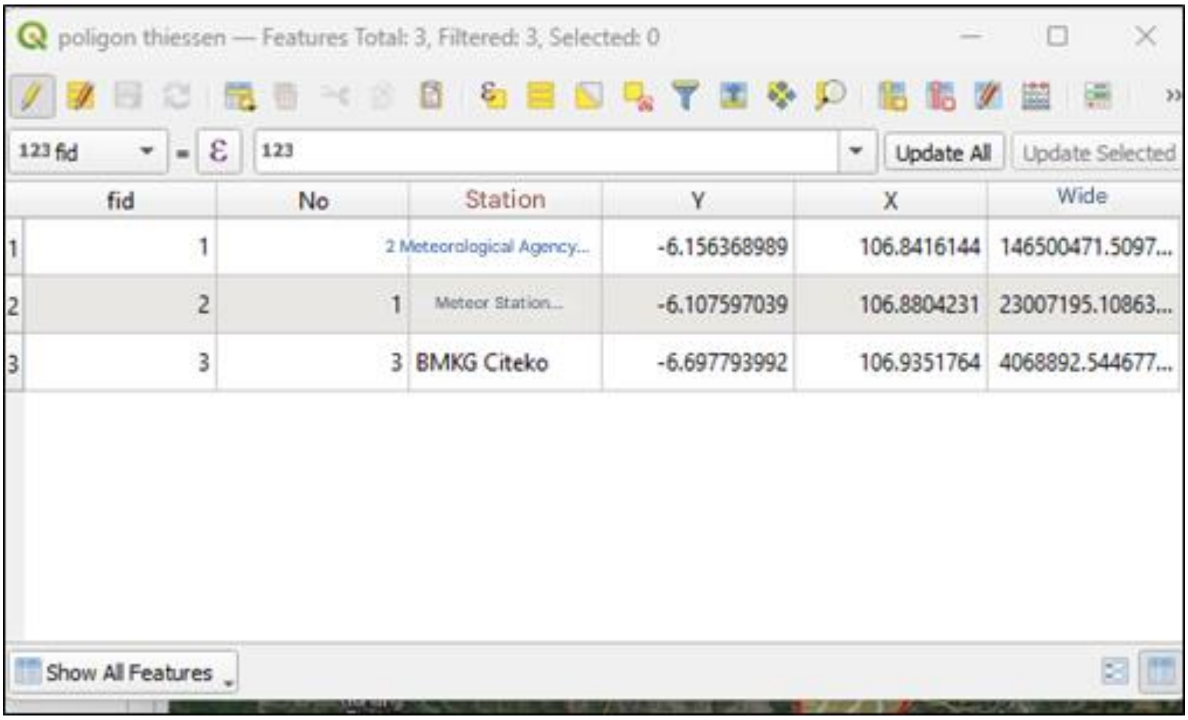

Figure 2.
Determination of Thiessen Polygon Area.
Source: QGis.

Table 1.
Average data rainfall by Polygon Thiessen.

Year	RAIN STATION			Average rainfall
	Tanjung Priok	Kemayoran	Bogor	
	mm			
2013	117.80	193.40	106.79	181.35
2014	104.10	147.90	121.94	141.49
2015	247.00	277.50	92.51	269.12
2016	112.70	124.50	69.75	121.65
2017	148.60	179.70	101.87	173.75
2018	130.30	104.60	82.87	107.50
2019	130.30	94.50	99.84	99.37
2020	155.50	277.50	118.70	257.61
2021	91.60	94.10	124.00	94.47
2022	134.70	204.00	89.10	192.12

3.1.2. Rainfall Distribution Analysis

Analysis of rainfall distribution is using the Log-Pearson Type III method as follows:

$$C_s = \frac{n\sum_{i=1}^{n}(X_i - X)^2}{(n-1)(n-2)S^3} \quad (1)$$

$$Log\ X_T = Log\ X_r + k.S\ LogX \quad (2)$$

The distribution of the data was analyzed using the log Pearson type III (SNI 2415-2016, 2016). Then, the Smirnov-Kolmogorov test was performed to determine the extent of the data in the horizontal direction to find out whether the data conforms to the selected type of theoretical distribution or not [9].

The inclination coefficient, as determined by the Log-Pearson Type III method of rainfall distribution analysis, is 0.22.

3.1.3. Rainfall Return Period

The logarithmic value of the rainfall distribution is returned to determine the rainfall return period:

$$Log\ X_r = Log\ X + K.S \qquad (3)$$

3.1.4. Frequency Distribution Conformity Testing

Distribution fit testing is performed to assess whether the frequency distribution of the sampled data fits the likelihood function that is expected to represent the frequency distribution.

In the Kolmogorof Smirnov Test D count = 0.12 and D critical = 0.4. So, it is concluded that D count < D critical, namely 0.12 < 0.4 so that the log person type III distribution is accepted.

3.1.5. Return Period Analysis

Rainfall frequency analysis using the log Pearson Type III method will be used to determine the maximum rainfall with return periods of 2, 5, 10, 25, and 50 years. Based on the analysis of the return periods, it is found that the maximum rainfall amount among the other return periods:

Table 2.
The maximum rainfall 2, 5, 10, 25, and 50 return period years.

Return Period (Year)	Rainfall (m^3/s)
2	164
5	223
10	262
25	310
50	347

3.1.6. Runoff Coefficient Analysis

Land use characteristics, i.e. the extent and type of land use, which greatly influence the flow coefficient and infiltration capacity.

Determined land cover use (C) in this study in accordance with data from ministry of environment and forestry (KLHK) is as in Figure 3.

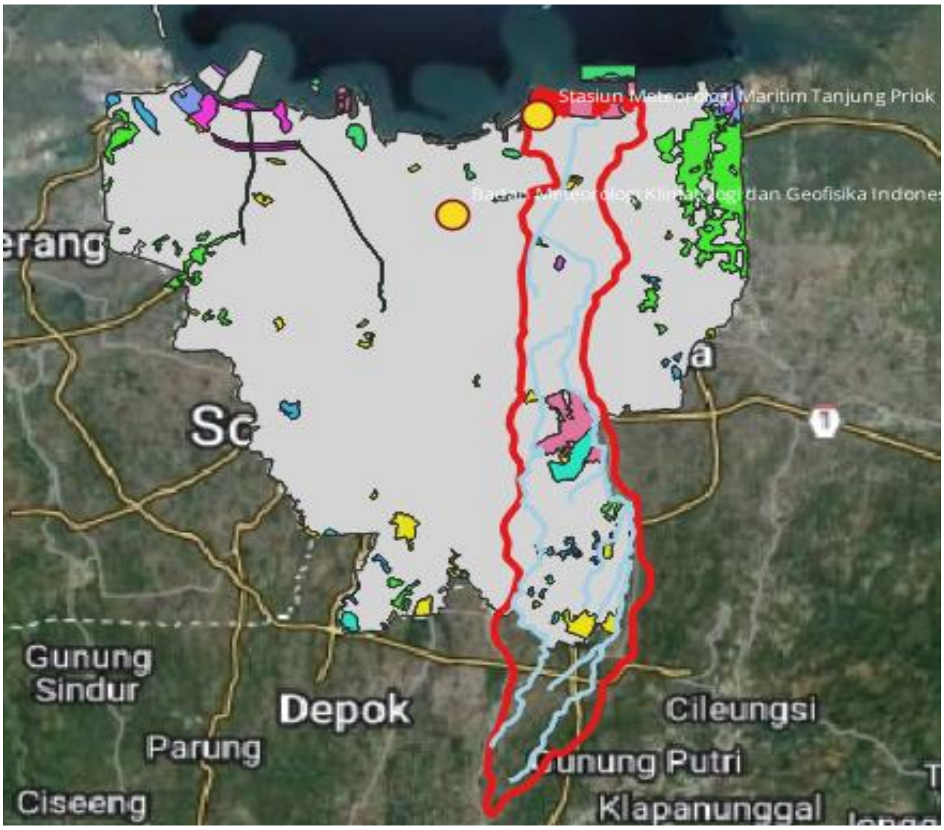

Figure 3.
Land Cover Year 2022.
Source: QGis.

The calculation of land cover in the Sunter watershed studied is as follows:

Table 3.
Coefficient Runoff of Sunter watershed land cover.

Area	C	A	C.A
Harbour	0.8	6.77	5.416
Dry Land	0.1	2.32	0.232
Dry land mixed with shrubs	0.1	6.5	0.65
Pond	0.05	1.33	0.0665
Open Land	0.2	0.25	0.05
Water Body	0.05	0.2	0.01
Settlement	0.6	94.63	56.778
Total		112	63.2025
Land Cover Coefficient		C Total/A Total	0.564

So that the land cover coefficient (c) used in the calculation of the Sunter watershed is 0.564.

3.1.7. Rainfall Intensity

Rainfall intensity can be thought of as the height or hardness of rain per unit time. If daily rainfall is available, then rainfall intensity can be determined using the Mononobe formula.

$$I = \frac{R_{24}}{24} \times \left(\frac{24}{tc}\right)^{m} \qquad (4)$$

The centralized rainfall distribution pattern that will be used in the study area is 6 hours each day (Indonesia has an average time of rain concentration t = 6 hours, now 2-4 hours) [9].

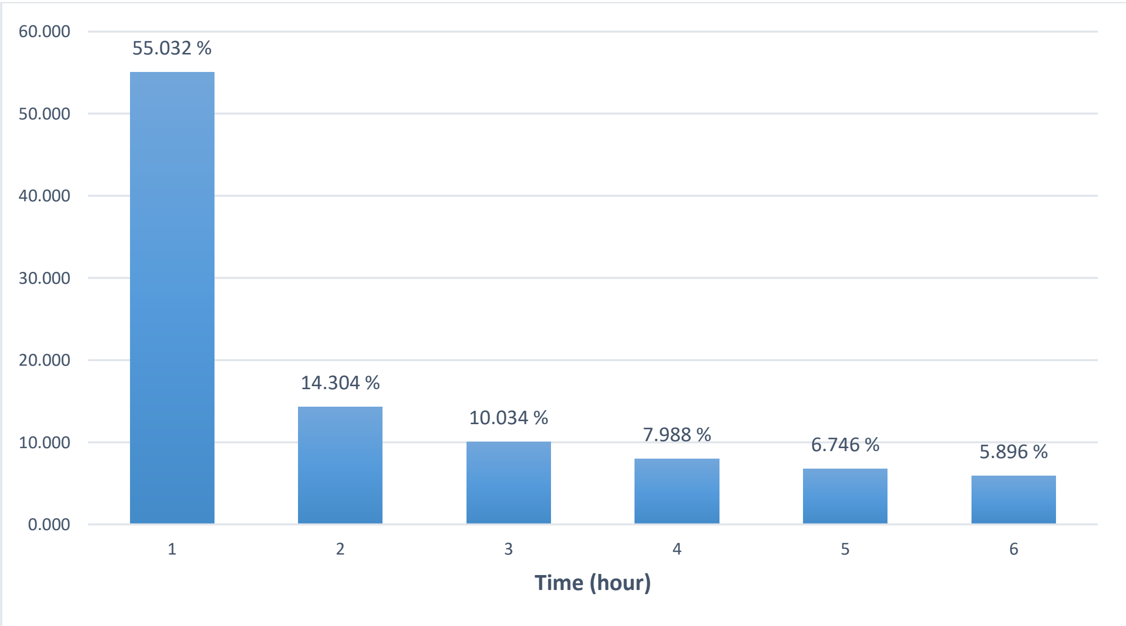

Figure 4.
Hourly Rain Distribution Calculation

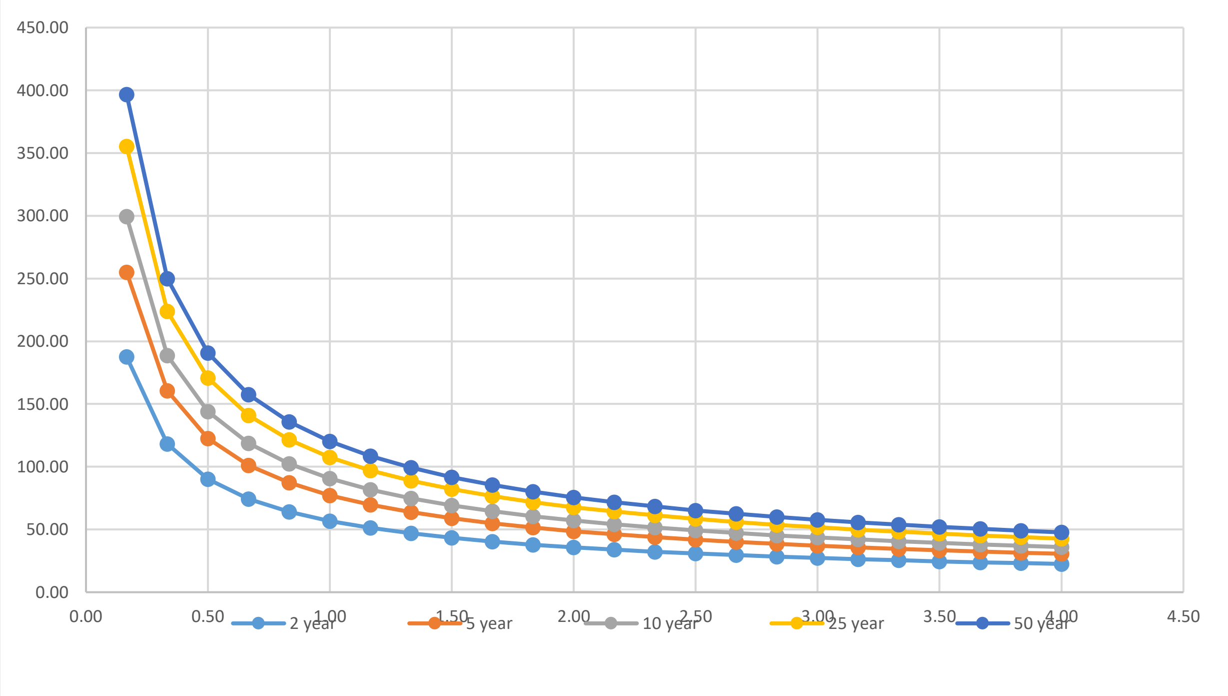

Figure 5.
IDF Curve for Rainfall Intensity.

3.1.8. Flood Discharge Plan

The design debit is the maximum discharge that will be channeled by the drainage channel to prevent flooding [10]. The analysis used when calculating the planned flood discharge in the Sunter River watershed research is using the Practical Rational Method.

Table 5.
The plan flood discharge in the Sunter River watershed.

Return Period (Year)	Peak discharge (Qp) (m^3/s)
2	187.368
5	254.750
10	299.112
25	354.936
50	396.425

4. Mainstay Discharge Analysis

The calculation of the mainstay discharge is done in several stages. The stages of calculation carried out are to calculate evapotranspiration using the modified Penman Method, then calculate the monthly mainstay discharge for ten years with the F.J. Mock Method, and finally determine the 50% probability mainstay discharge by using the Weibull Equation [11].

4.1. Evapotranspiration with Penman Method

Calculation of potential evapotranspiration (ETo) using the 'Penman Modification' method with the equation:

$$Eto = c \times Eto^* \quad (5)$$

$$Eto^* = W(0{,}75xRs\text{-}Rn1)+(1\text{-}W)x(f(u)x(ea\text{-}ed) \quad (6)$$

Table 6.
Results of Modified Pennman Method Evapotranspiration Analysis.

Description	Caption	Jan	Feb	Mar	Apr	May	June	July	Aug	Sept	Oct	Nov	Dec
Temperature (C°)	Data	27.877	27.713	28.417	28.989	29.275	28.848	28.483	28.635	29.051	29.251	29.025	28.425
Air Humidity, Rh (%)	Data	80.680	82.112	79.404	78.299	76.894	76.093	74.135	72.352	72.071	72.778	75.420	77.845
Duration of Mahatari irradiation, ss (hours)	Data	3.493	3.965	4.762	6.072	5.880	5.055	5.904	6.450	7.173	6.958	5.352	4.360
Wind Speed, U (km/hr)	Data	2.803	2.148	1.916	2.021	2.046	1.957	2.210	2.204	2.056	1.858	1.967	2.592
f(u) = 0.27 (1+U/100)	Calculate	0.278	0.276	0.275	0.275	0.276	0.275	0.276	0.276	0.276	0.275	0.275	0.277
Deficiency Ratio, n/N (%)	Calculate	0.291	0.330	0.397	0.506	0.490	0.421	0.492	0.538	0.598	0.580	0.446	0.363
Saturated Vapour Pressure, ea (mbar)	Table	37.542	37.197	38.759	40.075	40.733	39.750	38.911	39.261	40.217	40.677	40.158	38.778
Actual Vapour Pressure, ed = ea x Rh/100	Calculate	30.289	30.543	30.776	31.378	31.321	30.247	28.847	28.406	28.985	29.604	30.287	30.186
ea - ed	Calculate	7.253	6.654	7.983	8.697	9.412	9.503	10.064	10.855	11.232	11.073	9.871	8.591
Factor w	Table	0.779	0.777	0.782	0.785	0.786	0.784	0.782	0.783	0.785	0.786	0.785	0.782
(1-w)	Calculate	0.221	0.223	0.218	0.215	0.214	0.216	0.218	0.217	0.215	0.214	0.215	0.218
Extra Solar Radiation, Ra (mm/hr)	Table	15.848	15.848	15.848	15.848	15.848	15.848	15.848	15.848	15.848	15.848	15.848	15.848
Received solar radiation, Rs = (0.25 + 0.5 n/N) Ra	Calculate	6.269	6.580	7.107	7.972	7.845	7.300	7.861	8.221	8.699	8.557	7.496	6.841
Rns = (1-a) Rs, a = 0.25	Calculate	4.701	4.935	5.330	5.979	5.884	5.475	5.895	6.166	6.524	6.417	5.622	5.131
Temperature effect, f(t)	Table	16.275	16.243	16.383	16.498	16.583	16.470	16.397	16.427	16.515	16.575	16.508	16.385
f(ed) = 0.34 - 0.044 $(ed)^{0.5}$	Calculate	0.098	0.097	0.096	0.094	0.094	0.098	0.104	0.105	0.103	0.101	0.098	0.098
f(n/N) = 0.1 + 0.9 n/N	Calculate	0.362	0.397	0.457	0.555	0.541	0.479	0.543	0.584	0.638	0.622	0.501	0.427
Rn1 = f(t). f(ed). f(n/N)	Calculate	0.576	0.625	0.718	0.857	0.841	0.773	0.923	1.012	1.086	1.037	0.810	0.687
Residual energy, Rn = Rns - Rn1	Calculate	4.125	4.310	4.612	5.122	5.043	4.702	4.973	5.154	5.438	5.381	4.812	4.443
Correction Factors, C	Table	1.100	1.100	1.000	0.900	0.900	0.900	0.900	1.000	1.100	1.100	1.100	1.100
ETo = c. (W.Rn + (1-W). f(u). (ea-ed)), mm/hr	Calculate	4.024	4.134	4.085	4.082	4.067	3.826	4.046	4.686	5.428	5.370	4.798	4.393
Eto, mm/month	Calculate	124.73	115.76	126.64	122.45	126.08	114.79	125.41	145.27	162.83	166.45	143.94	136.18

Table 7.
Reliable Discharge of Kemayoran, Tanjung Priok and Bogor Stations (m^3/sec).

YEAR	MONTH											
	Jan	**Feb**	**Mar**	**Apr**	**May**	**June**	**July**	**Aug**	**Sept**	**Oct**	**Nov**	**Dec**
2015	312.204	796.231	82.038	84.528	280.000	280.000	896.000	2240.000	746.667	497.778	140.009	195.697
2018	70.000	199.403	71.111	93.333	186.667	320.000	2240.000	497.778	320.000	165.926	117.895	97.391
2019	82.326	137.635	64.928	82.963	165.926	407.273	1120.000	640.000	497.778	186.667	131.765	164.382
2020	337.280	638.447	68.923	101.818	124.444	160.000	248.889	263.529	640.000	101.818	93.333	74.667
2014	577.804	536.513	114.941	87.453	95.319	117.895	109.268	224.000	497.778	203.636	99.556	105.090
2017	84.528	402.395	78.596	89.600	172.586	131.765	203.636	640.000	194.783	101.818	95.319	137.722
2013	434.686	86.154	82.963	92.616	111.137	160.000	144.516	298.667	213.333	149.333	104.186	112.596
2021	94.161	437.232	72.258	91.429	160.457	99.556	213.333	224.000	154.483	112.000	84.528	75.932
2016	95.319	290.773	111.348	176.412	87.843	114.872	106.667	99.556	97.391	68.923	75.932	109.268
2022	121.544	67.879	81.455	137.176	97.391	106.667	165.926	186.667	121.081	95.319	89.600	70.000

4.2. Predictive Discharge F.J. Mock Method

Determination of water availability or streamflow in the catchment area Sunter River, the F.J. Mock method was used for 10 years. The data used as parameters for determining the mainstream discharge are:

1. Average monthly rainfall data
2. Potential evapotranspiration data calculated with the Penman Modification method

4.3. Determining Reliable Discharge Probability

Determination of reliable discharge probability using the Weibull equation below.

$$P = m/(n+1) \times 100\% \quad (7)$$

The value of the mainstay discharge of FJ. Mock is sorted from the largest to the smallest value, then using the Weibull equation to calculate the probability value.

Table 8.
Mainstay Discharge with 50% probability.

Month	Debit
Jan	95.32
Feb	290.77
Mar	78.6
Apr	91.43
May	124.44
Jun	131.76
Jul	203.64
Aug	263.53
Sept	213.33
Oct	112
Nov	95.32
Dec	105.09
Total	1805.23

4.4. Hybrid Infrastructure

The life cycles of green and grey infrastructure are very different. A key difference is that the societal functions of green infrastructure are characterized by regenerative processes, whereas grey infrastructure requires substantial financial investment in ongoing engineering to deal with material decay in order to maintain its functions [12].

4.5. Storage Volume

The volume of rainwater can be accommodated using 50% monthly mainstay discharge FJ mock calculation with runoff coefficient Sunter Watershed 0.564 is illustrated in the Figure 6.

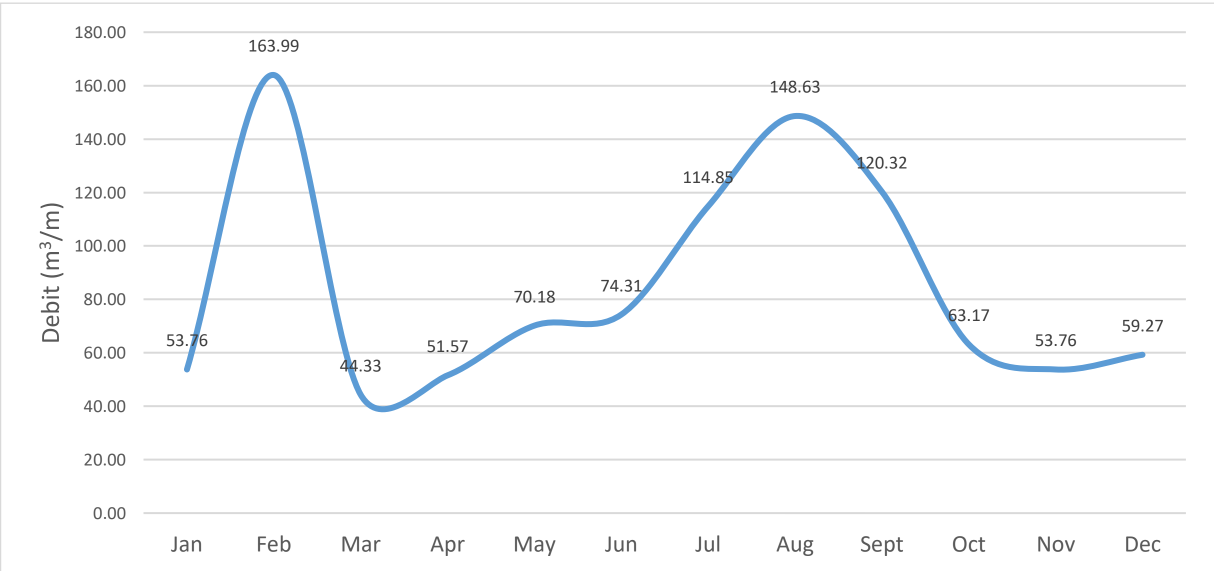

Figure 6.
Graphic of 50% monthly mainstay discharge FJ mock calculation.

4.6. Rainwater Harvesting (RwH)

RWH consists of the concentration, collection, storage, and treatment of rainwater from roofs, terraces, courtyards, and other impervious building surfaces for on-site use. The civil uses of collected rainwater vary (e.g., toilet flushing, laundry, garden irrigation, terrace cleaning, and other sporadic outdoor uses such as car washing), but all aim to reduce the consumption of potable water from centrally supplied sources [13]. Rainwater harvesting is a system that is utilized as a secondary source for daily non-consumable clean water needs [14].

Calculating the volume of rainwater collected in rainwater reservoirs throughout the year based on the mainstay rainfall [15].

$$\sum Q = \alpha \times R \times A \tag{8}$$

$\sum Q$ = Total harvestable rainwater (m^3/month)
A = Roof area (m^2)
α = Run off coefficient
R = Average daily rainfall (mm/month)
To calculate the total volume of the rainwater harvesting system to be built on the Sunter river is to use the monthly rainfall in 2021 with a probability of 90% [16].

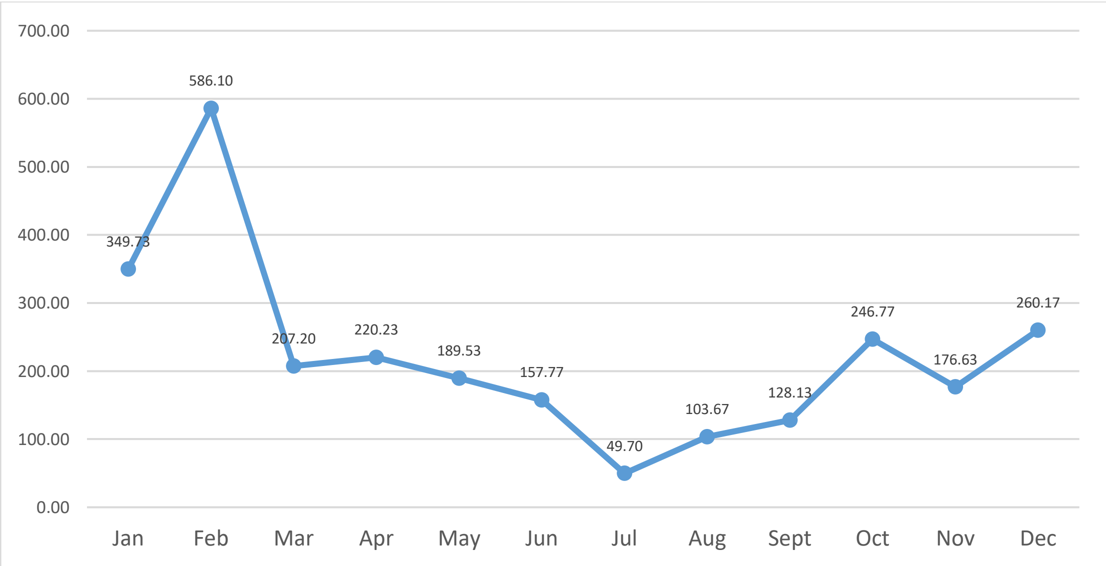

Figure 7.
Rainwater catchment areas in the form of roofs, the runoff coefficient is 0.75 – 0.95 [17]. Rainwater demand is the amount of water used for daily needs for one month.

The results of the calculation of rainwater availability (Q) as seen in Table 9.

Table 9.
Rainwater Volume from RwH.

Month	Rainfall (mm)	Rainfall (m)	Coeff Run off (C)	Area (A) (m^2)	Volume (m^3/m)
Jan	349.73	0.350	0.95	125	41.531
Feb	586.10	0.586	0.95	125	69.599
Mar	207.20	0.207	0.95	125	24.605
Apr	220.23	0.220	0.95	125	26.153
May	189.53	0.190	0.95	125	22.507
Jun	157.77	0.158	0.95	125	18.735
Jul	49.70	0.050	0.95	125	5.902
Aug	103.67	0.104	0.95	125	12.310
Sept	128.13	0.128	0.95	125	15.216
Oct	246.77	0.247	0.95	125	29.304
Nov	176.63	0.177	0.95	125	20.975
Dec	260.17	0.260	0.95	125	30.895
Total					317.731

4.7. Roof Garden (RGa)

Rain gardens, often called bioretention or bio-infiltration systems, have been recommended for local, near-source stormwater management because of their cost-effectiveness and positive ecosystem restoration effects [18].

The results of the calculation of rainwater volume in RGa as seen in Table 10.

Table 10.
Rainwater Volume from GRo

Month	Rainfall (mm)	Rainfall (m)	Coeff. Run Off (C)	Area (A/m^2)	Volume (m^3/m)
Jan	349.733	0.350	0.25	125	10.929
Feb	586.1	0.586	0.25	125	18.316
Mar	207.2	0.207	0.25	125	6.475
Apr	220.233	0.220	0.25	125	6.882
May	189.533	0.190	0.25	125	5.923
Jun	157.767	0.158	0.25	125	4.930
Jul	49.7	0.050	0.25	125	1.553
Aug	103.667	0.104	0.25	125	3.240
Sept	128.133	0.128	0.25	125	4.004
Oct	246.767	0.247	0.25	125	7.711
Nov	176.633	0.177	0.25	125	5.520
Dec	260.167	0.260	0.25	125	8.130
Total					83.614

4.8. Infiltration Trench

Thus, rainwater infiltration and retention techniques, such as rain gardens, infiltration trenches, infiltration basins, and permeable pavements, have emerged as means of reducing effective precipitation and assisting in water source control [19].

Building infiltration trenches is also one way of addressing groundwater conservation and environmental concerns. Water resource conservation efforts continue to be realized to meet the needs of living things that are always available and sustainable in sufficient quantity and quality, both at present and in the future [20].

Infiltration trenches are shallow excavated channels that have been filled with stone aggregate to create an underground storage reservoir. The purpose of the trench is to allow runoff to infiltrate into the ground as it enters the trench.

Infiltration trenches are stormwater management systems used to reduce the surface flow of stormwater and allow the water to infiltrate into the ground. Often used to address surface flow issues and increase water infiltration into the soil, infiltration trenches can help control erosion, improve water quality, and reduce flood risk.

In the HECRAS modelling, a 5-year period rainfall discharge of 254,350 m^3/s was entered, resulting in the following modelling:

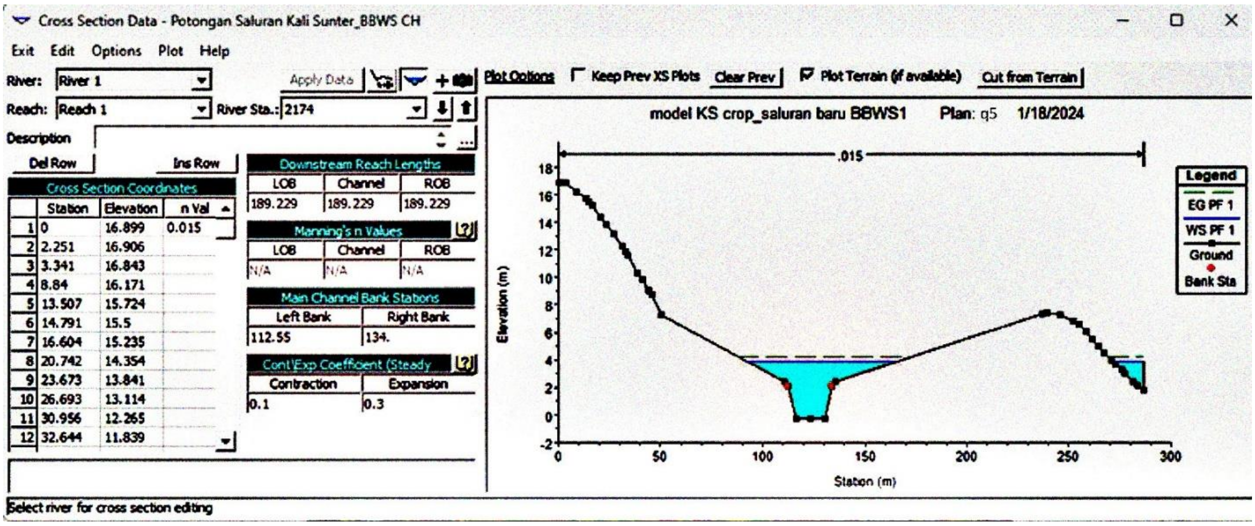

Figure 8.
River cross section.

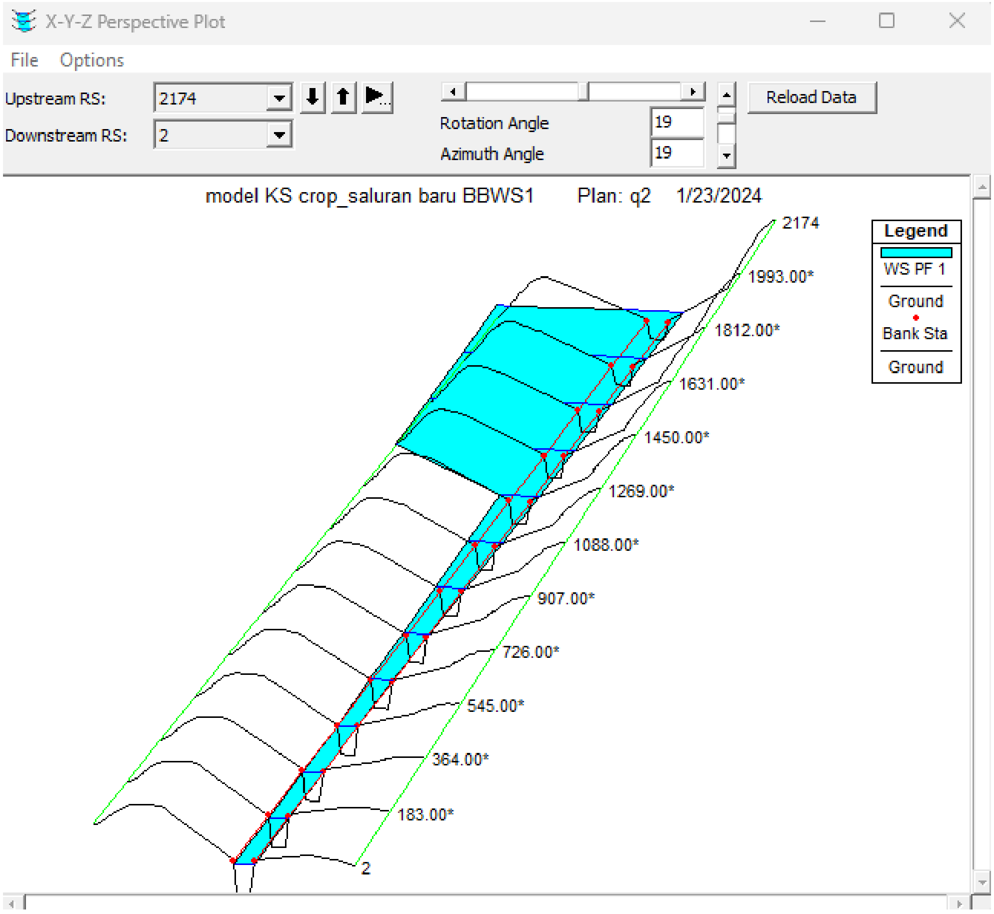

Figure 9.
Cross-section of x, y, z profiles modelled with 5-year return period.

It can be seen that the modelling in Fig. 9 with HECRAS obtained the possibility of flooding in the 5-year period of rainfall discharge.

In the channel design normalisation results by BBWS, obtained modelling with Q channel = 111,091 m^3/s. The magnitude of Q5 = 254,350 m^3/s, so that Q channel < Q5, then the discharge that overflows is 143,259 m^3/s. The plan to overcome the runoff of 143,259 m^3/s is to make infiltration trenches along the channel to absorb the runoff.

The design of infiltration trenches is as follows:

$$B = \frac{-\mathrm{fKT}}{nb\left\{\ln\left(1-\frac{fKH}{Q}\right)\right\}} \qquad (9)$$

B = ditch length (m)
b = width of ditch (m)
H = width of ditch (m)
f = trench geometric factor (m)
K= soil permeability coefficient (m/h) = 10^{-6} ((clay soil)
T = dominant duration of rain (hour)
Q = inflow water discharge (m^3/hour)
n = porosity of the material (the infiltration trench was filled with crushed stone (split) size 3 - 4 mm / porosity = 0.4)

$$200 = \frac{-2x\ X\ 10^{-6}\ X\ 4}{0{,}4x\left\{\ln\left(1-\frac{2x\ X\ 10^{-6}\ X\ 2{,}5}{143{,}259}\right)\right\}}$$

x = 2,86518 ≈ 3 m

Infiltration Trench Design Plan:
B (length of trench) = 200 m
H (trench height) = 2.5 m
b (trench width) = 3 m

The infiltration trench will be built at the starting point of the channel that experiences overflow according to the HECRAS model along 200 m with a planned depth of 2.5 m (approximately as deep as the existing channel by BBWS) and a Q of 143,259 m^3/s as shown in Figures 15 and 16.

4.9. Hybrid Infrastructure Design

An example is when wetland restoration is combined with engineering measures such as small levees for coastal flood protection. Other examples include bioswales, rain gardens, green roofs, and street trees installed in pavement tree pits, as well as other engineered ecosystem approaches [21].

The hybrid infrastructure system applied in the study area is a combination of green infrastructure and grey infrastructure. The infrastructure system is built right above the city drainage, in this case, the Sunter River, as shown in Fig. 10. Green infrastructure in the form of rainwater harvesting (RwH) and rooftop gardens (Gro) will collect and absorb rainwater that enters the roof where RwH and Gro are placed.

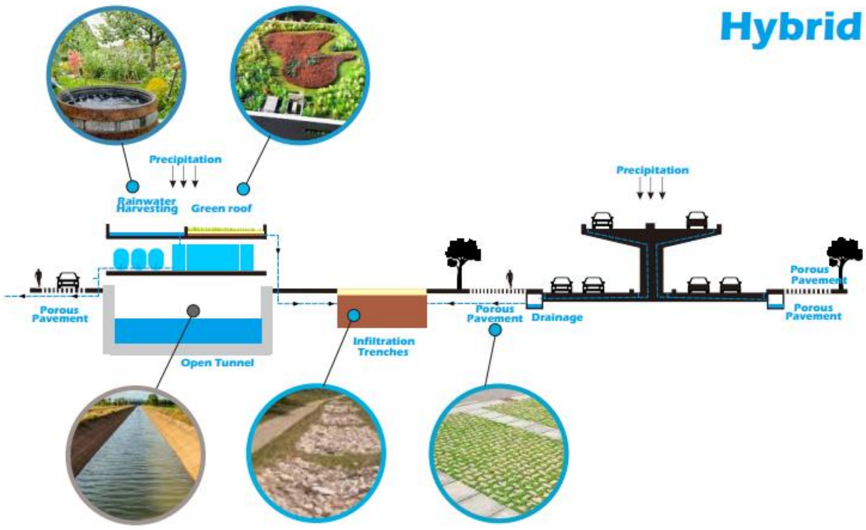

Figure 10.
Design Concept of Hybrid Infrastructure Applied.

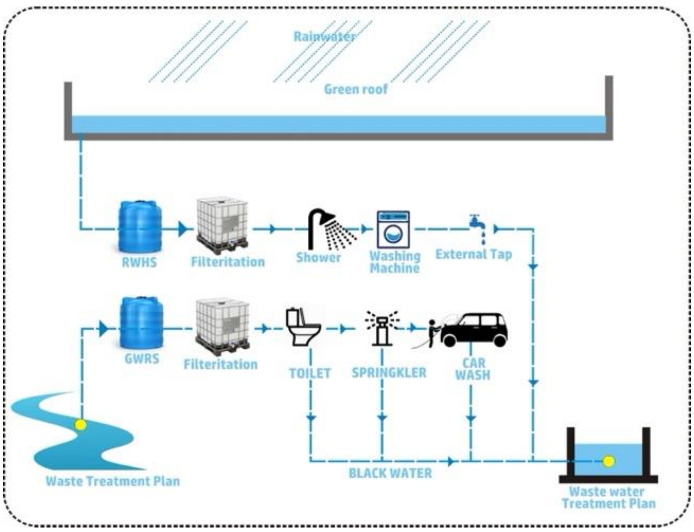

Figure 11.
Systematic process of hybrid infrastructure of rainwater harvesting and grey water.

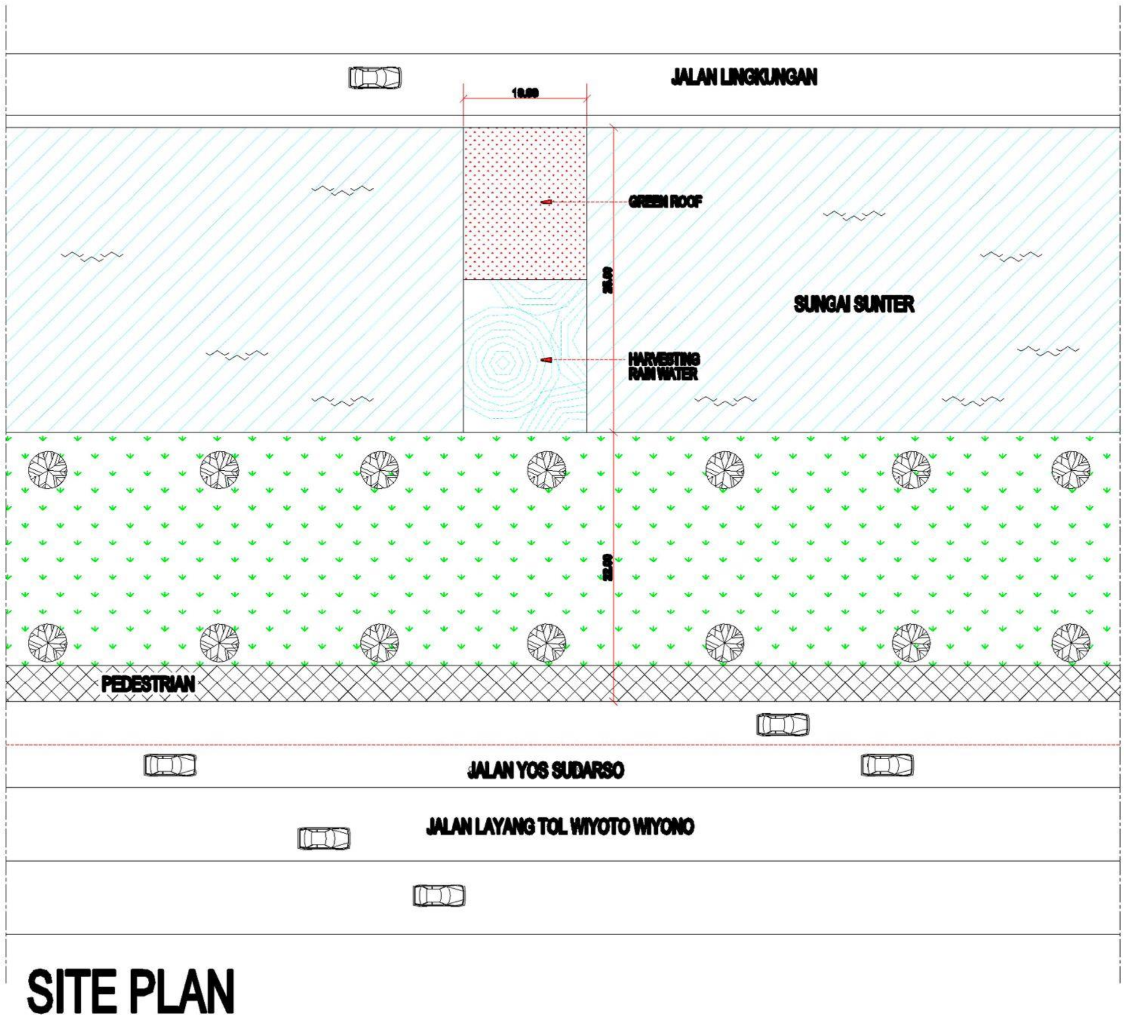

Figure 12.
Hybrid Infrastructure over the Sunter River.

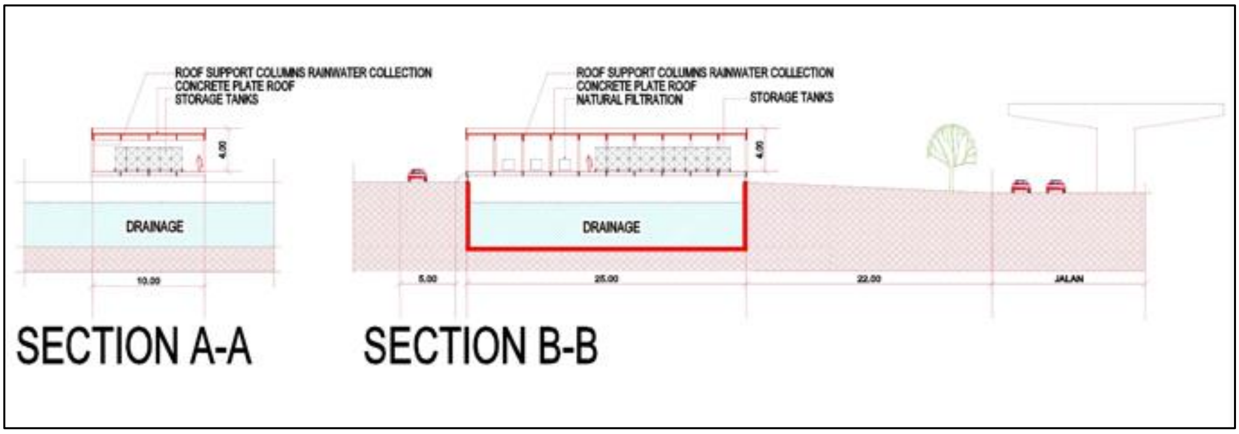

Figure 13.
Cross section Hybrid Infrastructure.

The planning of water reservoirs for RwH and GRo is mainly designed using fiberglass reinforced panel tanks with a knockdown system using bolt nuts. The bottom is reinforced using a slab structure and C-channel plate. The material is easily available; the price is quite economical and lightweight.

The module of water reservoir is 1m x 1m x 1m as shown in Figure 14. The Plan and perspective design shown in Figure 15 and 16.

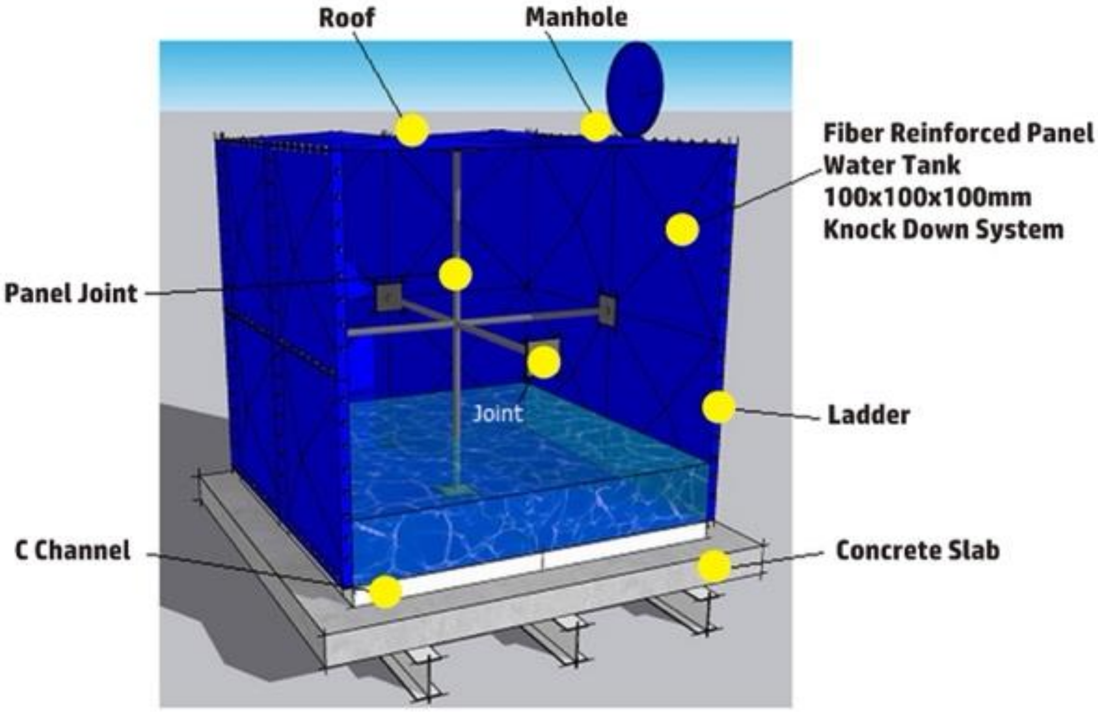

Figure 14.
Water Tank Reservoir Module.

In addition to green infrastructure, there is also a grey-green infrastructure system, namely infiltration trenches that are planned to be able to manage runoff from the Sunter River.

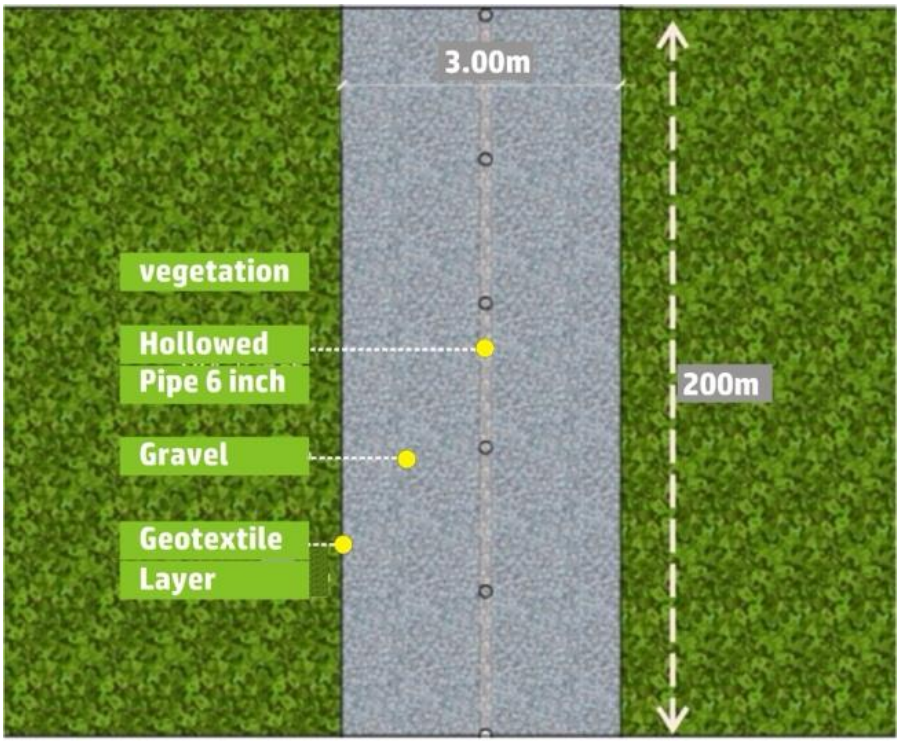

Figure 15.
Infiltration Trench Plan.

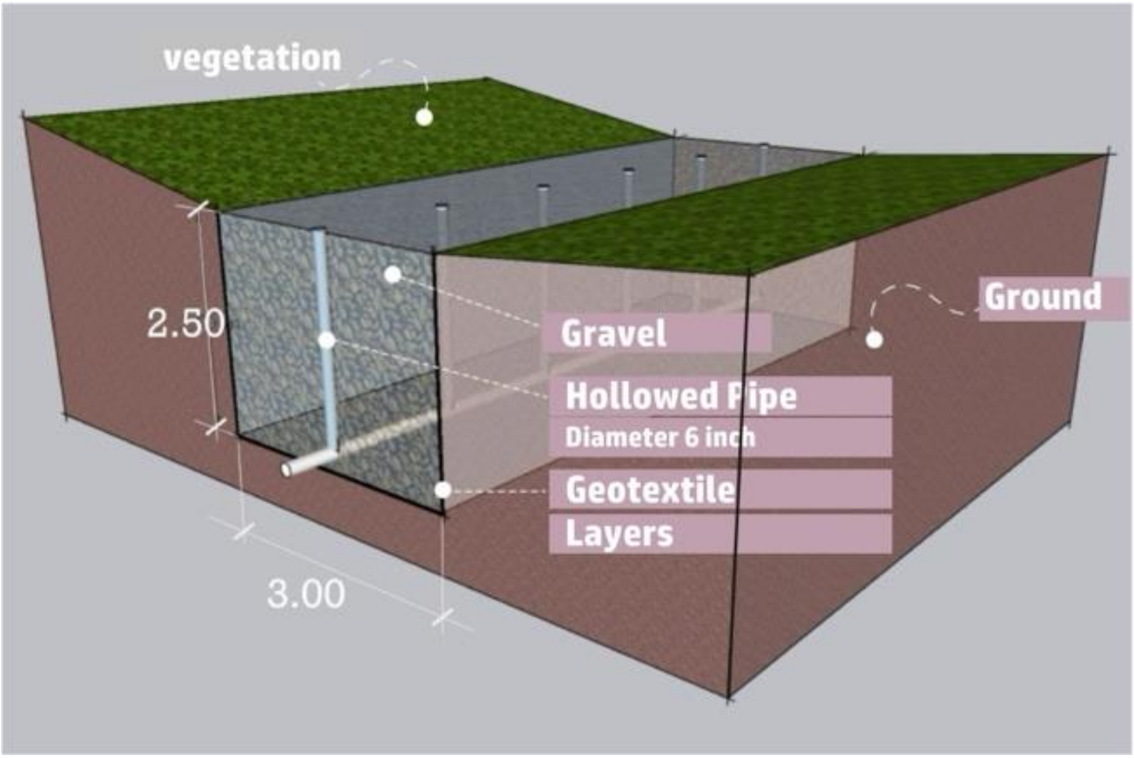

Figure 16.
Infiltration trench perspective.

5. Conclusion

With the hybrid system, the infrastructure offered shows that the rainwater that can be generated by RwH and GRo is 401,345 m^3/year. The average volume of harvestable rainwater on a hybrid infrastructure system is 2,107 m^3/day or 2.107 liters/day, 31.605 liters/15 days.

The number of reservoir tanks used is lined up according to the size of the elongated square room, as many as 6 pieces x 12 pieces and stacked 2 stacks up, so there are a total of 144 pieces or 144 m^3 = 144.000 liters. By calculating the volume of rainwater that can be captured with an average of 15 rainy days a year, the capacity of the water storage tank can still accommodate the amount of water.

The infiltration trench system will overcome runoff originating from the drainage channel, namely from the Sunter River, with a 5-year Q return period of 143,259 m^3/s, with a depth of 2.5 metres and a width of 3 metres.

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