Sustainable Infrastructure: Strategies & Initiatives
A Case Study for a Residential Project

By

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Project Supervisor:
Engr. Prof. Dr. Ishtiaq Hassan

BS CIVIL ENGINEERING

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DEPARTMENT OF CIVIL ENGINEERING
CAPITAL UNIVERSITY OF SCIENCE & TECHNOLOGY
ISLAMABAD, PAKISTAN

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Forwarded for necessary action.

Engr. Prof. Dr. Ishtiaq Hassan
(Project Supervisor)

Date: July, 2023

DEDICATION

This effort is devoted to our respected and cherishing parents, who helped us through each troublesome of our life and yielded every one of the comforts of their lives for our brilliant future. This is likewise a tribute to our best teachers who guided us to go up against the troubles of presence with ingenuity and boldness, and who made us what we are today.

DECLARATION

This report is a presentation of our assigned project work. Wherever commitments of others are included, each exertion is made to demonstrate this obviously, with due reference to the writing, and affirmation of communitarian project and exchanges. The work is carried out under the supervision of Engr. Prof. Dr. Ishtiaq Hassan, at the Capital University of Science and Technology, Islamabad, Pakistan.

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Date: July, 2023

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- We need to express our sincere thanks to Engr. Prof. Dr. Ishtiaq Hassan under whose direction the project was led. His direction was precious at each progression of this work. His outstanding showing aptitudes helped us get a handle on the topic rapidly. His collaboration at every single phase of our basic choices at Capital University has been significant.
- We thankfully recognize the affection and financial support received from our parents for BS studies.
- Last but not the least; we would mention our family and friends whose prayers have enabled us to complete this task.

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LIST OF ABBREVIATIONS

NSL	=	Natural Surface Level
FRL	=	Finished Reduced Level
PGL	=	Proposed Ground Level
RWH	=	Rainwater Harvesting
AASHTO	=	American Association of State Highway and Transportation Officials
PARAMP	=	Pervious All-Road All-weather Multilayered pavement
IL	=	Invert Level
ID	=	Invert Depth
SW	=	Storm Water
RWHT	=	Rainwater Harvesting Tank
PMD	=	Pakistan Meteorological Department
SD	=	Storm Drainage

LIST OF INTENDED PUBLICATIONS (If Any)

Referred Conference Articles

Intended Journal Article

Z. Sajid, B. Asif, T. Masood and I. Hassan. “Sustainable Infrastructure: Strategies & Initiatives- A case study for a residential project”. (Shengtai Xuebao/ Acta Ecologica Sinica) (2023)

Abstract

The growing concern for sustainable development has prompted the need for implementing sustainable infrastructure strategies and initiatives in various sectors worldwide. This research presents a comprehensive case study focused on sustainable infrastructure in a residential project located in Wah Cantt, Pakistan. The aim of this study is to analyze and propose sustainable strategies and initiatives for road design, storm drainage design, and rainwater harvesting The study begins with a thorough review of existing literature, policies, and guidelines related to sustainable infrastructure, focusing on road design, storm drainage systems, and rainwater harvesting techniques. This review provides a theoretical foundation for the subsequent analysis and recommendations.

For road design, the study explores the integration of geometric road design and sustainable forms of road pavement types. The majority of roads are profiled in such a manner that their cut and fill quantities are proportionate. The findings suggest that incorporating sustainable road design principles can enhance safety, reduce environmental impact, and improve overall mobility in residential areas. Regarding storm drainage design, the research investigates sustainable stormwater management practices, including green infrastructure solutions such as bioswales and permeable pavements. The proportion of collected stormwater of study area that can be reused is 45735 m^3. Furthermore, rainwater harvesting is examined as an effective technique for water conservation in residential settings. The study explores different rainwater harvesting systems, their design considerations, and their potential benefits in terms of water availability and usage efficiency. The total yearly amount of water that can be collected from this rainwater harvesting system is 45734700 litres (45735 m^3) in an average year

The outcomes of this research contribute to a deeper understanding of sustainable infrastructure strategies and initiatives applicable to residential projects in Wah Cantt and, more broadly, across Pakistan. The recommendations provide valuable insights for policymakers, urban planners, and developers seeking to implement sustainable practices in infrastructure projects throughout the country. By adopting sustainable road design, storm drainage systems, and rainwater harvesting techniques, Pakistan can move towards a more resilient and environmentally friendly built environment, fostering sustainable development for future generations

CHAPTER 1
INTRODUCTION

1.1 Background

Understanding what the term "infrastructure" means is necessary before one can comprehend what infrastructure engineering is. This phrase refers to all of the structures in place that sustain any size of the community, whether it be an apartment complex, a neighborhood, a city, or even an entire country. The set of facilities and procedures a nation, town, or other region utilizes to support its citizens, businesses, and other economic endeavors are referred to as its infrastructure. Infrastructure includes both private and public physical structures like roads, railways, bridges, tunnels, water supply, sewage systems, electrical grids, and internet access.

"Infrastructure encompasses not just these public works assets but also the operational procedures, management practices, and development strategies that interact with societal demand and the physical world to permit the transit of people and commodities, the provision of water for drinking, and a variety of other uses, the safe disposal of society's waste, the provision of energy where it is desired, and the communication of information within and between communities" (Council, 1987). Infrastructure has typically been characterized as the physical elements of interconnected systems that provide the goods and services necessary to enable, sustain, or improve society's living standards and preserve the environment.

Modern infrastructure discussions frequently center on sustainable development and green infrastructure, particularly in view of the significant social changes required to combat and adapt to climate change. The Sustainable Development Goals, especially Goal 9, "Industry, Innovation, and Infrastructure," have been devised by the international community in recognition of the importance of sustainable infrastructure.

Sustainability entails addressing our own needs without compromising the potential of future generations to do the same while maintaining a balance of economic growth, environmental care, and social well-being. Sustainability is considered a "standard notion." This might be exemplified as follows: "The goal of sustainability requires linking what is understood via scientific research to applications in pursuit of what people desire for the future (Harrington, 2016)."

The 1983 Commission on Environment and Development of the United Nations, also known as the Brundtland Commission, had a substantial impact on the modern usage of the term "sustainability." Sustainable development is defined in the 1987 report *Our Common Future* (also known as the Brundtland Report) as development that "meets the requirements of the present without compromising future generations' ability to meet their own requirements. The report contributed to mainstreaming "sustainability" and popularising the concept of "*Sustainable Infrastructure*" (Documents, 2022; Purvis et al., 2019).

The idea of sustainable infrastructure corresponds to systems and equipment that are intended to meet the vital service demand of the people, such as roadways, bridges, telephone piers, hydropower generation, etc., based on sustainable concepts. This also indicates that the infrastructure is eco-friendly from beginning to end, including financial, economic, cultural, and institutional considerations.

Pakistan's infrastructure has seen some progress over the last 50 years. For the majority of public infrastructure sectors, Pakistan's rate of development has been among the slowest among comparable countries. Due to the absence of the predicted economic boom, Pakistan's infrastructure is not being utilized to its full potential. People's lives are significantly impacted by Pakistan's relative lack of infrastructure by global standards. Freshwater availability, inadequate water, and sanitation facilities. Most importantly, the frightening population growth is exacerbating communities' issues. The lack of adequate infrastructure presents a challenge for the Pakistani government and its citizens.

Pakistan placed 67th in the area of basic infrastructure in the World Economic Forum Survey (2006–2007) of 125 nations. There has historically been an imbalance between the supply and demand for infrastructural development. Pakistan is ranked among the bottom 20 of the 144 world economies in the World Economic Forum's Global Competitiveness Report (GCR) 2012-2013. This paper claims that Pakistan lacks a long-term perspective on competitiveness (@UKEssays, 2022).

With the incredibly rapid growth of urban areas, particularly in developing nations, sustainable infrastructure in terms of *green infrastructure* is proving to be a more effective, productive, and eco-friendly alternative. Moreover, as stated by the World Bank, these facilities are more lucrative because they result in more dependable services, greater perseverance to severe weather events, and a reduced influence of natural catastrophes on the population and the economy.

Green infrastructure is a network that provides the "components" for addressing urban and climatic concerns by incorporating natural elements into construction. The main elements of this strategy are stormwater management, climate adaptation, rainwater harvesting, increasing biodiversity, sustainable water supply, more excellent air quality, sustainable drainage designs, and clean water, in addition to more humanistic functions, such as improved quality of life through the provision of green spaces as rainwater collection points.

Road design, stormwater drainage design, and rainwater harvesting are the targeted areas in this study for sustainable infrastructure development; all of these areas will be based on the concept of green infrastructure.

1.2 Project Motivation & Problem Statement

Pakistan is highly vulnerable to climate change and natural catastrophes directly affecting its infrastructure. Throughout the years, natural disasters like earthquakes, typhoons, floods, and water shortage have been significant causes of unsustainability. Pakistan is facing an acute water shortage due to being declared a water-scarce country. So, a sustainable strategy should be implemented at the planning and design phase of infrastructure including roadways, water supply, and stormwater drainage systems and also the concept of Rainwater Harvesting (RWH) should be adopted. RWH is a profitable plan that may assist in overcoming water scarcity challenges, land degradation, and flooding.

Sustainable/Green infrastructure can help lessen the catastrophes discussed and meet the infrastructural requirements of the present without compromising future generations and this concept is more effective, productive, and an eco-friendly alternative.

1.3 Overall Goal of Project Program and Specific Aim of BS Project

This dp falls under the umbrella of "WE R". This group carries out projects and research related to sustainability in the domains of water resources, climate change, environment and infrastructure.

The specific aim of this DP is to adopt strategies and initiatives towards the sustainable development and design of roads, stormwater drainage system and also adopting the techniques of Rainwater Harvesting (RWH) to overcome water scarcity challenges, land degradation, and flooding.

1.4 Scope of Work and Study Limitations

Scope of Work includes road design, stormwater drainage design, and rainwater harvesting, these are the targeted areas in this study for sustainable infrastructure development; all of these areas will be based on the concept of green infrastructure.

1.5 Methodology

Refer to section 3.8 for brief methodology.

1.6 Project Layout

This report comprises of the chapters listed below:

- ❑ **Chapter 1**

This chapter of the report contains the introduction. The sub-sections include background, project motivation, general project objective, work scope and study limitations, and a brief methodology.

- ❑ **Chapter 2**

This chapter of the report includes the literature review. The sub sections consist of sustainable road pavement design and strategies, stormwater drainage and rainwater harvesting.

- ❑ **Chapter 3**

This chapter of the report includes the methodology. The sub sections consist of the design method and calculation steps followed for road, storm water drainage design and rainwater harvesting with focus on sustainability of a society situated in WahCantt.

- ❑ **Chapter 4**

This chapter of the report includes the results, findings and discussions of the adopted methodology in chapter 3.

- ❑ **Chapter 5**

This chapter of the report contains the conclusion and recommendations in light of the findings and discussions presented in Chapter 4.

CHAPTER 2

LITERATURE REVIEW

2.1 General

The term "sustainable infrastructure" refers to the planning, development, and operation of physical systems that are meant to meet the demands of society while minimising negative consequences on the environment and promoting social and economic well-being. In other words, sustainable infrastructure aims to be both environmentally and socially responsible. It entails the adoption of practises and technology that maximise resource efficiency, increases the lifespan of structures and facilities, reduces greenhouse gas emissions, supports climate resilience, and enhances the overall quality of life (Song & Wu, 2021). This research project focuses on the creation of sustainable infrastructure in terms of the design, construction, and maintenance of physical systems such as roads, stormwater drainage, and rainwater harvesting system that minimize their environmental impact, promote resource efficiency, improves the quality of life of current people and also preserving the resources for the future and support long-term social and economic development.

Sustainable road infrastructure involves considering environmental, social, and economic factors throughout the life cycle of road construction and maintenance. Incorporating designs that minimize environmental disruption, preserve natural habitats, and consider the needs of pedestrians, cyclists, and public transportation users (Ignaccolo et al., 2022). Sustainable stormwater drainage systems aim to effectively manage and mitigate the adverse effects of stormwater runoff while promoting environmental stewardship includes Implementing strategies to conserve water, such as rainwater harvesting and reuse, and promoting water-efficient landscaping practices to reduce the volume of stormwater runoff, flood resilience and erosion control (Rosenberger et al., 2021). Sustainable rainwater harvesting involves capturing and utilizing rainwater for various purposes, minimizing reliance on freshwater sources. Key aspects of sustainable rainwater harvesting systems include Collection methods i.e. Implementing rainwater collection systems that capture runoff from rooftops, paved surfaces, and other catchment areas, utilizing harvested rainwater for non-potable applications, such as irrigation, toilet flushing, and industrial processes, reducing the demand for freshwater resources (Gómez-Monsalve et al., 2022).

Overall, sustainable infrastructure for roads, stormwater drainage, and rainwater harvesting focuses on minimizing environmental impacts, optimizing resource use, enhancing resilience to climate change, and promoting the well-being of communities both in the present and the future. All three aspects are discussed in detail in the approaching sections.

2.1.1 Road Network Design

The elimination of stormwater from roadway surfaces has become vital for several reasons, including the protection of pavements from water-prompt deterioration; to decrease in road fatalities linked with splashing and spraying of road water; to prevent road accidents linked to decreased friction coefficient produced by road water, and to minimize road accidents related with hydroplaning resulting due to road water. Therefore, removing stormwater from impermeable lands and road surfaces became a fundamental aspect of town planning and road design (Ndon, 2017). Following sections contain detail aspects, strategies and design approaches towards the sustainable development of roads.

2.1.2 Systems and Classification

For communication between engineers, administrators, and the broader population, roadways must be divided into several operating systems, functional categories, or geometrical types. Different classification methods have been used in various rural and urban places for various goals. The most useful method for highway location and design procedures is to categorise highways by design categories based on the main geometric elements (such as freeways, normal streets, and highways) (Forbes, 1999). For traffic operations, grouping by route numbering (e.g., U.S., State, and County) is the most beneficial method. The administrative classification system is used to identify the tiers of government in charge of and the means of financing highway facilities (e.g., National Highway System or Non-National Highway System). For the purpose of transportation planning, functional categorization, or the grouping of roadways by the type of service they offer, was created. Functional classification is a crucial planning technique in the process of thorough transportation planning, which is a crucial component of overall economic and social development (aboutcivil.com, 2022). The policies outlined in this article are congruent with the rise of functional categorization as the primary method of classifying roadways.(AASHTO, 2011)

Streets and highways are grouped using functional categorization according to the type of service they are designed to offer. This categorization takes into account the fact that individual streets and roads cannot independently service travel. Instead, the majority of travel includes moving via road networks and may be categorised by how it interacts with these networks in coherent and reasonable ways. As a result, categorization of travel and functional classification of highways and streets are uniform.(AASHTO, 2011; Van HIEP & SODIKOV, 2017)

A diagrammatic illustration of this functional classification is shown in Figure 2.1. In Figure 2.1, lines of travel are straight lines linking the origin and destination (circles) of a trip. The lane widths represent the varying levels of travel desire. The diameters of the circles represent the density of destinations. Trips should be channelized on a small road network in the way depicted in Figure 2.1 since it is difficult to offer connections for every demand line. Smaller movements are directed into relatively indirect channels whereas massive travel movements are supplied directly or almost so. According to (Baerwald, 1970) Local access, collector, and arterial are words used to explain the functional connections between the facilities in Figure 2.1. The hierarchy of travel distances provided by the network is observed to be connected to the functional hierarchy in this system.(AASHTO, 2011)

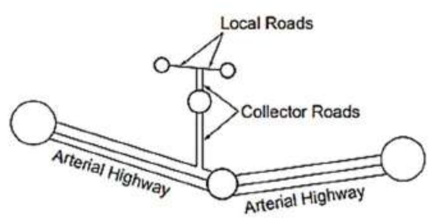

Figure 2. 1: Functional classification of roadways (AASHTO, 2011)

Density and forms of land use, density of roadway and highway networks, nature of traffic patterns, and the relationship between these factors are fundamentally different in urban and rural locations. As a result, different categories exist for rural and urban functional systems. For urban and rural locations, the functional systems' roadways are different. Principal arterials (for main movement), minor arterials (distributors), collectors, and local roads and streets make up the hierarchy of functional systems; however, in urban areas, there are comparatively more arterials with additional functional subdivisions of the arterial category, whereas there are comparatively more collectors with additional functional subdivisions of the collector category in rural areas (Brindle, 1996). Urban primary arterials, minor arterials, collectors and local streets are the four functional highway networks for urbanized regions. The nature and degree of development in rural and urban regions varies, which justifies different features of the urban system in comparison to the correspondingly titled rural system.

There are only local roads in the study area of this design project and as per AASHTO Geometric Design of Highways and Streets, all amenities not included in one of the higher systems are included in the urban local street system. It mainly allows links to higher tier networks and direct access to adjacent territories. It provides the least amount of mobility and typically has no bus lines. Typically, service to through traffic flow is purposefully prohibited.

2.1.3 Highway Design Elements

The design of highway is broadly divided into two categories; geometric and Structural design. Both types of design are discussed in detail in the following paragraphs:

(I). Geometric Design

The sizes and configurations of a road's visible elements are referred to as its geometric design. A highway or street's alignment has a significant impact on the surrounding area, the community, and the highway user. The alignment is consisting of a number of design components that work together to produce a structure that serves traffic safely and effectively, in line with the structure's intended use. To establish a consistent, secure, and effective design, each alignment component should complement the others(Veer et al., 2018). Several key design components are shared by all classifications of highways and streets. Sight distance, superelevation, broadening of travelled ways, gradients, horizontal and vertical alignments, and other geometric design components are among them.(AASHTO, 2011)

According to (Baerwald, 1970); alignment, profile, and cross-section are the three fundamental components of geometric roadway design. When combined, they give a roadway a three-dimensional layout.

- The alignment is the path taken by the road, which is represented by a collection of horizontal curves and tangents.
- The road's profile is its vertical aspect, which includes its crest and sag curves as well as the parallel grade lines that connect them.
- The cross section displays the details, and cross slope or banking of the road. Additionally, cross sections display pavement structure, drainage features, and other non-geometric design elements.

Following are the two aspects of geometric design of roads:

a) Horizontal Alignment

(AASHTO, 2011) states that in the design of roads, horizontal alignment consists of circular horizontal curves joining straight portions of road known as tangents. Radius (tightness) and deflection angle are the parameters that form circular curves. Designing a horizontal curve requires the determination of a minimum radius (based on speed limit), length of curve, and obstructions in the driver's field of vision. (J. & Taylor, 2011) states that in any geometric roadway design for horizontal alignments, location of curve; sharpness of curve; length of tangents; and their relationship to the vertical profile should be taken into account. Designing a horizontal curve is based on physical rules and how a driver will react to lateral acceleration. According to (*Horizontal Curve Safety - Safety | Federal Highway Administration*, 2022) horizontal curves permits us to change the direction or alignment of the road (as opposed to vertical curves, which change the slope). A horizontal curve is linked to more than 25% of fatal collisions, and roadway departures account for the great majority of these collisions. In comparison to other types of roadway segments, the average crash rate for horizontal curves is around three times higher. Approximately 75 percent of fatal collisions involving curves involve a single car leaving the road and colliding with trees, utility poles, rocks, or other stationary objects, or flipping over.

Figure 2. 2: Horizontal alignment of roads (*Geometric design of roads - Wikipedia*, 2022)

The study area for our research project is totally flat i-e there is no hilly area and the study area is also developed as per the masterplan, so, horizontal alignment is not applicable in our project.

b) Vertical Alignment

The term "grade line," "profile," "long section," or simply "long section" refers to a road's vertical alignment (J. & Taylor, 2011). (Veer et al., 2018) articulates that the profile consists of straights, or grades, joined by curves. These curves, known as vertical curves to distinguish them from horizontal curves, are defined by two parameters, which are:

- a comfort element that facilitates a seamless transition from one grade to another.
- a safety measure ensuring that motorists have a safe viewing distance along the whole vertical curve.

Therefore, the profile serves as a reference point for determining the elevation of the pavement and other road features. (AASHTO, 2011) states that factors to be considered in the development of a profile include:

- topography
- road type
- horizontal alignment
- sight distance
- drainage
- heavy vehicle operational characteristics
- appearance.
- land purchase and construction costs
- cultural developments

The roadway's geometric layout should be in line with the highway's intended functional classification and accommodate the needs and characteristics of all of its users (Engineers, 2022).

Curves are important to be provided in both the horizontal and vertical alignments, so following write up clarifies concepts of curves related to road / highways design.

c) Curves

Road curves are unusual bends that cause a graduation in direction. Canals and railroads both have corresponding curves. Horizontal curves are defined as curves that are delivered in the horizontal plane and are typically circular or parabolic. Vertical curves are curves that are offered in the vertical plane. As, in study area of this design project, only vertical curve lies, so, generally there are two types of vertical curves on roads, as explained below.

i. Sag Curve

According to (Wang et al., 2015), The sag curve, often referred to as the valley curve, rises and then descends as illustrated in figure 2.3. They are situated at the base of hills. It is the opposite of the summit (crest) curve. Sag vertical curves connect falling grades by producing a bowl or a sag; for this reason, the curve's convexity is frequently downward in this situation (constructor.com, 2018).

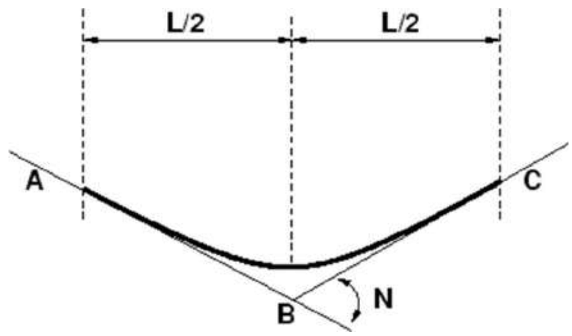

Figure 2. 3: Sag vertical curve (constructor.com, 2018)

ii. Crest Curve

Also called the summit curve, this curve rises and then dips down as illustrated in figure 2.4. Mainly situated at the peak of hills. The opposite of valley curve(Wang et al., 2015) . Crest curve connects the descending and ascending gradients and hence, the curve has its convexity upwards (constructor.com, 2018).

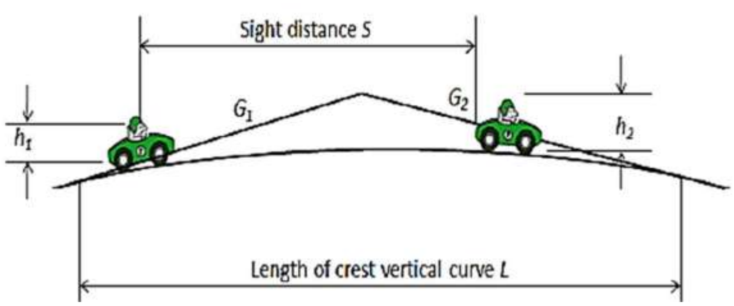

Figure 2. 4: Crest vertical curve (Zilioniene & Vorobjovas, 2011)

d) Design Speed

Design speed is another key consideration in road / highways design. (J. & Taylor, 2011) states that roadway design includes design speed as one of its major controls. AASHTO defines it as "the highest safe speed that can be maintained over a specific segment of roadway when conditions are sufficiently favorable that the highway design features govern". (Choi et al., 2013) articulates that a key design consideration in roadway design is design speed, which may be equal to or greater than the statutory speed limit. The level of service has a direct impact and a direct relation to the facility's design speed. It must fulfil drivers' expectations and be appropriate for the location and functional classification of the roadway. According to (Krammes, 2000), a crucial decision that should be made at the start of the planning and design process is choosing the design speed of a roadway. With respect to potential environmental quality, economic, social, and political implications, this speed should strike a balance between safety, mobility, and efficiency. The design speed has a direct impact on elements of road design such curve radii, super elevation, and sight distance. Additionally, parameters not directly connected to design speed could also be affected. Therefore, any adjustments to design speed may have an impact on a variety of roadway design components.

(Garber & Gadiraju, 1989) sates that the the design speed for rural roads should be as high as is practical to provide the highest level of safety and operational effectiveness. Studies have demonstrated that drivers can work relatively well at speeds higher than those used in standard design. Lower speed designs for metropolitan areas could be appropriate for some locales (residential streets, school zones, etc.). The use of traffic calming strategies has been shown to be an effective way to manage traffic in residential areas. Urban arterials should be designed to balance safety (pedestrians, driveways, parking, etc.) and high speed.

Table 2.1 shows the corresponding design speeds in metric and U.S. customary units in 10-km/h (5-mph) increments. *The type of terrain of the study area of this research study is level and the design speed adopted is 50 km/h.* This table should be used in converting the units of measurement of design speeds.

Tabel 2. 1: Corresponding Design Speeds for local rural roads in Metric and U.S. Customary Units (AASHTO, 2011)

	Metric						U.S. Customary					
	Design Speed (km/h) for Specified Design Volume (veh/day)						Design Speed (mph) for Specified Design Volume (veh/day)					
Type of Terrain	under 50	50 to 250	250 to 400	400 to 1500	1500 to 2000	2000 and over	under 50	50 to 250	250 to 400	400 to 1500	1500 to 2000	2000 and over
Level	50	50	60	80	80	80	30	30	40	50	50	50
Rolling	30	50	50	60	60	60	20	30	30	40	40	40
Mountainous	30	30	30	50	50	50	20	20	20	30	30	30

2.2 Green/Sustainable Infrastructure Applications & Approaches for Road Design

(James & Von Langsdorff, 2003) investigated the best possible way to construct environment friendly and sustainable road infrastructure that is aappropriately designed interlocking concrete block pavers to be used on the surface of roads instead of typical rigid or flexible pavement techniques as illustrated in figure 2.7 and figure 2.8.

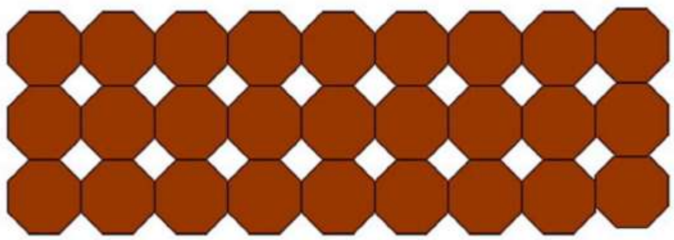

Figure 2. 5: Schematic of concrete paver blocks (permeable paving stone pavement) (James & Von Langsdorff, 2003)

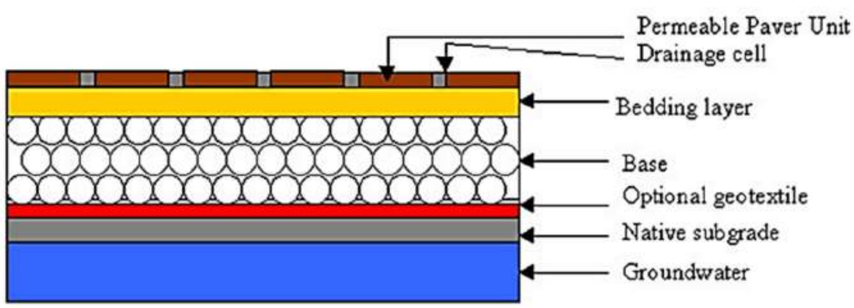

Figure 2. 6: Sectional view of permeable concrete blocks paving stone pavement (James & Von Langsdorff, 2003)

Appropriately designed interlocking concrete block pavers allows water to seep into the subsurface layers, by allowing this concrete block paving may lessen the quantity of contaminants that enter receiving waters. Stormwater can swiftly permeate permeable pavement to reach a high-void aggregate base layer, creating a detention reservoir as illustrated in figure 2.8 and figure 2.9. The gathered runoff is held in this reservoir until it either seeps into the underlying subgrade or is sent to a typical stormwater conveyance through a perforated underdrain system. When creating roadways, parking lots, and other areas where regular pavement is typically used, a permeable pavement can be used as a sustainable alternative.

Figure 2. 7: Permeable concrete pavers for road surfacing (paving stone pavement) (Maty, 2022)

The primary benefit of permeable concrete block paving stone pavements is its capacity to mimic the flow reduction and water quality improvement characteristics of natural surfaces and vegetation. Their capacity to lower the amount of overland flow reaching receiving waters, hence lowering peak flows in rivers and streams, is another significant benefit (James & Von Langsdorff, 2003; Legret et al., 1996; Pratt et al., 1989). When comparing the effectiveness of permeable concrete block and stone pavements with that of conventional pavements , (James & Von Langsdorff, 2003; Pratt et al., 1989) found that the discharge rates from permeable pavements were considerably lower (only 30% of the peak rainfall rate) and the time of concentration was longer (5 to 10 minutes, compared to 2 to 3 minutes for traditional pavements). As they closely resemble the pollutant-removal qualities of natural soil, permeable pavements also demonstrate good features for removing pollutants.

(James & Von Langsdorff, 2003; Legret et al., 1996) showed that in permeable pavement installations, heavy metals (Pb, Cu, Cd, and Zn in particular) collected at the surface of drainage cells as well as at the geotextile layer underlying the base material as shown in figure 2.8. The mechanism also prevented heavy metals from moving farther into the subgrade beneath the pavement (less than 15cm in the investigation by [26]). Additionally, permeable pavements offer the necessary surface roughness for enough depression storage to control pollutants before they wash off (Balades et al., 1995).

Additionally, permeable pavement can be installed to efficiently remove water from the driving surface and lessen hydroplaning (Chandrappa & Biligiri, 2016). Also, open aerated pavement is clearly safer than impervious heavy pavement where subterranean explosive gases are a hazard (James & Von Langsdorff, 2003).

2.2.1 Pervious All-Road All-weather Multilayered pavement (PARAMP)- A Sustainable approach

(Singh et al., 2022) in his study proposed Pervious All-Road All-weather Multilayered pavement (PARAMP) system based on pervious concrete pavement (PCP) systems, which have gained acceptance as sustainable alternative to conventional materials. His research's main goal was to create a pavement system that outperformed conventional PCP in terms of structural and hydrological performance while also measuring the energy used, the amount of GHG (Green House Gases) created, and the expenses involved in its design and installation. Thus, a Pervious All-Road All-Weather Multilayered pavement (PARAMP) was envisioned and designed. It comprised of 300 mm square paver blocks constructed with a 60 mm lower structural layer on top of a 30 mm water-draining surface wearing course pervious concrete layer. The main characteristics of PARAMP products included porosity ranging from 17 to 24 percent, permeability from 0.77 to 1.33 cm/s, and flexural strength between 4.83 and 6.13 MPa, showing their better structural and hydrological performance in comparison to conventional designs. Further, a comparative study of PARAMP and Portland cement concrete (PCC) pavement was carried out using a cradle-to-gate lifecycle approach. Comparing PARAMP products to PCC blocks of same dimensions, the PARAMP products used less energy (8.22 to 8.51%) and released fewer greenhouse gases (8.23 to 8.43%). Additionally, PARAMP blocks were almost 10% lighter and 10% cheaper than PCC paver blocks.

A sustainable class of roadway materials, PARAMP blocks are indicated by the decrease in GHG emissions, energy use, and capital expenses. Additionally, PARAMP strength and permeability magnitudes suggest that they have a great potential for use in a variety of road classes and weather circumstances (Chandrappa & Biligiri, 2016; Singh et al., 2022).

2.2.2 Pervious Concrete- A Sustainable Approach

(Debnath & Sarkar, 2020) in his study articulates that Due to the development of the sustainable drainage system, pervious concrete has emerged as one of the best management models for successful stormwater management strategy and has aided as a key strategy for "green approach" in runoff management (SUDS) (Scholz & Grabowiecki, 2007). Compared to the conventional impermeable pavements, this approach dramatically lowers the volume of stormwater runoff and lower the peak flow rates from the urban catchments. According to studies, pervious pavements can reduce a street's effective imperviousness by 42 % and its runoff volume by up to 70-98 % ((Collins et al., 2008; Dreelin et al., 2006; Rankin & Ball, 2004)). Due to this high rate of infiltration, pervious concrete supports groundwater recharge, reduces the salinity of the water, and improves the water quality and as a result preparation of large detention basin and laying of bigger sewer pipes has also become obsolete. The infiltrated water can be directly passed through subgrade for groundwater recharge or can be stored in an aquifer Because of the high rate of infiltration, pervious concrete helps to recharge groundwater, lower salinity levels, and enhance water quality; as a result, the need for huge detention basins and larger sewer pipes is no longer necessary. The infiltrating water can be used for agricultural purposes, animal feeding pads, or manure storage facilities. It can also be immediately conveyed through the subgrade for groundwater recharge or stored in an aquifer.

2.2.3 Watershed Driven Highway Design

(Nusa et al., 2015) in his study proposed a sustainable/Green approach towards the development of roads and highways. The act of minimising runoff from a highway or, to put it another way, purifying the runoff water and redirecting it to a location where the water can penetrate into the ground water table, is known as watershed driven storm water management (Authority, 2010). *Bio-slopes, bio-swales, bio-retention cells, permeable pavers, vegetated filter strips, and street trees* are a few examples of watershed-driven storm water management technologies used in highway construction. These technologies are widely used in the United States, and the initiative to develop suitable but still economical with a proper design and analysis for storm-water management and treatment alongside the highway (Nusa et al., 2015).

2.2.4 Recycle, Reuse and Renewable

Utilizing recycled materials made from industrial by-products not only dramatically lowers the energy used to build a roadway and the amount of greenhouse gases it emits, but it also lowers the cost of building a highway overall (Authority, 2010). It has been demonstrated in European nations that the high tax rate for virgin material pits necessary for highway building lowers the quantity of waste material from highway construction ending up in landfills (Nusa et al., 2015). Reusing, recycling, and using renewable resources in the construction of highways also helps to save water, cut carbon emissions, and clean the air (Liu et al., 2017).

2.2.5 Green Highways-Provision of Green Spaces as Recharging wells

(Talati et al., 2013) claimed that provision of green spaces on road sides is significant in reducing the storm water runoff from a highway as well as treating the runoff by natural ways. Green spaces for storm water management is the technique for holding and treating the runoff produced by a highway and retain it so that it can infiltrate to the ground water table, in this way the ground water table recharges naturally. Green spaces as recharging wells and rainwater collection points helps the society in both ways, first by avoiding the accumulation of stormwater which causes flood and secondly in infiltrates in to the ground water resulting in the natural recharge of ground water table.

The suitable methodologies for provision of green spaces for storm water management have to be evolved considering the present practices. In the USA, green spaces are created using a variety of technologies, including bio-retention (landscape designed to remove silt and pollution from surface water runoff), pervious pavement shoulders, environmentally friendly concrete, forest buffers, restored and storm water wetlands, stream restoration, soil amendments, and wildlife crossings. Researchers must pay attention to the topic of watershed-driven storm water management and green spaces since it is continually evolving (Barua et al., 2021).

2.3 Stormwater Drainage System

(Holm et al., 2014) states that the usage and control of stormwater runoff is known as stormwater management. It includes runoff planning, collection, storage, and movement of stormwater. Its primary goal is to create a sustainable community while limiting the demand on the public and preventing floods and infrastructure damage. It improves the quality of life and reduces flood threats. Large portions of urbanized regions have impermeable surfaces that prevent water from penetrating the soil. These surfaces significantly enhance runoff and the rate at which it enters rivers and lakes. (Nanía et al., 2015; Teshome, 2020) articulates that stormwater management is a process for controlling the quality and amount of runoff that involves institutional and technological elements. (Guo & Zhuge, 2008) in their study shows that calculating runoff volume frequency distribution and peak discharge rate is unique in its own kind. (Petit-Boix et al., 2015) also supports that it plays a major role in preventing floods. According to (Teshome, 2020) it aids in managing issues caused by the imperviousness of urban areas, such as decreased groundwater recharge, frequent floods, instability of stream channels, and infrastructure damage. (Torgersen et al., 2014) proposed that stormwater sewer, sock ways and collection in storage tanks are the basic ways of disposing of rainfall. Proper attention should be given to drainage and sewerage system to prevent urban flooding. The complex increasing factors of flooding need a change from a conventional drainage system to a sustainable one. (Sharma, 2008) suggests a sustainable urban drainage system (SUDS), SUDS is an idea to minimize the effect of urbanization using natural systems that are cost-effective and have a low impact on the environment.

2.3.1 Sustainable Design Approach

According to (Yunianta & Setiadji, 2019) the sustainable drainage system in urban areas helps to manage surface water runoff to overcome problems like an inundation, flooding and drought. Drainage systems that directly drain water towards eco-drain are preferred over conventional drainage systems with the passage of time. (Yunianta & Setiadji, 2018) in his study, explained that eco-drain works on the principle of improving water quality and reducing drainage loads in drainage systems. He proposed a rectangular Drainage Channel (U-ditch) design model with a structure made of precast concrete with a width of 90 cm, a height of 140 cm, and a length of 100 cm, with a wall thickness of 10 cm. At the bottom of the channel is a water storage room with a height of 20 cm and a width of 70cm, and a 10 cm thick channel bed. The infiltration well structure is made of circular shape concrete with a diameter of 0.8 meters, a depth of 1 meter and a wall thickness of 0.1 meters. The depth of infiltration, wells are 3 meters or 3 concrete, as shown in figure 2.8.

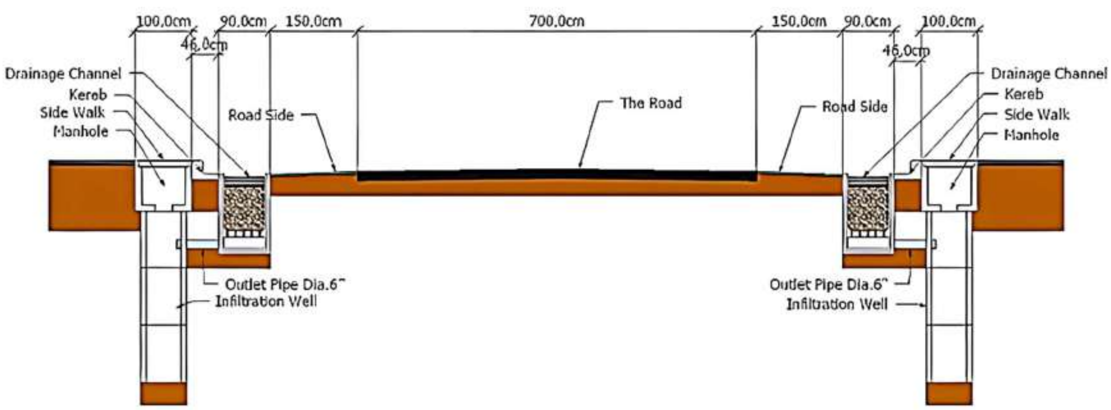

Figure 2. 8: Cross section showing drainage design (*Stormwater Drainage Conveyance Systems (Non-BMP related) General Design and Construction*, 2023)

a) Design Criteria

According to (Sheng, 1990), a road drainage system must satisfy two main criteria if it is to be effective throughout its design life:

1. The natural drainage pattern must be disturbed as little as possible.
2. It must drain surface and subsurface water away from the road to minimize excessive water buildup in potentially unstable regions and subsequent erosion downstream.

(*Stormwater Drainage Conveyance Systems (Non-BMP related) General Design and Construction*, 2023) asserted that all drainage systems shall be designed and sized based on the project's conditions, keeping in mind future needs. It shall be designed to convey stormwater runoff from onsite, offsite, or a combination of these sources. The design should divide the existing drainage to the greatest extent possible. (Teshome, 2020) states that close conduit/Closed channel consists of underground pipe as shown in Figure 2.9 and flows normally occur under pressure. Open channels, however, need frequent cleaning and are also a source of air pollution when the flow is stagnant. Moreover, Open channels generate safety risks to residents and traffic as well.

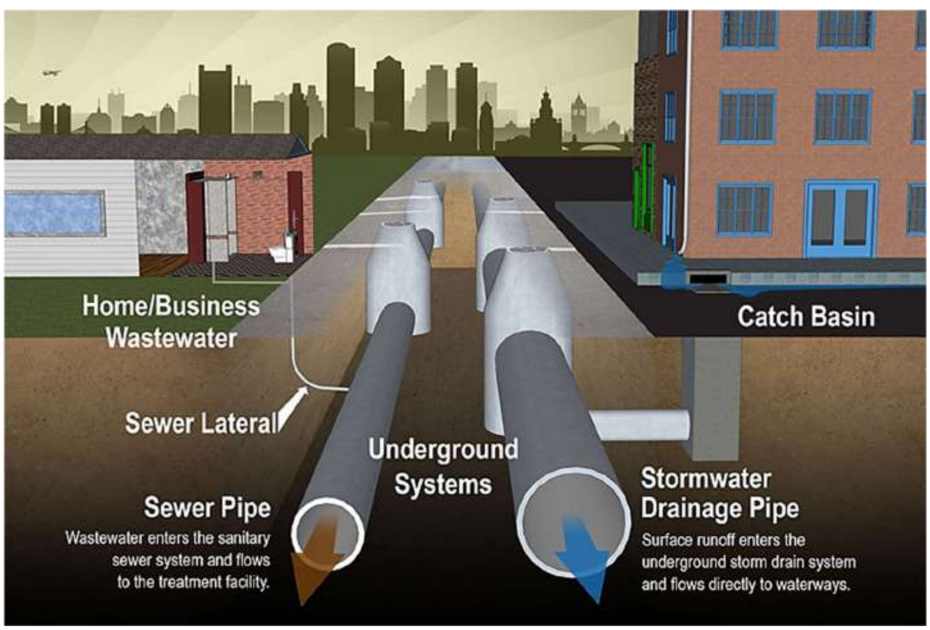

Figure 2. 9: Stormwater flowing through underground closed pipe system (*Stormwater Drainage Conveyance Systems (Non-BMP related) General Design and Construction*, 2023)

b) RCC Pipes

Different types of pipes are used for drainage worldwide. It varies with materials like PVC & RCC pipes. PVC is a thermoplastic material that is generally a good storm sewer drainage material because it is less costly to purchase. It often needs more backfill to ensure the performance of the pipe. (Bınıci et al., 2012) articulates that the usage of RCC pipes in stormwater drainage design is cost-effective, long-lasting, uses less energy during production, and can be made anywhere. RCC pipes are frequently used in sewerage and stormwater systems, overground irrigation facilities, water transmission lines, water tanks, water towers, pumping lines, pumping stations, and water structures. Moreover, RCC pipes sustain the lateral gravity load of soil to the maximum extent and prevent it from collapsing. RCC pipes shall conform to ASTM C-76-08.

c) Runoff Estimation

The runoff estimation is determined using the rational method.

i. Rational Method

The rational method was originally proposed by (Mulvany, 1850). Different methods are used to calculate runoff estimation, like SCS, Hydrograph, etc. The rational method is widely used to calculate runoff estimation because it is simple and easy to apply. It helps to determine peak discharge by using rainfall intensity, watershed area, and runoff coefficient. This method is typically recommended for natural watersheds having an area less than 5 mi2 (3200 acres). Since the selected area of this project is less than 3200 acres, the rational method is the most suitable method for calculating runoff. The following equation is used to calculate the peak discharge.

$$\boldsymbol{Q} = \boldsymbol{CIA} \qquad (2.1)$$

where,

Q = Discharge in cusecs

C= Runoff coefficient

I = average rainfall intensity in inch/hr corresponding to time of concentration Tc

A= Drainage area in ft^2

The value of flow coefficient (c) depends upon the land surface conditions and possible changes in land use. Flow coefficient value can be obtained from table2.2 below by selecting the land cover type.

Tabel 2. 2: Value of Runoff Coefficient (C) (Department of Public Works, 2006) (Yunianta & Setiadji, 2018)

No.	Material		Runoff Coefficient
1	Concrete road & asphalt road		0.70 – 0.95
2	Gravel road & dirt road		0.40 - 0.70
3	Roadside	Fine-grained soil	0.40 – 0.65
		Coarse-grained soil	0.10 – 0.20
		Hard massive rock	0.70 – 0.85
		Soft massive rock	0.60 – 0.75
4	Green	Green belt/Grass	0.30 – 0.35

d) Sizing of Storm water Drains

Manning's equation is used most commonly for the design of sanitary sewers because it is efficient, popular and, fully satisfies the experimental results in terms of accuracy (Bansal, 2016; Kumar et al., 2015). So, the same is used for this design as shown in figure 2.10.

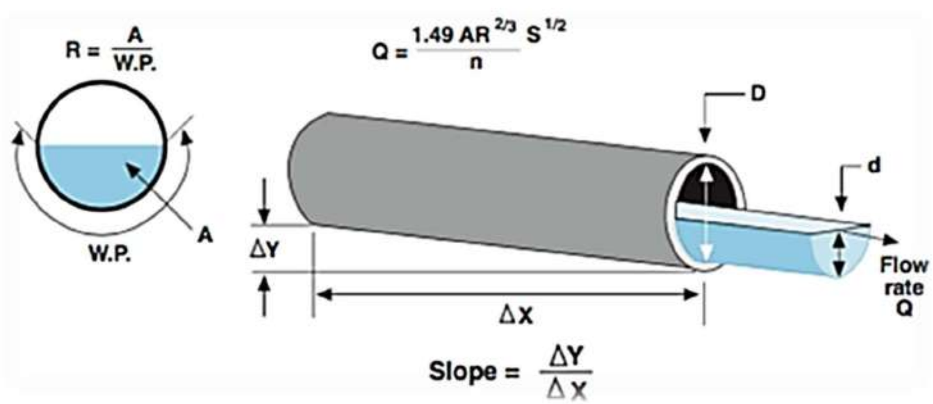

Figure 2. 10: Concept of Manning's Equation (Tanwer, S. M. G, 2020)

The manning's equation (eq 2.2) is written below as

$$\boldsymbol{V} = \mathbf{1.49}/\boldsymbol{n} * R^{2/3} * S^{1/2} \tag{2.2}$$

Where,

V = Velocity in ft/sec

n = Friction Factor/ Mannings Coefficient i.e: 0.013 (For Cement-concrete pipe)

R = Hydraulic Radius in ft = Cross sectional area of channel/ wetted perimeter

S = Slope of Drain

The study area for our research project is already developed and consists of open drains, hence opting open drains for design in this project.

The value of the Manning coefficient can be obtained from table 2.3 depending on the pipe material (Bansal, 2016; Kumar et al., 2015).

Tabel 2. 3: Mannings roughness coefficients for some common materials (*Manning's Roughness Coefficients*, 2023)

Materials	Manning's (n-value)
Reinforced Concrete	0.013
Corrugated Metal Pipe	0.023
Polyvinyl Chloride (PVC)	0.01
Smooth Welded Pipe	0.011

If manning's velocity exceeds the limit (2.5-8.5ft/sec) then we'll use equation 2.3 for steps:

$$Q_f = \text{Area x Velocity} \tag{2.3}$$

Where,

Q_f = *flowing full flow obtained by multiplying area with velocity*

So, if $Q_f \geq Q$ (cumulative discharge); (Design Satisfied)

The same design is applied for all other stormwater drainage systems.

2.3.2 Time of concentration (TC)

(Tanwer, 2020) defined Tc as the time required by the water to reach the concerned point from the most remote point of the drainage area. i.e. the period after which the entire area shall start contributing to the runoff is called the concentration time. Time of concentration consists of two parts:

a) Inlet Time (Ti)

$$Ti = \frac{(0.885 \times LxL \times L)^{0.385}}{H} \tag{2.4}$$

Where

Ti= Inlet time in hours

L= Length of overland flow in kilometers from the critical point to the mouth of drain.

H= Elevation difference in meters between the two points.

b) Channel Flow Time (Tf)

The total time of concentration at a given point in the drain for working out the discharge at that point can be obtained by:

$$Tf = \frac{Length\ of\ Drain}{Velocity\ of\ Flow} \tag{2.5}$$

Hence,

$$Tc = Ti + Tf \tag{2.6}$$

2.4 Rainwater Harvesting

Water is a naturally occurring compound in the world. (Khatri & Tyagi, 2015) conducted research that represented the distribution of world water, as shown in figure 2.11. According to this, the total percentage of water present on Earth is 71%. Out of this 71%, salt water is 98% and fresh water is only 2%. Out of 2% fresh water, 12% is as groundwater, 87% as ice and 1% flows in rivers and streams.

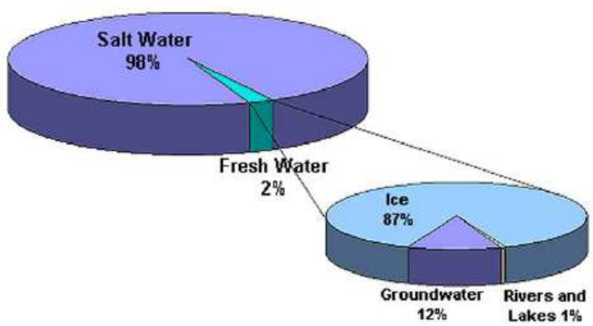

Figure 2. 11: World Water Distribution (*Water Cycle Diagram*, 2022)

The occurrence of water is a result of a natural process, which is called the Hydrological cycle (*Water Cycle Diagram*, 2022). The hydrological cycle as shown in figure 2.12 is composed of different phases, which are mentioned as:

- Evaporation
- Condensation
- Deposition
- Precipitation
- Runoff
- Percolation

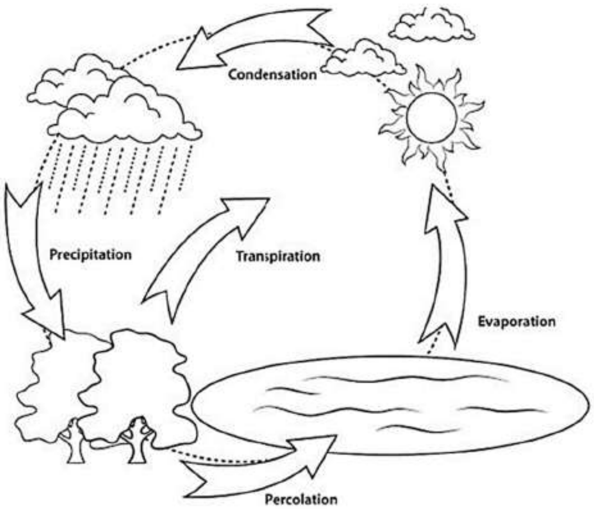

Figure 2. 12: Hydrological cycle (*Water Cycle Diagram*, 2022)

Rainwater is a naturally occurring source of water. Instead allowing rainwater to enter different water bodies without any consumption is an approach towards sustainable development, which is known as Rainwater Harvesting. Rainwater should be harvested and brought to daily human usage to meet the population's needs (Rashid et al., 2018). The increase and densification of the population around the globe have triggered water scarcity. Groundwater has been depleting over time and is about to lack in fulfilling the daily water demand and supply of the population, especially in major cities (Hassan, 2016). To meet the population's needs and save natural resources by consuming it most efficiently, it is important to harvest rainwater and fulfil daily needs before allowing it to enter unconsumed water bodies (Zhang et al., 2022). Many countries have adopted different techniques and methodologies for harvesting rainwater for domestic/personal usage to meet humankind's needs. Japan encouraged the rainwater retention and infiltration plan to recharge groundwater and even to improve environmental conditions (Helmreich & Horn, 2009).

Urbanization and climate change have affected the globe on a mass scale. It led to many devastating events, such as floods and even droughts. The techniques of rainwater harvesting are becoming popular over time. The benefits of rainwater harvesting result in a decrease in the events mentioned above (Payne et al., 2019).

As urbanization has increased with the increase in population, it has led to an alarming deficit in fresh water. To fulfil the demand, there is a fundamental shift of approach with the help of a non-traditional water supply approach: rainwater harvesting (Mitchell et al., 2008).

2.4.1 Determination of Rainwater Harvesting

There are two approaches for rainwater harvesting which includes the empirical method and modelling through rainwater harvesting tool, both are discussed below:

2.4.1.1 Empirical Equations

(Philp et al., 2008; Rashid et al., 2018) conducted research according to which to harvest rainwater, it is important to design the harvesting system according to the potential of rainwater. Various formulas calculate the potential of rainwater; four of them are presented in table 2.4.

Tabel 2. 4: Empirical Equation for Rainwater Harvesting

Methods	Calculation Equations	Applications
Empirical formula	$Wr = \sum_{i=1}^{n} Ai * \phi i * P * \alpha * \beta * 10^{-3}$ • W_r is the Rainwater Harvesting Potential, m^3 • P is the amount of rainfall in mm. • α is the coefficient of the first flush • β is the reduction coefficient of the rainfall season • A_i is the area of land usage in Km. • Φ_i is the runoff coefficient	Suitable for places where detailed below surface data is available
Water balance	$Wr = Wsp + Wsimp + Wg$ • W_r is the Rainwater Harvesting Potential, m^3 • W_{sp} is the surface runoff in a porous area • W_{simp} is the surface runoff in the impervious area. • W_g is the groundwater runoff.	Suitable for areas with little data
Influence factors	$Wr = P * \lambda p * (\lambda l + \lambda s * \lambda d)$ • W_r is the Rainwater Harvesting Potential, $m^{3.}$ • P is the amount of rainfall in mm. • Λ_p is the rainfall characteristic factor. • Λ_s is the impact of terrain on rainwater harvesting. • Λ_l and $\lambda_{d \text{ represent}}$ the impact of utilization mode.	Suitable for areas with detailed
Urban water mass balance formula	$\Delta S = (C + D + P) - (W + Rs + G + ET)$ • ΔS is the change in water stored in the specified boundary. • C is the centralized or imported water. • D is the decentralized water. G is the groundwater. • P is the precipitation. ET is the actual evapotranspiration. • W is the wastewater discharged. • Rs is the stormwater runoff.	The difference in the storage of water storage boundary

2.4.2 SamSam Model Application

To harvest the rainwater for future use in start it must be stored in some place. Storage reservoirs are produced depending upon the daily demand of the user (Yildirim et al., 2022). SamSam water tool is a model application used for rainwater harvesting. It allows the user to develop different models such as Universal Transverse Mercator zones (UTM), rainwater harvesting and others. The UTM coordinate system is a method used for specifying locations on Earth. The model of rainwater harvesting depends upon the below-mentioned phases:

- Location
- Roof size
- Water demands
- Results

It also provides its user with past data on annual rainfall and a comparison with the water demand that shows the water scarcity months and normal months (Foundation, 2023).

2.4.3 Techniques of Rainwater Harvesting

The techniques and strategies for rainwater harvesting are discussed below:

2.4.3.1 Green Roofs and Runoff Collection

Instead of using old-age methods for rainwater harvesting, the world has started to move towards sustainable developments, which has introduced the concept of "Green Roofs". It is the implantation of vegetation on the top of the roof, which is used to filter the rainwater before collection, and it reduces the amount of overflow. Due to the reduction in the amount of rainwater inflow in the soil the collected runoff from the roof could be used to meet the population's daily needs (Almeida et al., 2021).

2.4.3.2 Bioretention Ponds

Bioretention ponds are the second technical phase of stormwater harvesting. In this phase, the rainwater is collected from different nearby locations and the water is left to pass through various layers to improve the quality of water and to avoid the disasters such as flooding (Zanin et al., 2020). The improved quality of water after being passed from different layers is collected at the outlet from where it is stored in the stormwater storage tank (Shafique, 2016). The different layers of Bioretention ponds are represented in figure 2.13.

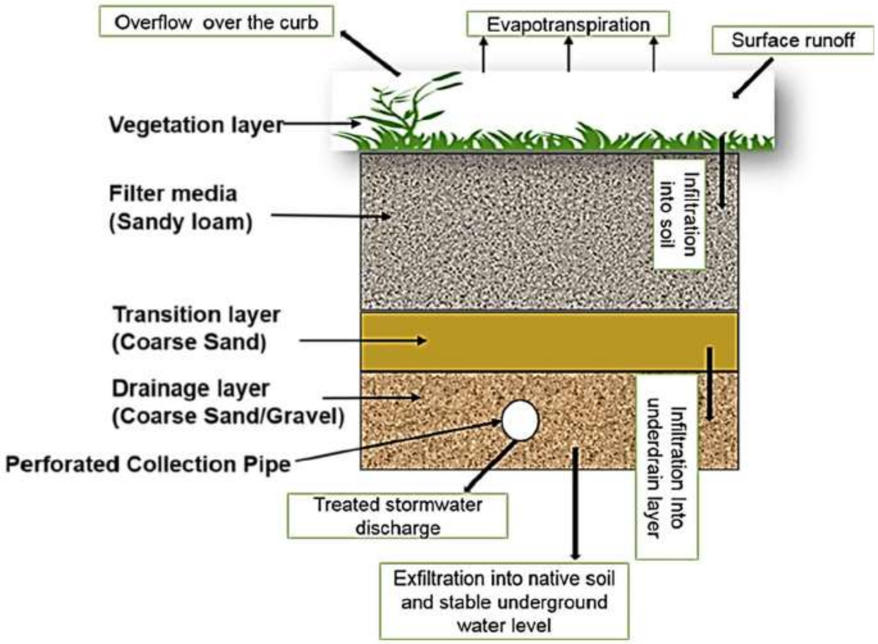

Figure 2. 13: Layers of Bioretention ponds (*Underground Water Tanks - Argo Sciences*, 2023)

2.4.3.3 Storage Tanks

The storage tanks are used for the collection of rainwater after being passed from Bioretention ponds. The stored water is brought to daily required usage and the overflow from the storage tanks moves to the last phase which is the infiltration wells. The mechanism of rainwater harvesting tank is shown in figure 2.14.

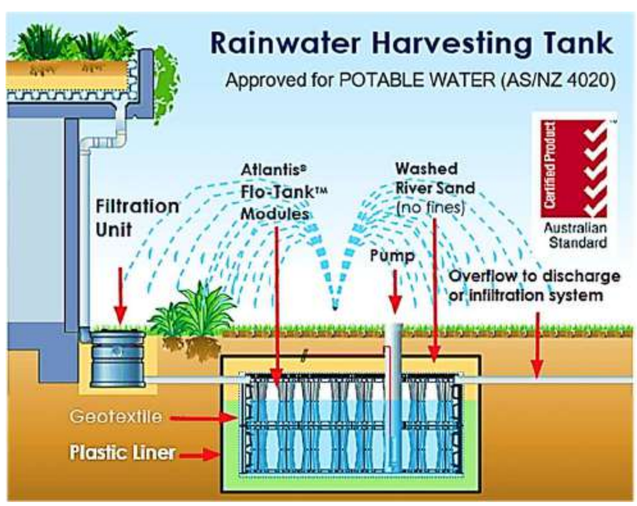

Figure 2. 14: Rainwater Harvesting storage tank (*Underground Water Tanks - Argo Sciences*, 2023)

(Almeida et al., 2021) conducted research according to which the size of storing tank of rainwater harvesting depends upon the population, which is to be facilitated with the harvested water and the purpose of usage to fulfil the needs or requirements of the population.

2.4.3.4 Infiltration Wells

Infiltration wells are a phenomenon, which is used for rainwater harvesting and groundwater recharging. The main reason for the need for groundwater recharging is the depletion in the groundwater table with the increase in population worldwide. ("Rainwater Harvesting to Repel Water Scarcity - IITOYA | Membrane-based Filtration," 2019) develop an approach of rainwater harvesting to prevent water scarceness. The collected rainwater moves from filters to a storage reservoir and through “V” wire technology the water is inserted into the ground from different networks, which recharges the groundwater table.

CHAPTER 3

STUDY AREA AND METHODOLOGY

3.1 Study Area

The area of study selected for the this study pproject is a residential society situated in Wahcantt on G.T. Road at the gateway of Jhang-Bahatar interchange having coordinates 33.761984, 72.735003 as shown in figure 3.1.

Figure 3. 1 Area of Study

3.2 Study Area Features

The study area is located at 1545 ft above sea level. The topography of the area is such that the area is generally flat and slopes towards North and North-East. The coldest month is January**,** with an average high-temperature of 17°C and an average low-temperature of 2°C. The warmest month is July, with an average maximum temperature of 39°C. The total average annual precipitation is about 795 mm. The driest month of the year is November with an average of 11 mm of precipitation. The wettest month is August having an average 193 mm of precipitation. (Data taken from PMD).

3.3 Master Plan

The master plan of the study area is shown in figure 3.2.

Figure 3. 2 Master Plan of Study Area

3.4 Climate Data

Table 3. 1: Climate Data of Study Area

Month	Temperature (Avg.)	Precipitation
January	17°C	96 mm
February	20°C	85 mm
March	24°C	91 mm
April	29°C	73 mm
May	30°C	28 mm
June	35°C	130 mm
July	39°C	175 mm
August	38°C	197 mm
September	30°C	85 mm
October	28°C	35 mm
November	23°C	08 mm
December	15°C	41 mm
Average	26°C	87 mm

3.5 Codes and Standards

To accomplish the aim of the project, which is to develop a sustainable road (geometric design), storm water drainage, and rainwater harvesting system for the study area, the following standards will be employed:

- ASTM Design Standards
- AASHTO Design Standards
- CDA Pakistan Standards

3.6 Planning and Design of Roads

3.6.1 Planning

The following activities are included in the planning process for roads:

1). Performing an analysis on the masterplan of the study area.
2). Indicating road type.
3). Analysis of the topography of study area.
4). Determine the dimensions (length, width) of roads and streets.

5). Determine the required gradients for roads as per the topography.

6). Determine width of walkways, footpaths and green area.

3.6.2 Design

1). Develop an excel file for the geometric design of roads having Natural Surface Levels (NSLs) of existing study area to calculate gradients and Finished Road Levels (FRLs) at each Reduce Distance (RD).

The FRLs at each RD are calculated by using equation 3.1 as shown below:

$$\begin{matrix}\text{Elevation}\\ \text{at respective RD}\end{matrix} = \left(\begin{matrix}\text{Elevation}\\ \text{of Previous RD}\end{matrix}\right) \pm [(\text{Gradient}) \times (\text{Change in Chainage})] \qquad (3.1)$$

"+" sign will be used if the elevation is increasing i.e. ascending

"-" sign will be used if the elevation is decreasing i.e. descending

Where,

$$\text{Gradient} = \left(\frac{Rise}{Run}\right) \qquad (3.2)$$

Here,

Rise = Initial Elevation – Final Elevation

Run = Final Chainage – Initial Chainage

2). Design a vertical curve (where necessary) with a specified length and design speed in accordance with AASHTOO design specifications.

Table 3. 2: Design Control for Vertical Curves

Design Speed	**Maximum Grade Change without Vertical Curve**	**Minimum Length of Vertical Curve for Satisfactory Appearance**
(km/h)	%	(m)
50	**1**	**20-30**
60	0.8	40-50
70	0.6	60-80
80	0.4	80-100
100	0.2	100-150

The maximum grade change that can be achieved without requiring a vertical curve depends on various factors such as the design speed of the road, the length of the grade, and the characteristics of the vehicles using the road.

In general, a grade change of up to 3% can be achieved without requiring a vertical curve. However, if the design speed of the road is higher, a smaller grade change may be required to ensure the safety of the drivers.
It's important to note that even if a vertical curve is not required, it may still be beneficial to include one in the design to improve the comfort and safety of the road users, especially for longer grades.

3). Having FRLs at each RD, develop an AUTOCAD file for profiling of each road and for the determination of the amount of cut and fill.

3.7 Planning and Design of Storm Drainage

3.7.1 Planning

The storm drainage planning phase comprises a series of sequential steps which are as follows:

1). Analysis of the masterplan of study area
2). Development of storm drainage network plan as per calculated FRLs.
3). At each intersection or at each location where there is a change in direction, indicate nodes and drainage lines.
4). Position rain water harvesting tanks (RWHT) in areas that are optimal for doing so I-e depression areas where there is an accumulation of water, taking into account the general terrain and the flow direction.

3.7.2 Design

The storm drainage design phase comprises a series of sequential steps which are as follows:

1). Create a sheet in Excel that details the design of each drainage line.
2). Determine the flow rate of water from each drainage line utilizing the following rational formula.

$$\boldsymbol{Q = CIA} \tag{3.3}$$

where,

Q = Discharge in cusecs

C= Runoff coefficient

I = average rainfall intensity in inch/hr corresponding to time of concentration Tc

A= Drainage area in ft^2

The value of flow coefficient (c) depends upon the land surface conditions and possible changes in land use. Flow coefficient value can be obtained from the table 2.2.

Following is the table showing areas necessary for the design of storm drainage of different features in this study area:

Table 3. 3: Area Calculation of Study Area

Area				
PLOT			**Total Road Area**	**Total Green Area**
Plot Type	**Quantity**	**Area (ft^2)**	(ft^2)	(ft^2)
35x90	56	152646.93	266675.44	213145.126
30x90	50	110727.22		
25x75	41	123508.88		
25x50	45	32757.29		
40x135	38	135721.23		
Commercial (size varies)	24	93215.01		
Total =	254	648576.56		
Total Area of Society			=	1128397.13 ft^2

3). Following CDA Standard(s) have been used:

- Maximum rainfall intensity = 3 in/hr

4). Minimum width of drains is 1ft and up to 2ft maximum. Drain size is dependent on the available space as per the section of the road.

5). Perform the calculation using manning's formula for velocity.

$$\boldsymbol{V} = \mathbf{1.49}/\boldsymbol{n}\ \boldsymbol{x}\ \mathbf{R}^{2/3}\ \boldsymbol{x}\ \mathbf{S}^{1/2} \tag{3.4}$$

Where,

V = Velocity in ft/sec

n = Friction Factor/ Manning's Coefficient I-e: 0.013 (For Cement-concrete pipe)

R = Hydraulic Radius in ft = $\frac{\text{Area}}{\text{Wetted perimeter}}$

S = Slope of Drainage line

The value of the Manning coefficient can be obtained from table 2.3 depending on the material.

6). Following design checks need to be applied to each drainage line:

- Velocity = 2.5 – 8.5 ft/sec (Velocity Check)
- $Q_{(Full)} \geq Q_{(cumulative)}$ (Discharge Check)
- Invert $Level_{(Backward)} \geq$ Invert $Level_{(Forward)}$ (Invert Level Check)

To ensure proper drainage flow and prevent any backflow in the drainage line, it is necessary for the invert level of the forward/incoming drainage line to be less than or equal to the invert level of the backward/outgoing drainage line at the node.

3.8 Methodology

The overall methodology developed in this study is explained with the help of the flow chart given in figure 3.3.

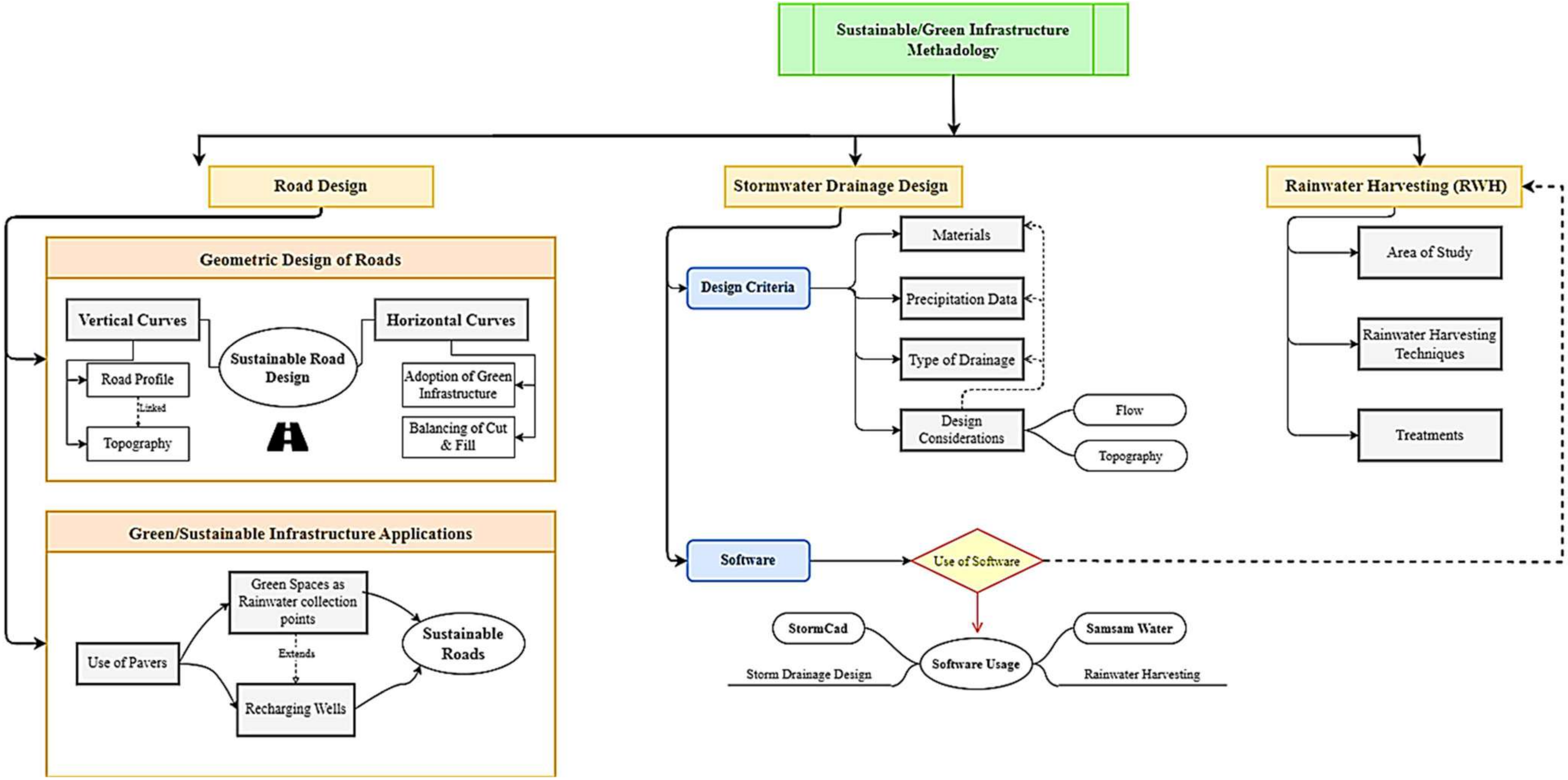

Figure 3. 3 Methodology Flowchart

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Road Design

4.1.1 Background

The project encompasses the geometric design of roads, the design of stormwater drainage, and the collection of rainfall via the rainwater harvesting all leading towards the creation and development of sustainable infrastructure. The geometric design of the roads in the study area incorporates vertical curves based on the topography and elevation points at 100-foot intervals. The design of the stormwater drainage is based on the total discharge calculated using the catchment area of each drain. The development of the rainwater harvesting system is based on the accumulation of water at the nodes, and the rainwater harvesting system is installed in low-lying areas.

4.1.2 Profiling of Road 13

Profiling of roads refers to the process of measuring and analyzing the vertical and horizontal alignment of a road. This information is used to identify the volume of cut and fill or any irregularities or deviations from the desired design standards, which can impact the safety and efficiency of the road.

In order to create profile, we need the following information:

- Existing N.S.L.
- RD Interval
- Gradient

Accquiring the above data, following is the detailed computation for the profiling of road 13:

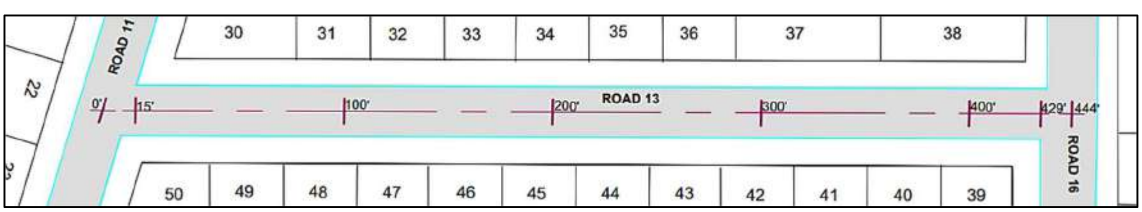

Figure 4. 1: Road 13 Plan

NSLs and FRLs at each RD are defined in table 4.1.

Actual starting RD of road should be 0 ft but here 15ft patch of intersecting road 11 is added with this road to make the junction smooth and level I-e to level the slope so that the vehicles can get stable and make smooth and secures turns similarly at end of this road, 15ft patch of road 16 is also added into profiling of this road (13) for the said purpose. The elevations are defined in table 4.1.

Hence,

NSL at 0'0'' of Road 13 = 1506 ft

FRL at 0'0'' of Road 13 = 1509 ft

4.1.2.1 F.R.L. Calculation

Calculating elevations at each RD using Eq 3.1 as shown below:

$$\underset{\text{at respective RD}}{\text{Elevation}} = \left(\underset{\text{of Previous RD}}{\text{Elevation}}\right) \pm [(\text{Gradient}) \text{ x } (\text{Change in Chainage})]$$

where,

$$\text{Gradient} = \left(\frac{Rise}{Run}\right) = \left[\frac{(1509)\text{-}(1497)}{(429\text{-}15)}\right] = 0.028985507$$

The observation of the initial and final elevation indicates a decline in elevation from 1509ft to 1497ft. As the value is negative, hence, it is appropriate to incorporate a negative (-) sign into the formula.

So,

Elevation at 15 ft = $(1509) - [(0.028985507)x\ (15 - 0)] =\ 1508.56$ ft

Elevation at 100 ft = $(1509) - [(0.028985507)x\ (100 - 15)] =\ 1506.536$ ft

Elevation at 200 ft = $(1506.536) - [(0.028985507)x\ (200 - 100)] =\ 1503.638$ ft

Elevation at 300 ft = $(1503.638) - [(0.028985507)x\ (300 - 200)] =\ 1500.739$ ft

Elevation at 400 ft = $(1500.739) - [(0.028985507)x\ (400 - 300)] = 1497.841$ ft

Elevation at 429 ft = $(1497.841) - [(0.028985507)x\ (429 - 400)] = 1497$ ft

Elevation at 444 ft = $(1497) - [(0.028985507)x\ (444 - 429)] = 1497$ ft

The above calculated data is summarized in the table 4.1 below:

Table 4. 1: Profile Table for Road 13.

Road	RD.	N.S.L.	F.R.L.	Remarks
13	0	1506	1509	Junction with Road 11
	15	1505.8	1509	
	100	1504.65	1506.54	
	200	1503.3	1503.64	
	300	1501.95	1500.74	
	400	1500.59	1497.84	
	429	1500.2	1497	
	444	1500	1497	Junction with Road 16

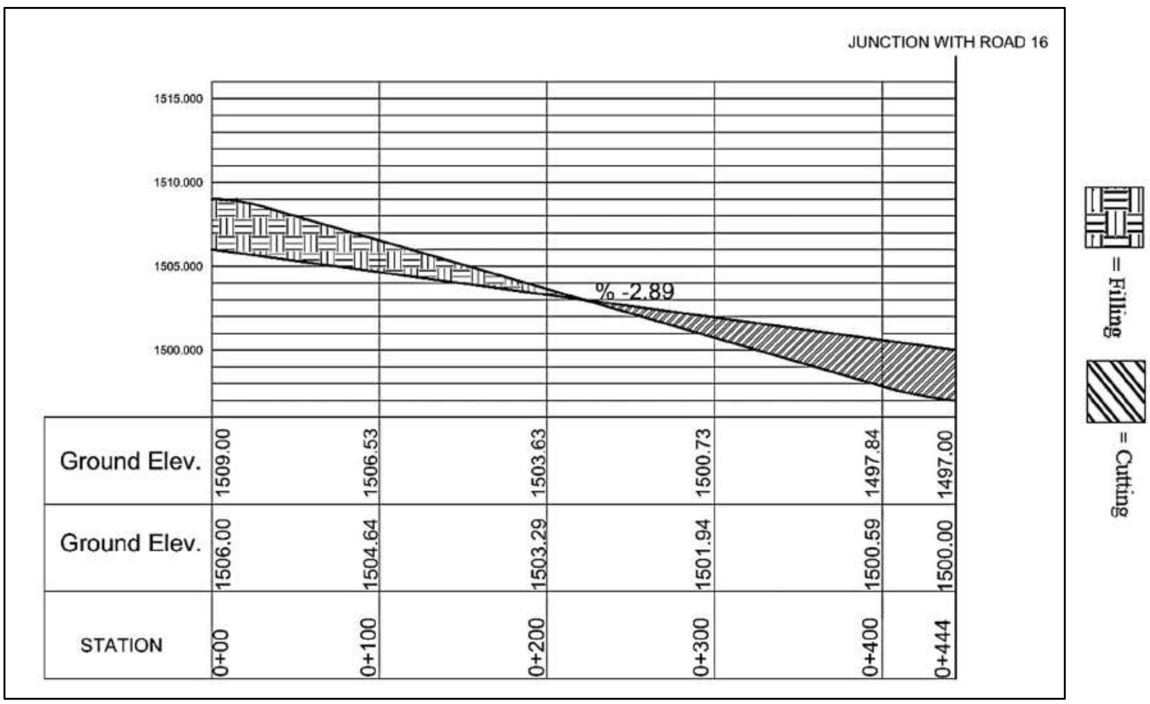

Figure 4. 2: Profiling of Road 13.

Hence, the vertical profile of road 13 has been developed which is showing a balanced profile, the volume of cut and fill for this is almost equal which means that the amount of material excavated from the roadbed is roughly equal to the amount of material used to build up embankments or fills along the road alignment. This can be beneficial in terms of cost and environmental impact, as it reduces the need for importing or exporting large quantities of material to or from the construction site.

Similarly, the profiles of all the remaining roads can be developed with this procedure. The profiles of the remaining roads are shown in ANNEXURE-A.

4.2 Stormwater Drainage Design

The stormwater drainage network is designed based on the combination of factors, including the amount and intensity of rainfall in a particular area, the topography and geology of the site, and the intended use of the site. The network is designed based on the Finished road levels (FRLs), profile of roads and the storm drain plan of the study area as shown in figure 4.3. The drainage plan is developed in such a way that the maximum quantity of the storm water is collected in their respective rainwater harvesting tanks.

4.2.1 Storm Drainage Network Plan

The storm drainage network plan of the study area is shown in figure 4.3.

Figure 4. 3: Storm Drainage Network Plan of Study Area

4.2.2 Stormwater Drainage Design of Road 13

The design of the storm drainage system for Road 13 includes the following procedures, which are carried out with reference to the information obtained from the profile of road 13 as shown in figure 4.2 and with reference to storm drainage plan of Road 13 as shown in figure 4.4.

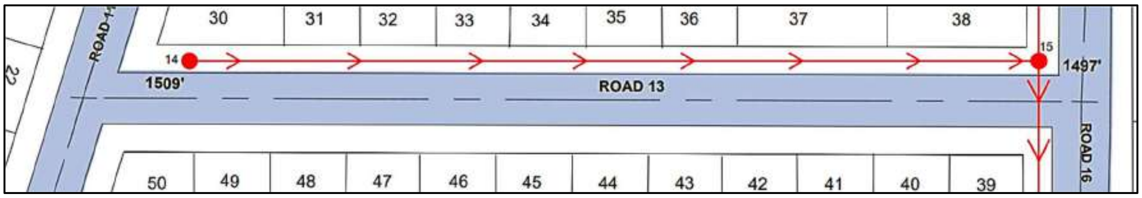

Figure 4. 4: Storm Drainage Plan of Road 13

4.2.2.1 Primary Data

1). Road Number = 13

2). Drainage Line = 10 (between node 14 & 15)

3). Length of Drainage Line = 382 ft

4). Node

- Start Node = 14
- End Node = 15

4.2.2.2 Elevation Data

1). Finished Reduced Levels (FRLs)

- Start Node = 1509 ft
- End Node = 1497 ft

2). Invert Elevation (IL)

- Start Node = 1508 ft
- End Node = 1496 ft

3). Invert Depth (ID)

- Start Node = FRL at start node – IL at start node

  = 1509 – 1508

  = 1 ft

- End Node = FRL at end node – IL at end node

  = 1497 – 1496

  = 1 ft

4.2.2.3 Discharge Calculations

The discharge is estimated using equation 3.3 and the approach described in section 3.7.2. Following are discharge calculations:

1). Rainfall Intensity (I) =

$$3\ {}^{in.}/_{hr}$$ (CDA Standard)

Table 4. 2: Contributing Areas to Road 13.

Contributing Areas (ft^2)			**Drainage Coefficient 'C'**		
Plot	Green	Road	Plot	Green	Road
43981	10182	10515	1	0.35	0.9

2). Discharge (Individual)

$$Q_{(plot)} = (1)x\left(\frac{3}{43200}\right)x\ 43981$$ (Calculating Discharge using eq. 3.3)

$$Q_{(plot)} = 3.054\ cusec$$

$$Q_{(Green)} = (0.35)x\left(\frac{3}{43200}\right)x\ 10182$$

$$Q_{(Green)} = 0.247\ cusec$$

$$Q_{(Road)} = (0.9)x\left(\frac{3}{43200}\right)x\ 10515$$

$$Q_{(Road)} = 0.657\ cusec$$

$$Total\ Q_{(individual)} = 3.96\ cusec$$

3). Discharge (Cumulative)

As there is previous adjoining drainage, hence, the cumulative discharge will be same as that individual discharge

Hence,

$$Q_{(Cumulative)} = 3.96\ cusec$$

4.2.2.4 Drain Size

- **Average Depth**

$$= \frac{\text{ID at start node + ID at end node}}{2}$$

$$= \frac{1+1}{2}$$

$$= 1 \text{ ft}$$

- **Drain width**

$$= 1 \text{ ft}$$

The width of the drain is altered according to the design checks. According to the cross section of the roads, it is recommended that the minimum width should not be less than 1 foot and the maximum width should not exceed 2.5 feet. This is necessary to allow for the accommodation of other services and to provide a significant distance between each service.

- **Water Depth**

$Water\ Depth = Average\ Depth - Free\ board$

$Water\ Depth = 1 - 0.3$

$Water\ Depth = 0.7\ ft$

- **Area**

$Area = Water\ Depth\ x\ Drain\ Width$

$Area = 0.7\ x\ 1$

$Area = 0.7\ ft^2$

- **Hydraullic Mean Depth (R)**

$$R = \frac{Area}{Wetted\ Perimeter\ (P)} \tag{4.1}$$

$Wetted\ Perimeter\ (P) = 2x(\ Water\ Depth) + Drain\ Width$

$Wetted\ Perimeter\ (P) = 2x(\ 0.7) + 1$

$$P = 2.4\ ft$$

$$R = \frac{0.7}{2.4}$$

$$R = 0.292\ ft$$

4.2.2.5 Velocity

Using equation 3.4 (Manning's Formula) for velocity calculation:

$$\text{Velocity (V)} = \frac{1.49}{n}\ x\ R^{\frac{2}{3}}\ x\ S^{\frac{1}{2}}$$

$$\text{Velocity (V)} = \frac{1.49}{0.013}\ x\ (0.292)^{\frac{2}{3}}\ x\ (0.031)^{\frac{1}{2}}$$

$$\text{Velocity (V)} = 8.9\ ft/s$$

4.2.2.6 Full Discharge

$$\text{Full Discharge } (Q_{Full}\ ) = Area\ x\ Velocity$$

$$(Q_{Full}\ ) = 0.7\ x\ 8.9$$

$$(Q_{Full}\ ) = 6.25\ cusec$$

4.2.2.7 Design Checks

The design checks as discussed in section 3.7.2 should be satisfied to ensure that the storm drainage network is designed to meet the required standards and can effectively handle stormwater runoff.

1). Discharge Check

$Q_{(Full)} \geq Q_{(cumulative)}$

$6.25 \geq 3.96$

2). Velocity Check

Velocity should lie within 2.5 – 8.5 ft/sec

Velocity (V)= $8.9\ ft/s$

<u>Remarks</u>: The Velocity of this drainage line slightly exceeds the maximum value of 8.5 ft/s. In order to control velocity in this drainage line, incorporate steps or obstacles in the channel to create friction and slow down the flow of water and hence the velocity of water get minimized. This can be an effective way to reduce velocity in the channel while maintaining adequate flow.

3). Invert Level$_{\text{(Backward)}}$ ≥ Invert Level$_{\text{(Forward)}}$

No previous adjoining drainage line

4.2.3 Stormwater Drainage Design of Road 16

The design of the storm drainage system for Road 16 includes the following procedures, which are carried out with reference to the information obtained from the profile of road 13 as shown in figure 4.2 and with reference to storm drainage plan of Road 13 as shown in figure 4.5.

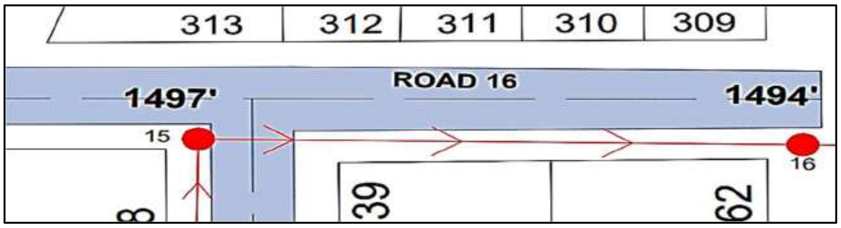

Figure 4. 5: Storm Drainage Plan of Road 16

4.2.3.1 Primary Data

1). Road Number = 16

2). Drainage Line = 11 (between node 15 & 16)

3). Length of Drainage Line = 175 ft

4). Node

- Start Node = 15
- End Node = 16

4.2.3.2 Elevation Data

1). Finished Reduced Levels (FRLs)

- Start Node = 1497 ft
- End Node = 1494 ft

2). Invert Elevation (IL)

- Start Node = 1496 ft
- End Node = 1493 ft

3). Invert Depth (ID)

- Start Node = FRL at start node – IL at start node

  = 1497 – 1496

  = 1 ft

- End Node = FRL at end node – IL at end node

  = 1494 – 1493

  = 1 ft

4.2.3.3 Discharge Calculations

The discharge is estimated using equation 3.3 and the approach described in section 3.7.2. Following are discharge calculations:

1). Rainfall Intensity (I) = 3 $^{in.}/_{hr}$ (CDA Standard)

Table 4. 3: Contributing Areas to Road 16.

Contributing Areas (ft^2)			**Drainage Coefficient 'C'**		
Plot	Green	Road	Plot	Green	Road
8538	4280	4678	1	0.35	0.9

2). Discharge (Individual)

$$Q_{(plot)} = (1)x\left(\frac{3}{43200}\right)x\ 8538$$

$$Q_{(plot)} = 0.592\ cusec$$

$$Q_{(Green)} = (0.35)x\left(\frac{3}{43200}\right)x\ 4280$$

$$Q_{(Green)} = 0.104\ cusec$$

$$Q_{(Road)} = (0.9)x\left(\frac{3}{43200}\right)x\ 4678$$

$$Q_{(Road)} = 0.292\ cusec$$

$$Total\ Q_{(individual)} = 0.99\ cusec$$

3). Discharge (Cumulative)

As there is previous adjoining drainage, hence, the cumulative discharge will be same as that individual discharge

Hence,

$$Q_{(Cumulative)} = 3.96 + 0.99$$

$$Q_{(Cumulative)} = 4.95\ cusec$$

4.2.3.4 Drain Size

- **Average Depth**

$$= \frac{\text{ID at start node + ID at end node}}{2}$$

$$= \frac{1 + 1}{2}$$

$$= 1 \text{ ft}$$

- **Drain width**

$$= 1.25 \text{ ft}$$

The width of the drain is altered according to the design checks. According to the cross section of the roads, it is recommended that the minimum width should not be less than 1 foot and the maximum width should not exceed 2.5 feet. This is necessary to allow for the accommodation of other services and to provide a significant distance between each service.

- **Water Depth**

$Water\ Depth = Average\ Depth - Free\ board$

$Water\ Depth = 1 - 0.3$

$Water\ Depth = 0.7\ ft$

- **Area**

$Area = Water\ Depth\ x\ Drain\ Width$

$Area = 0.7\ x\ 1.25$

$Area = 0.875\ ft^2$

- **Hydraullic Mean Depth (R)**

$$R = \frac{Area}{Wetted\ Perimeter\ (P)}$$

$Wetted\ Perimeter\ (P) = 2x(\ Water\ Depth) + Drain\ Width$

$Wetted\ Perimeter\ (P) = 2x(\ 0.7) + 1.25$

$$P = 2.65\ ft$$

$$R = \frac{0.875}{2.65}$$

$$R = 0.330\ ft$$

4.2.3.5 Velocity

Using equation 3.4 (Manning's Formula) for velocity calculation:

$$\text{Velocity (V)} = \frac{1.49}{n} \ x \ R^{\frac{2}{3}} \ x \ S^{\frac{1}{2}}$$

$$\text{Velocity (V)} = \frac{1.49}{0.013} \ x \ (0.330)^{\frac{2}{3}} \ x \ (0.017)^{\frac{1}{2}}$$

$$\text{Velocity (V)} = \ 7.17 \ ft/s$$

4.2.3.6 Full Discharge

$$\text{Full Discharge } (Q_{Full}) = \ Area \ x \ Velocity$$

$$(Q_{Full}) = \ 0.875 \ x \ 7.17$$

$$(Q_{Full}) = \ 6.27 \ cusec$$

4.2.3.7 Design Checks

The design checks as discussed in section 3.7.2 should be satisfied to ensure that the storm drainage network is designed to meet the required standards and can effectively handle stormwater runoff.

1). Discharge Check

$Q_{(Full)} \geq Q_{(cumulative)}$

$6.27 \geq 4.95$

2). Velocity Check

Velocity should lie within 2.5 – 8.5 ft/sec

$\text{Velocity (V)} = \ 7.17 \ ft/s$

3). Invert Level$_{\textbf{(Backward)}}$ ≥ Invert Level$_{\textbf{(Forward)}}$

1496 ft = 1496

The invert level of previous adjoining drainage line 10 is 1496 ft and the invert level of current drainage line 11 is 1496, both levels are equal. Hence, the check is satisfied.

The same approach is adopted for the design of all other storm drainage of the study areas. The detailed working and computation for storm drainage design is shown on ANNEXURE [B].

4.3 Rainwater Harvesting

The collected storm water from the storm drainage network will be harvested and reused via the rainwater harvesting system. The collected rainwater can be used for a variety of non-potable purposes such as irrigation, washing clothes, flushing toilets, and other uses as discussed in section 2.4. The "SamSamWater Rainwater Harvesting Tool" is utilised to ascertain the most suitable dimensions of rainwater harvesting tanks and the proportion of water demand that can be repurposed for non-potable applications. The tool takes into account the location's climate, roof size, and water demand, and provides recommendations for the appropriate size of a rainwater harvesting system, as well as estimates of potential water savings. The methodology and sequential actions are mentioned in figure 4.6 below:

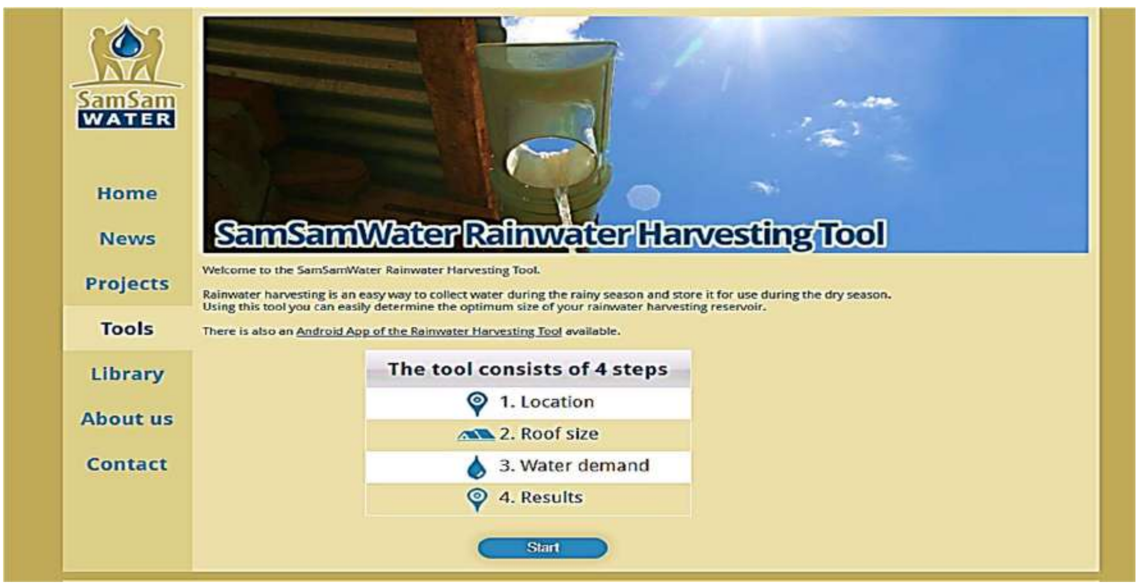

Figure 4. 6: SamSam Model Home Page

4.3.1 Step 01: Defining Location

The location where the study is situated is located and pinned in the map as shown in figure 4.7.

Figure 4. 7: SamSam Model Defining Location.

4.3.2 Step 02: Defining Roof Size

The roof size of the whole study area which is 742940.01 sq. Ft (69021 sq. m), also mentioned in table 4.4 is entered, and the roof type is selected as shown in figure 4.8.

Table 4. 4: Area Classification of Study Area

Area				
PLOT			Total Road Area	Total Green Area
Plot Type	**Quantity**	**Area (ft^2)**	(ft^2)	(ft^2)
35x90	56	176400		
30x90	50	135000		
25x75	41	76875		
25x50	45	56250	266675.44	213145.126
40x135	38	205200		
Commercial	24	93215.01		
Total =	254	742940.01		
Total Area of Society			=	**1222761 ft^2**

Figure 4. 8: SamSam Model Defining Roof Size and Roof Type.

4.3.3 Step 03: Defining Population and Water Demand

The population of the study area as mentioned in table 4.5 and the water demand in entered as shown in figure 4.9.

Table 4. 5: Population Estimation for Study Area

Population			
Plot Type	**PLOT Quantity**	**Area (ft^2)**	**Population**
35x90	56	176400	560
30x90	50	135000	400
25x75	41	76875	246
25x50	45	56250	180
40x135	38	205200	608
Commercial	24	93215.01	280
Total Population of Study Area		=	**2274**

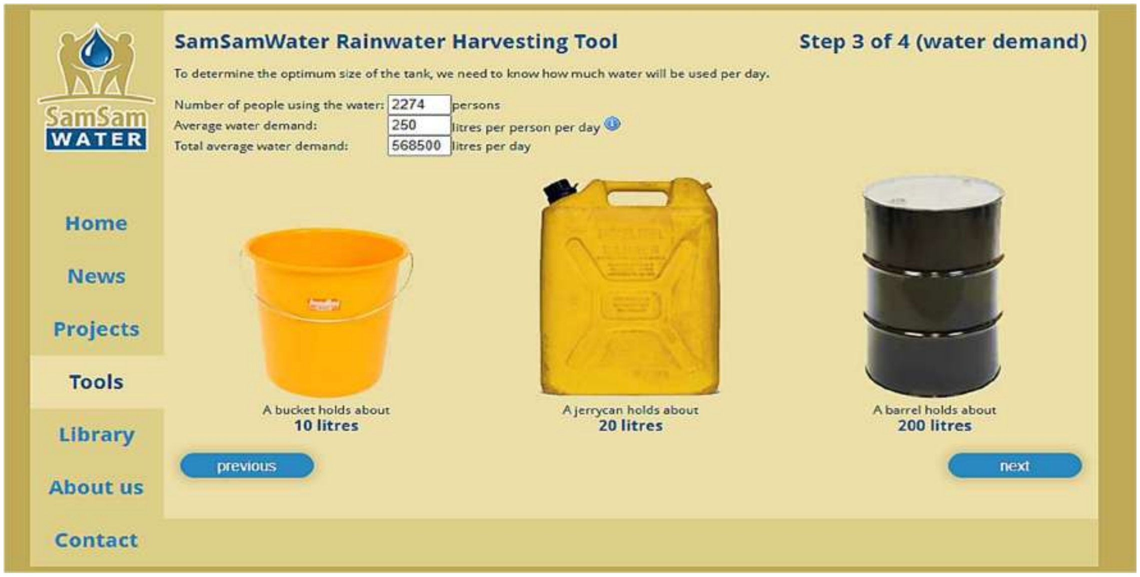

Figure 4. 9: SamSam Model Defining Water Demand.

4.3.4 Step 04 Displaying Result

The "SamSamWater Rainwater Harvesting Tool" results show the capacity of rainwater harvesting tank which comes 12992.2 m^3 and the percentage of reusable water which comes 22% are shown in figure**. The detailed output is mentioned in ANNEXURE-B.

Figure 4. 10: SamSam Model Displaying Results.

CHAPTER 5

CONCLUSIONS AND RECOMMENDATIONS

5.1 Roads

1). Sustainable road infrastructure also addresses water management; thus, the roads are designed and planned in such a manner to also address water management, such as reducing runoff, capturing rainwater, or implementing water filtration systems.

2). The majority of roads are profiled in such a manner that their cut and fill quantities are proportionate.

3). To ensure that vehicles can safely navigate the road without experiencing excessive wear and tear, increased fuel consumption or a loss of control the ruling gradients varying between 0.5% to 3.5% are provided in roads. The average gradient of all the roads varies between 0.5% to 3.5%. An exceptional gradient of 6.5% and 8% are also provided in road 01 and 16 respectively to satisfy the the technical and physical constraints of the transport mode with the needs of road users to create a safe and sustainable road network. terrain conditions and minimum cut and fill.

4). Roads are profiled in such a way that they have balanced cut and fill. Balanced cut and fill is achieved by making a grading plan that balances cut and fill as much as possible I-e minimizing the steepness of the road, making use of natural contours, and considering the drainage patterns.

5). Social equity is also the part of planning and design of roads. The construction of this Road infrastructure will enhance social equity by improving accessibility for all users, including pedestrians, cyclists, and public transport users.

6). The roads are designed and planned in such a manner that the space for utilities such as water supply line, sewerage line, telecommunication is provided on both sides of the road having two feet of interval between each.

Overall, sustainable design of roads requires a holistic approach that considers the needs of road users, the environment, and the local community. By incorporating green infrastructure, interlocking concrete block pavers (discussed in section 2.2), energy efficiency, sustainable materials, traffic management, social considerations, and lifecycle costs, road designers can create a safe, efficient, and environmentally responsible road network.

5.2 Stormwater Drainage Design

1). Stormwater drainage network for the whole study area is designed by carefully considering the finished reduced levels so that the network is constructed as close as possible to the FRLs so that large invert elevations could be avoided.
2). The slope of the drains in the system is engineered in such a manner to provide sufficient flow velocity to move water through the system. The velocity of the drainage network lies between 2.5 ft/s to 8.5 ft/s.
3). Around 55% of the drainage lines are satisfying the velocity check while for remaining drainage lines the velocity is exceeding 8.5ft/s, so, those drainage lines are provided with steps to avoid scouring, erosion and excessive velocity.
4). The minimum width of the drainage network is 1 foot. Invert depths at the start and end point of majority of drainage lines is 1 foot. Invert depth of 3.75ft and 4.50ft at the start and end point respectively of drainage line 31 is provided to satisfy the discharge and velocity requirements, hence, creating an economical and sustainable Stormwater Drainage infrastructure.
5). The maximum width of the drainage line provided in 2 feet.
6). The collected stormwater of the study area will be utilized via Rainwater harvesting system. Rainwater harvesting tanks with a storage capacity as mentioned in figure 4.10 are to be provided.
7). The proportion of collected stormwater of study area that can be reused is 45735 m^3.

Hence a sustainable and economical stormwater drainage network is designed to help to reduce the risk of flooding and protect the environment, while also providing important benefits to the community.

5.3 Rainwater Harvesting

1). The water demand is 568500 litres per day, which equals to about 17055000 litres per month. The total water demand is 207502500 litres (207502.5 m^3) per year
2). The total yearly amount of water that can be collected from this rainwater harvesting system is 45734700 litres (45735 m^3) in an average year.
3). The amount of water that can be collected from the roof (45735 m^3) is less than the water demand (207502.5 m^3). However, it might still be worthwhile to construct a rainwater harvesting system, only a part of the water demand can be fulfilled using this rainwater harvesting system.

4). The optimum size of rainwater harvesting tank to harvest the collected stormwater for the study area is 12992200 litres (12992.2 m^3), this rainwater harvesting system could provide 125301 litres of water per day, which is 22% of the total demand per day. Considering the natural slope of the land and ensuring that the tank is placed in a location where rainwater runoff can easily flow into it, the recommended location for this rainwater harvesting tank is at the end of drainage line 22 beyond point 29 (as shown in figure 4.3) because all the collected water will pass through this point, hence it ensures efficient collection and minimizes the need for long and complicated piping systems (also this is the ending point of the study area).

5). As for determining the percentage of water demand that can be reused for non-potable uses, it depends on the specific uses and the quality of the harvested rainwater. Generally, rainwater harvested from roofs can be used for non-potable uses without treatment. However, if the water quality is poor, treatment may be required to ensure that it is safe to use.

6). In terms of the percentage of water demand that can be met by rainwater harvesting, it varies depending on the location and the amount of rainfall. In areas with high rainfall, a larger percentage of water demand can be met through rainwater harvesting. However, in areas with low rainfall, the percentage may be lower.

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ANNEXURE [A]

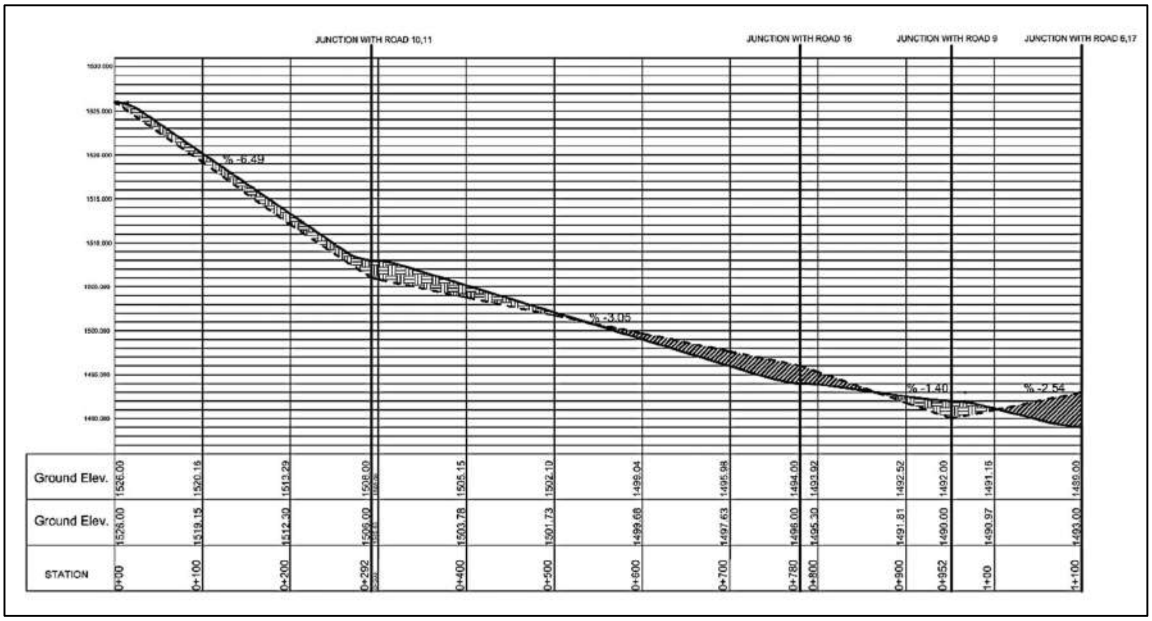


Figure A- 1: Profile of Road 1, 2 and 3.

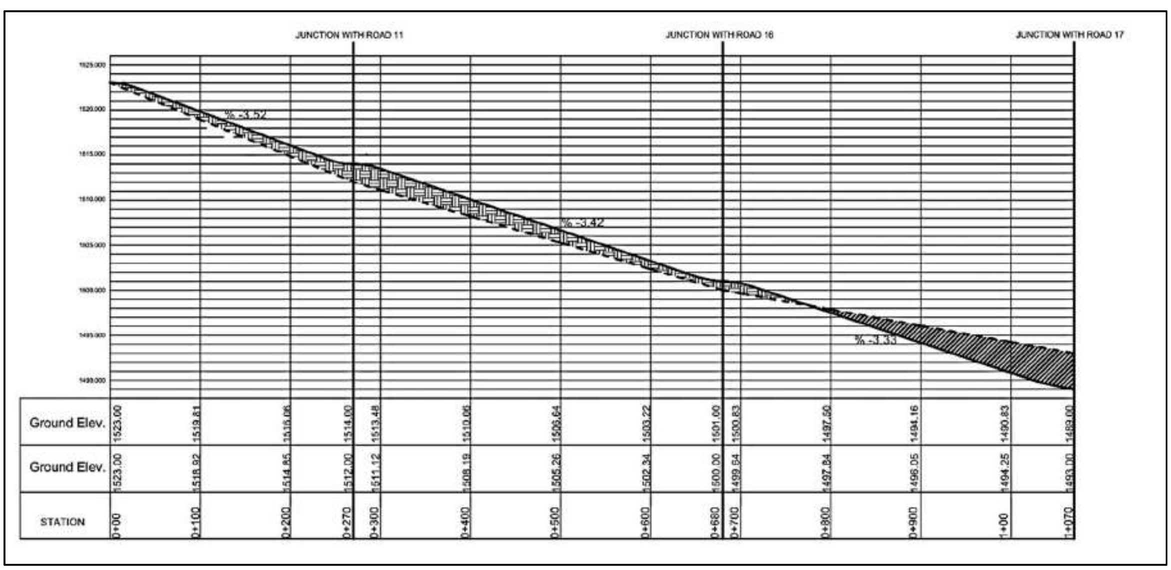


Figure A- 2: Profile of Road 4, 5 and 6.

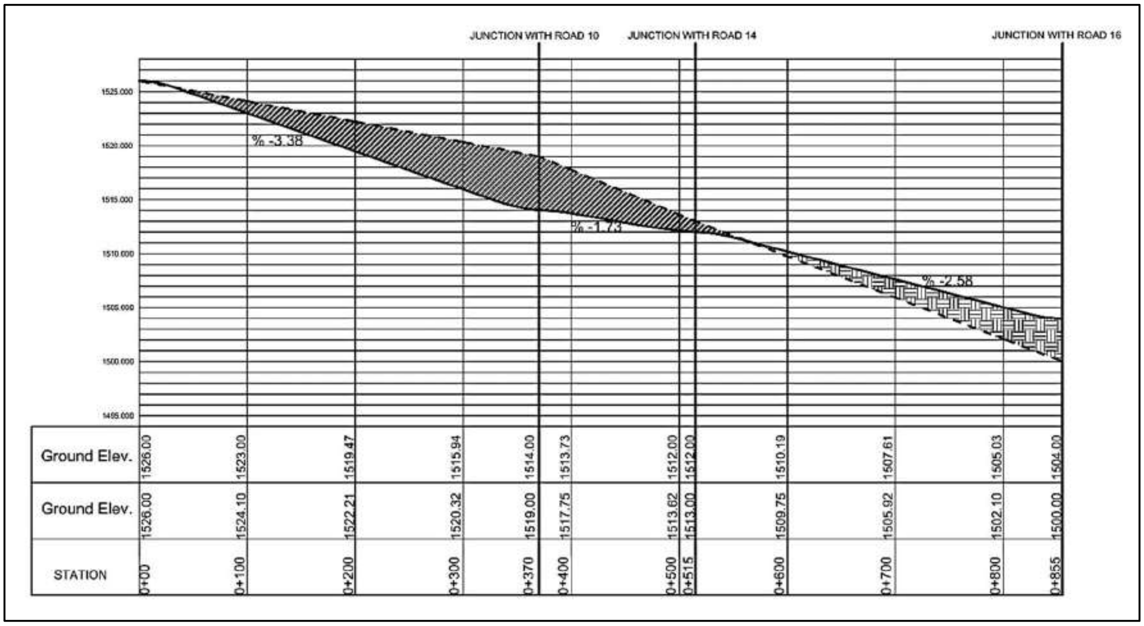
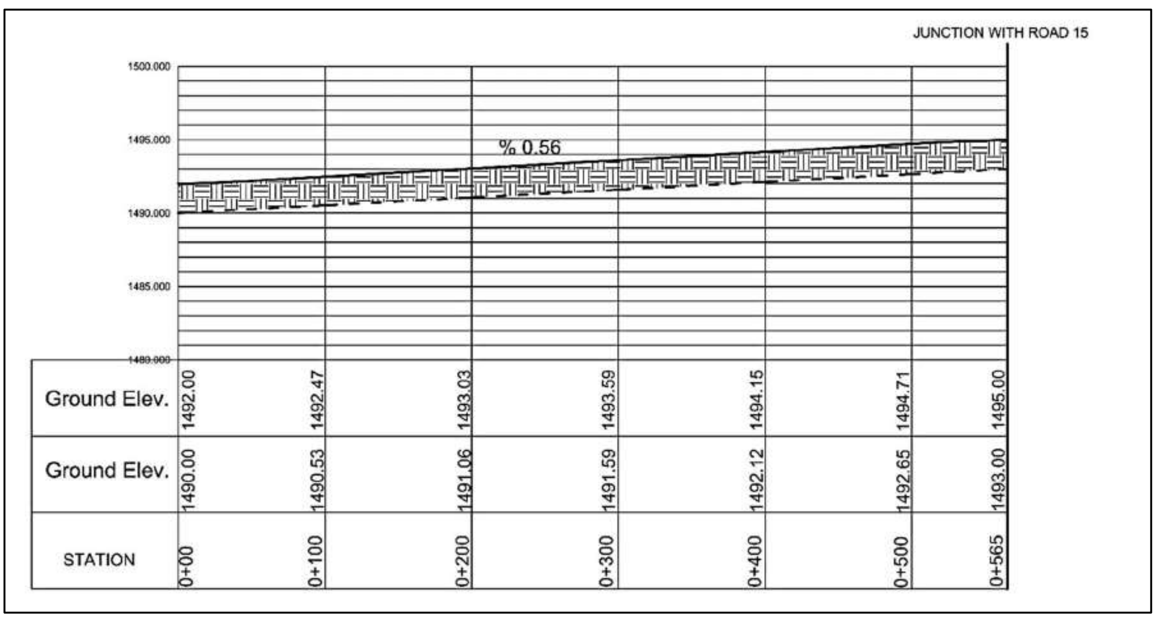


Figure A- 3: Profile of Road 7 and 8.



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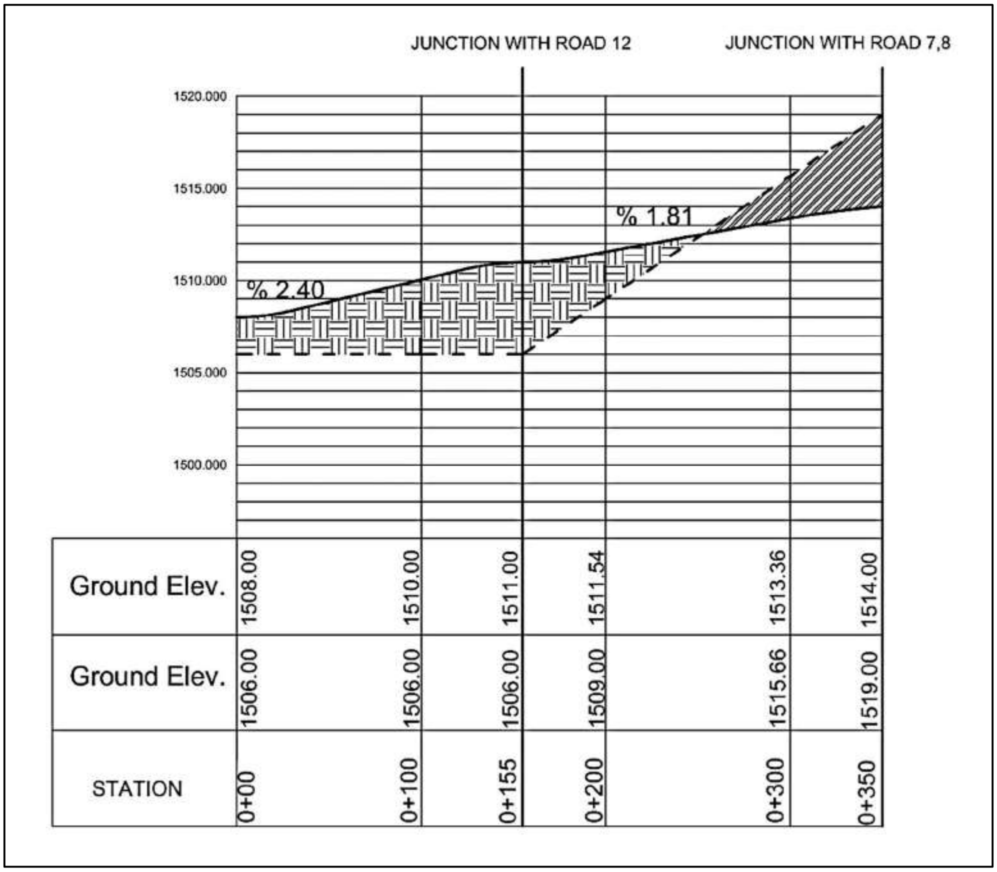

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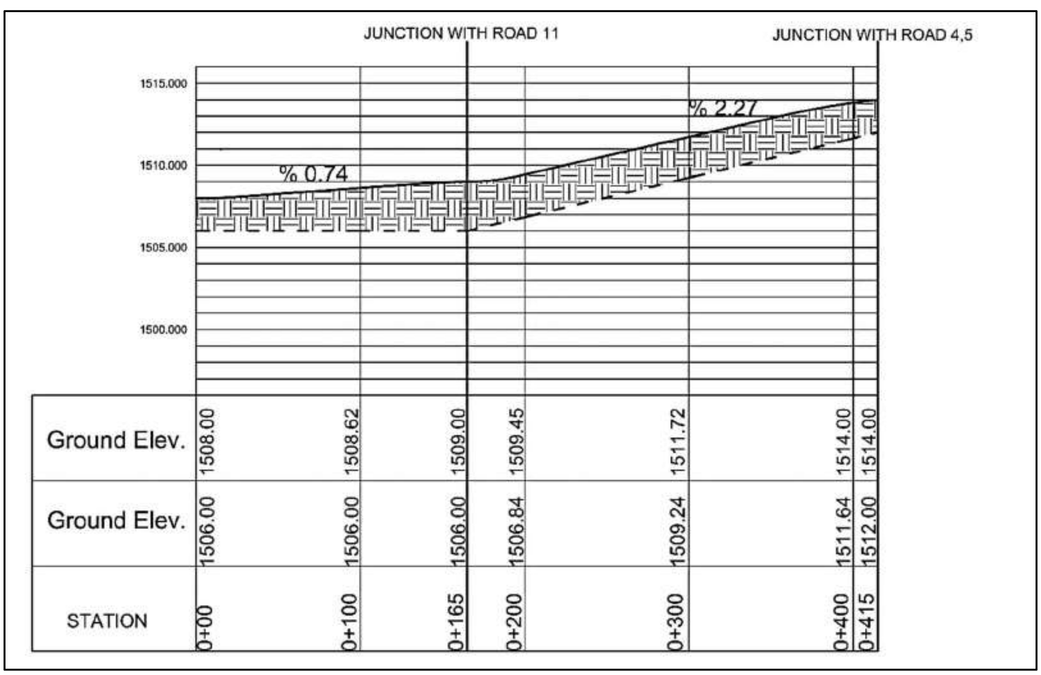

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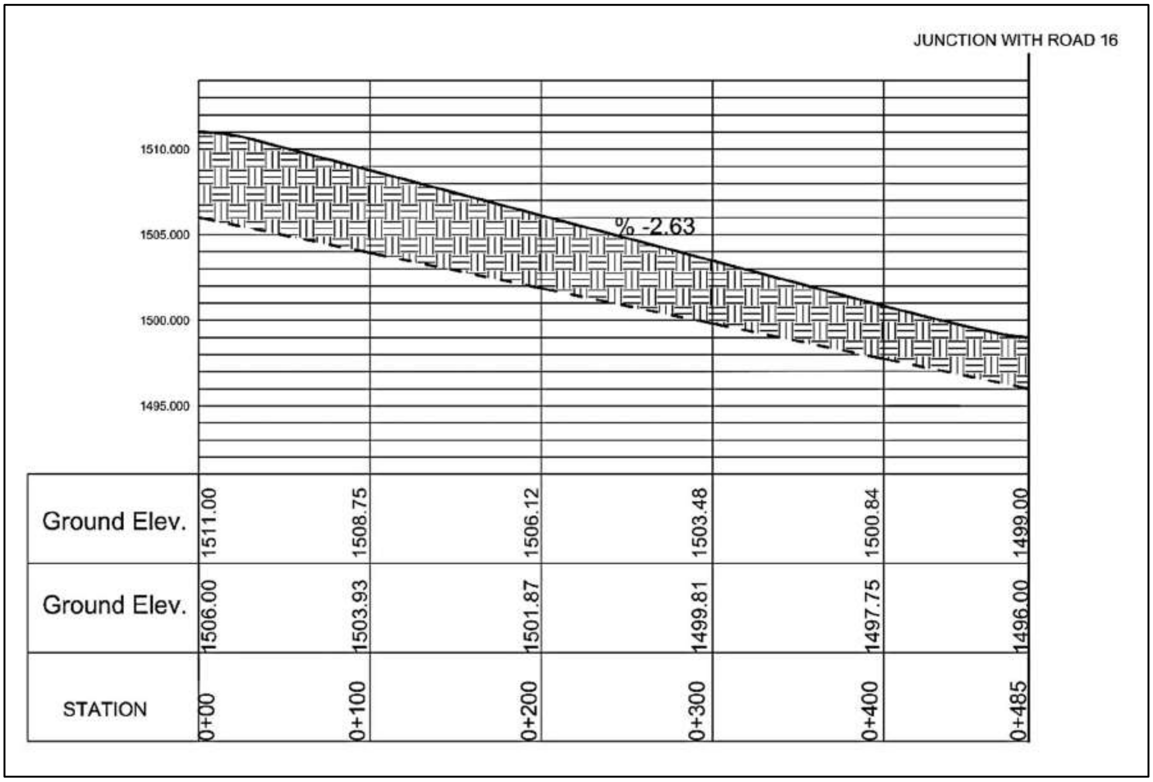

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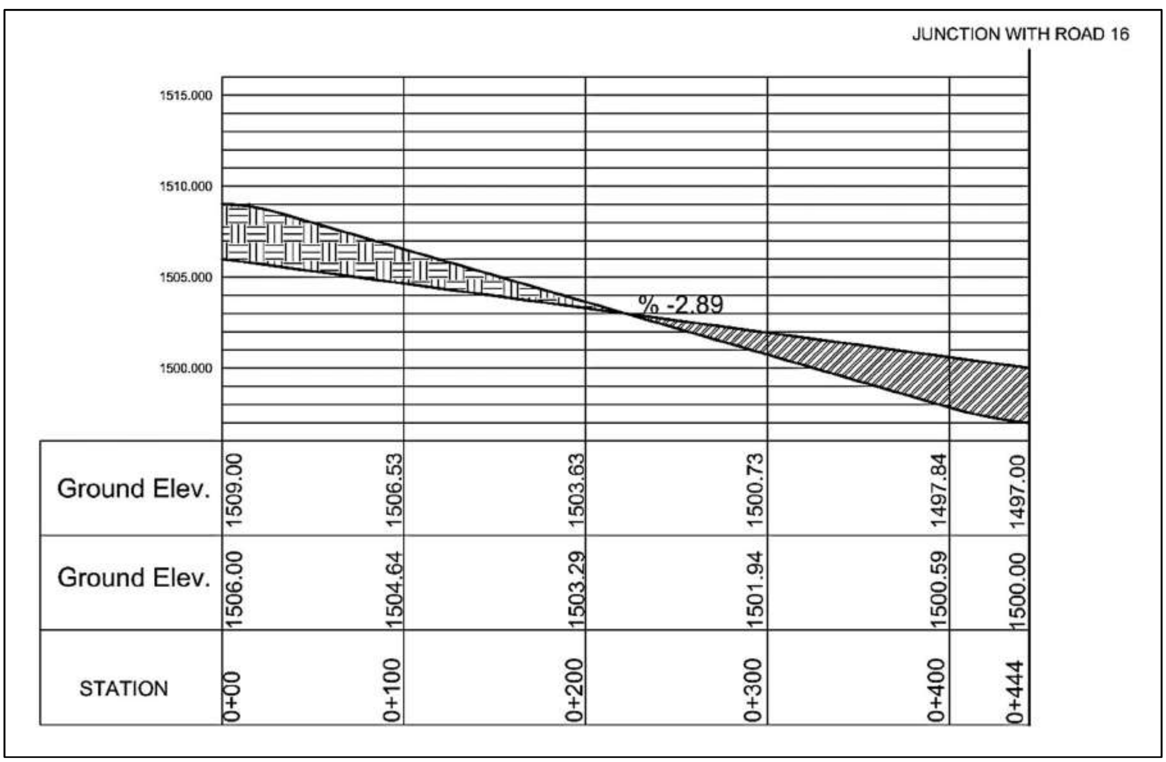

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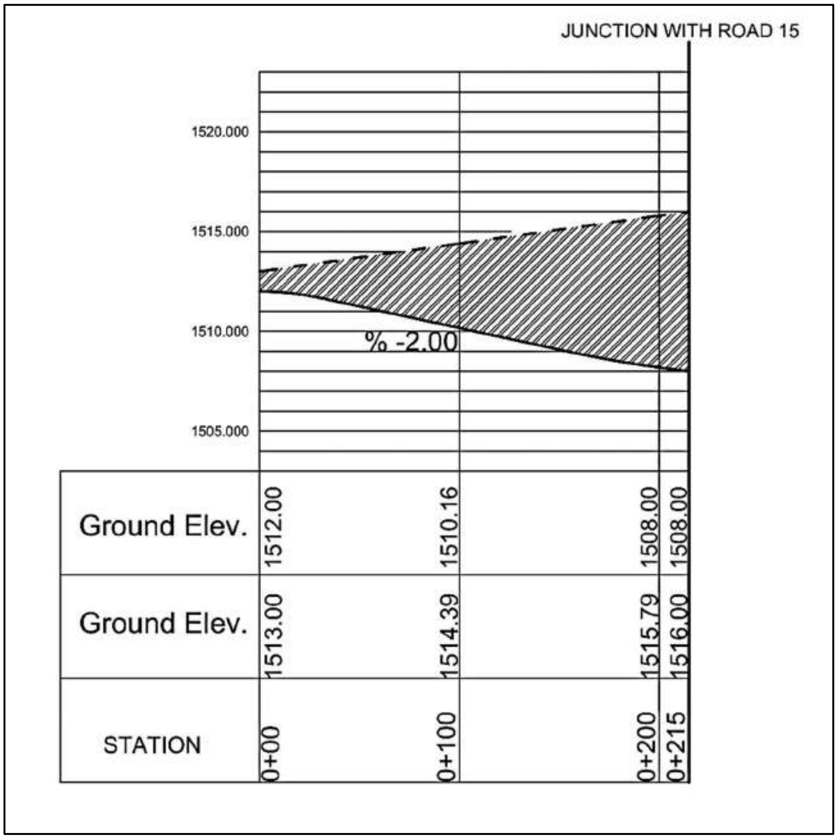


Figure A- 9: Profile of Road 14.

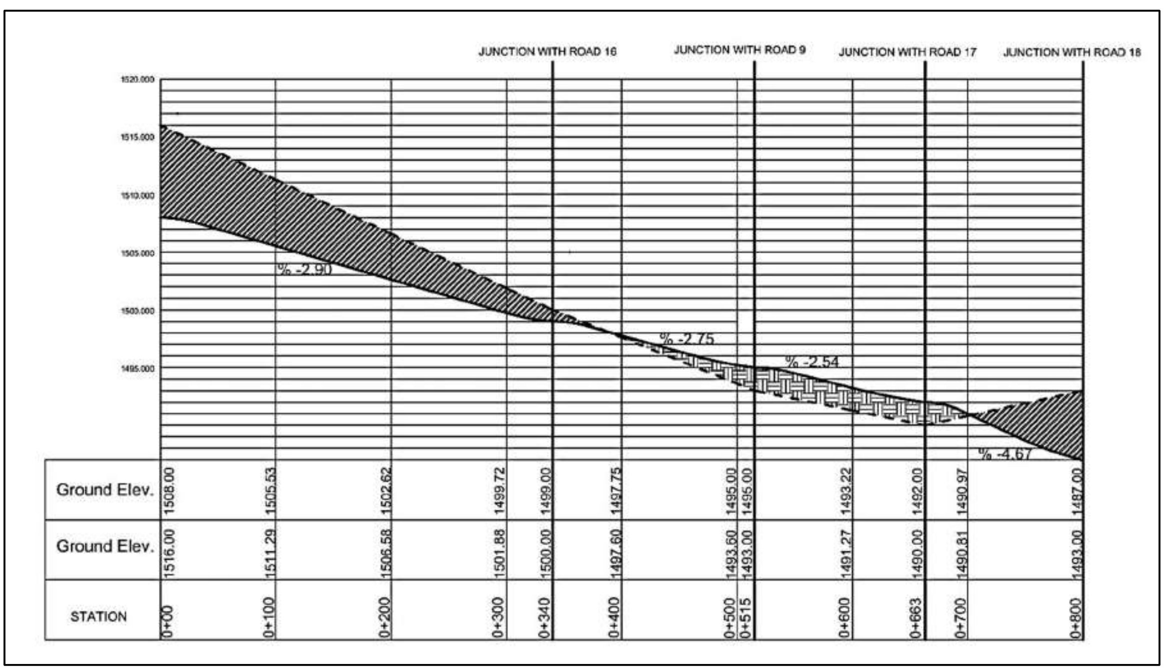


Figure A- 10: Profile of Road 15.

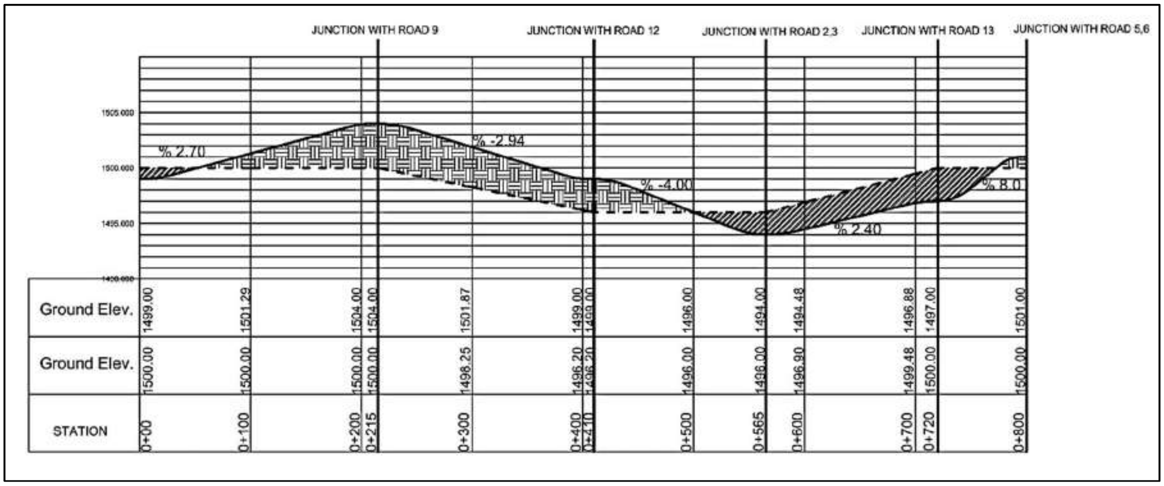


Figure A- 11: Profile of Road 16.

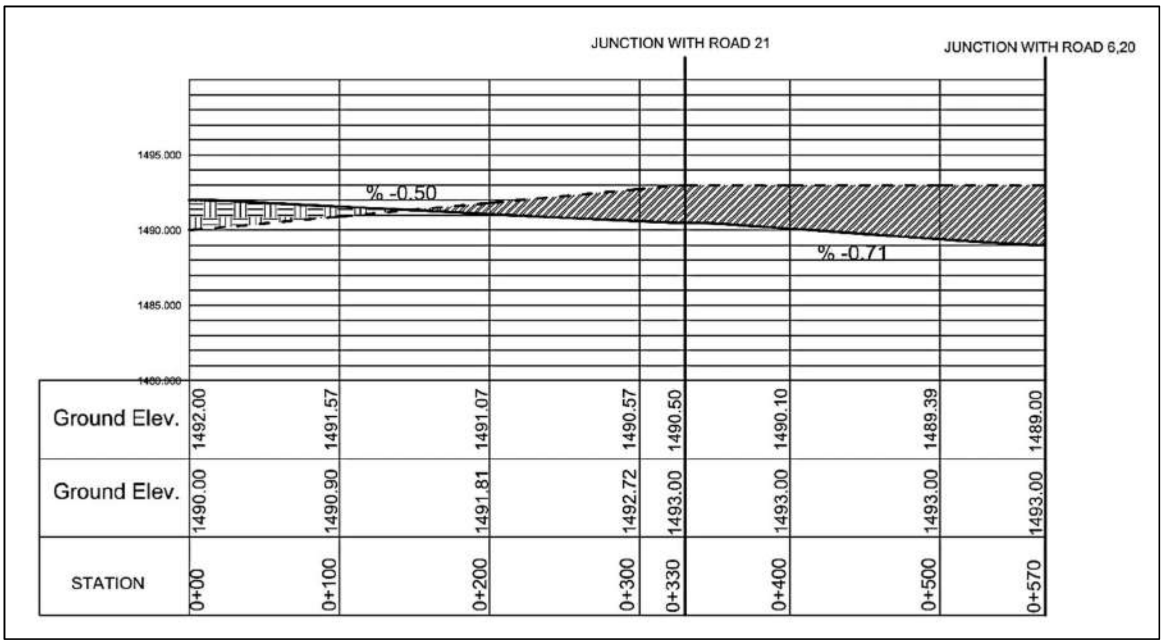


Figure A- 12: Profile of Road 17.

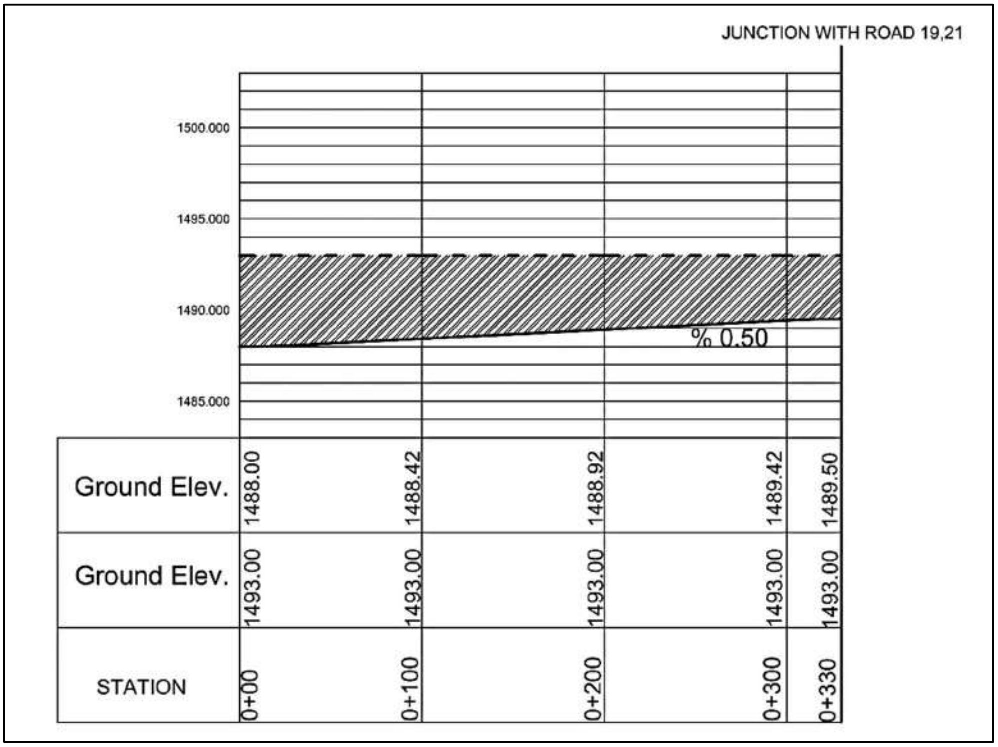


Figure A- 13: Profile of Road 18.

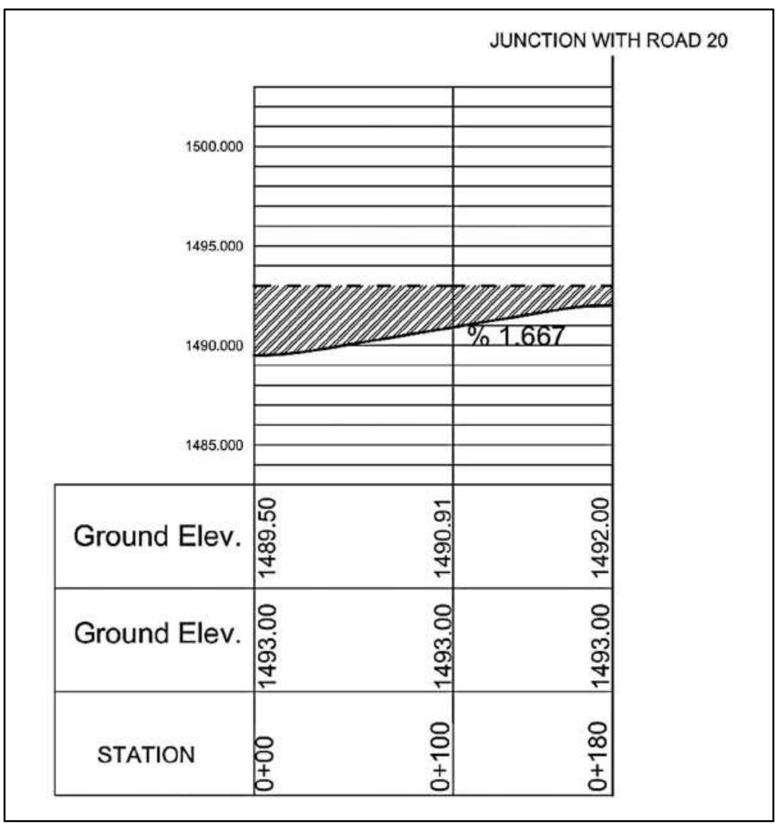


Figure A- 14: Profile of Road 19.

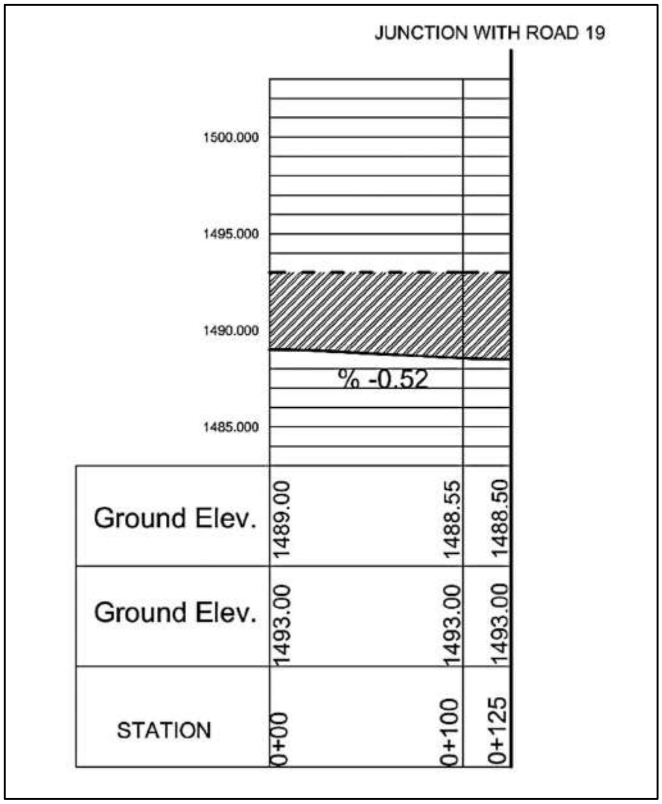


Figure A- 15: Profile of Road 20.

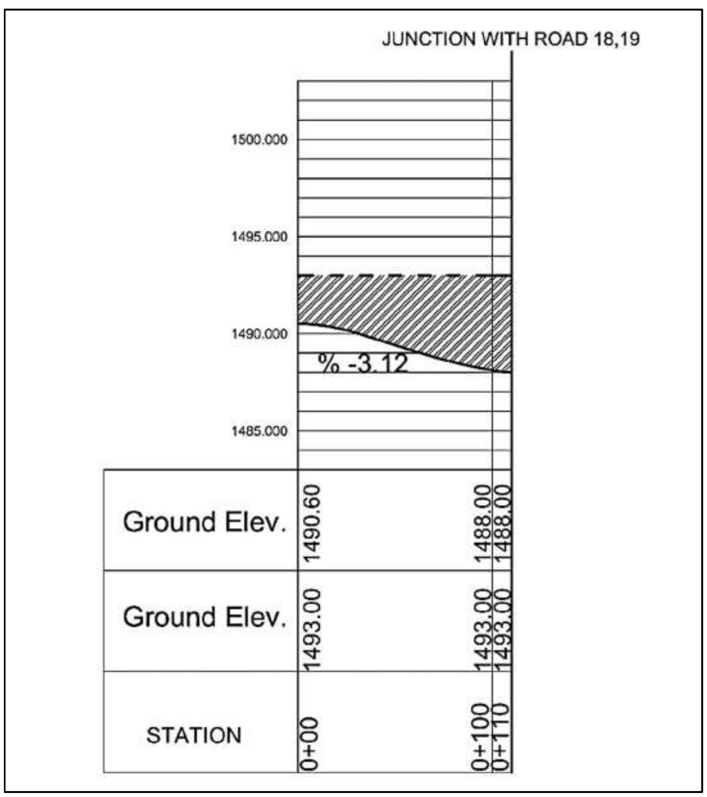


Figure A- 16: Profile of Road 21.

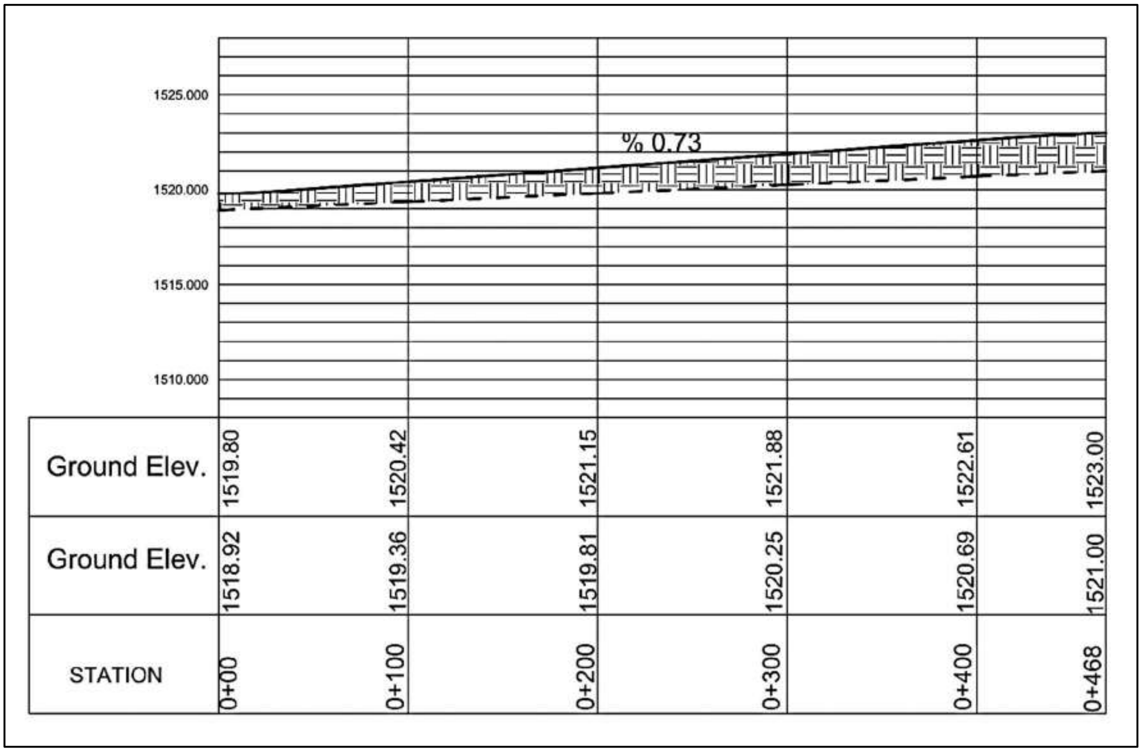


Figure A- 17: Profile of Road 22.

ANNEXURE [B]

Drain		Length	Frl		Area			C			I	Q=CIA		Invert Elevation (IL) (FT)		Invert Depth (ft)		Average Depth	Free Board	Water Depth	width	Area	Wetted Perimeter (P)	Hydraulic Mean Depth	Slope of road	Manning's Velocity	Full Discharge	Design check		
No.	Node		Start	End	Road Area (ft^2)	Green (ft^2)	Plot(s) Area (ft^2)	Road	Green	Plot	in/hr	cusec	$Q_{cummulative}$	Start (ft)	End (ft)	Start (ft)	End (ft)	D (ft)	(ft)	W_D (ft)	ft	ft^2	(ft)	R (FT)	S	(ft/s)	Q_{full} (cusec)	Discharge	Velocity	IL
DL # 1	1-2	428	1523	1519	10843	12197.00	35784	0.9	0.35	1	3	3.46	3.46	1522.00	1518.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.009	5.29	4.63	O.K	O.K.	O.K
DL # 2	2-30	188	1519	1514	8376	7846.00	0	0.9	0.35	1	3	0.71	4.17	1518.00	1513.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.027	8.93	7.81	O.K	False	O.K
DL # 3	30-31	281	1514	1504	10301	8875.00	15273	0.9	0.35	1	3	1.92	6.09	1513.00	1503.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.036	10.33	9.04	O.K	False	O.K
DL # 4	31-32	160	1504	1501	6041	5007.00	4723	0.9	0.35	1	3	0.83	6.92	1503.00	1500.00	1.00	1.00	1.0	0.3	0.70	1.50	1.05	2.90	0.362	0.019	7.97	8.37	O.K	O.K.	O.K
DL # 5	32-33	230	1501	1493	8542	7770.00	15001	0.9	0.35	1	3	1.76	8.69	1500.00	1492.00	1.00	1.00	1.0	0.3	0.70	1.50	1.05	2.90	0.362	0.035	10.86	11.40	O.K	False	O.K
DL # 6	33-23	182	1493	1489	6321	5484.00	0	0.9	0.35	1	3	0.53	9.21	1492.00	1487.50	1.00	1.50	1.3	0.3	0.95	1.50	1.425	3.40	0.419	0.025	10.09	14.38	O.K	False	O.K
DL # 7	6-7	373	1514	1508	9412	10687.00	42051	0.9	0.35	1	3	3.77	3.77	1513.00	1507.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.016	6.39	4.48	O.K	O.K.	O.K
DL # 8	3-7	208	1523	1508	5741	6278.00	16539	0.9	0.35	1	3	1.66	1.66	1522.00	1507.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.072	13.54	9.48	O.K	False	O.K
DL # 9	7-16	479	1508	1494	15201	13283.00	52021	0.9	0.35	1	3	4.89	14.18	1507.00	1492.50	1.00	1.50	1.3	0.3	0.95	1.50	1.425	3.40	0.419	0.030	11.17	15.91	O.K	False	O.K
DL # 10	14-15	382	1509	1497	10515	10182.00	43981	0.9	0.35	1	3	3.96	3.96	1508.00	1496.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.031	8.93	6.25	O.K	False	O.K
DL # 11	15-16	175	1497	1494	4678	4280.00	8538	0.9	0.35	1	3	0.99	4.95	1496.00	1493.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.017	7.17	6.27	O.K	O.K.	O.K
DL # 12	9-17	505	1506	1499	11641	10849.00	54782	0.9	0.35	1	3	4.80	4.80	1505.00	1498.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.014	6.45	5.64	O.K	O.K.	O.K
DL # 13	17-16	187	1499	1494	3096	2805.00	8744	0.9	0.35	1	3	0.87	8.12	1498.00	1493.00	1.00	1.00	1.0	0.3	0.70	1.50	1.05	2.90	0.362	0.027	9.52	10.00	O.K	False	O.K
DL # 14	10-7	233	1511	1508	5904	5467.00	11550	0.9	0.35	1	3	1.30	3.87	1510.00	1507.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.013	5.72	4.00	O.K	O.K.	O.K
DL # 15	4-10	261	1518	1511	9639	3632.00	15663	0.9	0.35	1	3	1.78	1.78	1517.00	1510.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.027	8.26	5.78	O.K	O.K.	O.K
DL # 16	11-10	121	1514	1511	8734	2207.00	2702	0.9	0.35	1	3	0.79	0.79	1513.00	1510.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.025	7.94	5.56	O.K	O.K.	O.K
DL # 17	18-17	189	1504	1499	5374	5154.00	28655	0.9	0.35	1	3	2.45	2.45	1503.00	1498.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.026	8.20	5.74	O.K	O.K.	O.K
DL # 18	5-19	811	1523	1504	21812	19191.00	61814	0.9	0.35	1	3	6.12	6.12	1522.00	1503.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.023	8.38	7.33	O.K	O.K.	O.K
DL # 19	12-13	175	1512	1508	6064	5808.00	6731	0.9	0.35	1	3	0.99	0.99	1511.00	1507.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.023	7.62	5.33	O.K	O.K.	O.K
DL # 20	13-20	325	1508	1499	8334	8165.00	27320	0.9	0.35	1	3	2.62	3.60	1507.00	1498.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.028	8.39	5.87	O.K	O.K.	O.K
DL # 21	19-20	234	1504	1499	6387	6271.00	20350	0.9	0.35	1	3	1.96	8.09	1503.00	1498.00	1.00	1.00	1.0	0.3	0.70	1.50	1.05	2.90	0.362	0.021	8.51	8.94	O.K	False	O.K
DL # 22	20-29	532	1499	1488	14664	14371.00	14284	0.9	0.35	1	3	2.26	13.95	1498.00	1486.75	1.00	1.25	1.1	0.3	0.83	2.00	1.65	3.65	0.452	0.021	9.82	16.20	O.K	False	O.K
DL # 23	16-21	210	1494	1492	6557	6037.00	6431	0.9	0.35	1	3	1.00	28.25	1493.00	1489.50	1.00	2.50	1.8	0.3	1.45	2.00	2.9	4.90	0.592	0.017	10.43	30.25	O.K	False	O.K
DL # 24	21-23	180	1492	1489	5806	5263.00	7500	0.9	0.35	1	3	1.01	35.38	1491.00	1486.50	1.00	2.50	1.8	0.3	1.45	2.00	2.9	4.90	0.592	0.025	12.77	37.05	O.K	False	O.K
DL # 25	22-21	608	1495	1492	14172	12655.00	70909	0.9	0.35	1	3	6.12	6.12	1494.00	1491.00	1.00	1.00	1.0	0.3	0.70	2.00	1.4	3.40	0.412	0.005	4.46	6.24	O.K	O.K.	O.K
DL # 26	26-23	270	1490.5	1489	6498	5437.00	20267	0.9	0.35	1	3	1.95	1.95	1489.50	1488.00	1.00	1.00	1.0	0.3	0.70	1.00	0.7	2.40	0.292	0.006	3.76	2.63	O.K	O.K.	O.K
DL # 27	26-27	130	1490.5	1488	3505	2159.00	2759	0.9	0.35	1	3	0.46	3.24	1489.50	1487.00	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.019	7.59	6.64	O.K	O.K.	O.K
DL # 28	28-26	297	1492	1490.5	8013	7091.00	30311	0.9	0.35	1	3	2.78	2.78	1491.00	1489.50	1.00	1.00	1.0	0.3	0.70	1.25	0.875	2.65	0.330	0.005	3.89	3.40	O.K	O.K.	O.K
DL # 29	23-25	187	1489	1488.5	6550	2276.00	0	0.9	0.35	1	3	0.46	47.00	1488.00	1484.75	1.00	3.75	2.4	0.3	2.08	2.00	4.15	6.15	0.675	0.017	11.62	48.24	O.K	False	O.K
DL # 30	25-27	163	1488.5	1488	4422	1985.00	0	0.9	0.35	1	3	0.32	47.33	1487.50	1484.25	1.00	3.75	2.4	0.3	2.08	2.00	4.15	6.15	0.675	0.020	12.45	51.67	O.K	False	O.K
DL # 31	27-29	328	1488	1487	8490	6871.00	13122	0.9	0.35	1	3	1.61	52.18	1484.25	1482.50	3.75	4.50	4.1	0.3	3.83	2.00	7.65	9.65	0.793	0.005	7.17	54.86	O.K	O.K.	O.K

Figure B. 1 Storm Drainage Design Calculation Sheet

ANNEXURE [C]

7/3/23, 9:59 PM SamSamWater - Rainwater Harvesting Tool (results)

Unit Conversion Other languag

SamSamWater Rainwater Harvesting Tool

Step 4 of 4 (results

print

Summary of results

The total amount of water that can be collected from this roof is not enough to fulfil the total water demand.
However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of **12992200 litres** (12992.2 m�) a rainwater harvesting system could provide 125301 litres of water per day, which is 22% of the total demand.

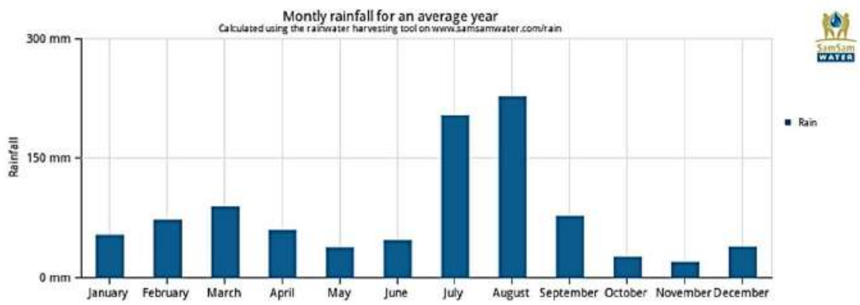
Details on the results and calculations can be found below.

Location

Location:	QP6M+J4R, 2, phase Wah Model Town, Wah Cantt, Rawalpindi, Punjab 47040, Pakistan
Latitude:	33.76177 degrees
Longitude:	72.73271 degrees
Roof size:	69021 square metres
Roof type:	flat
Runoff coefficient:	0.7
Water demand:	568500 litres per day

Rainfall

The average rainfall at this location varies between 19.4 mm in the driest month (November) and 226.5 mm in the wettest month (August). The total annual rainfall in an average year is 947 mm.

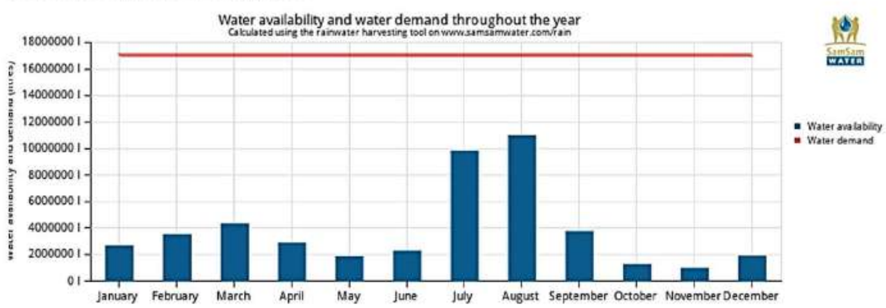


Water availability

A flat roof has a runoff coefficient of 0.7, which means that 70% of the rain can be harvested. Based on this runoff coefficient and a roof area of 69021 square metres a volume of 937305 litres (19.4 mm x 69021 m� x 0.7) of water can be collected in the driest month (November) and 10943280 litres (226.5 mm x 30 m� x 0.7) in the wettest month (August).
The total yearly amount of water that can be collected from the roof is 45734700 litres (45735m�) in an average year.

Water demand

The water demand is 568500 litres per day, which equals to about 17055000 litres per month. The total water demand is 207502500 litres (207502.5 m�) per year.
The amount of water that can be collected from the roof (45735m�) is less than the water demand (207502.5 m�). Only a part of the water demand can be fulfilled using a rainwater harvesting system.



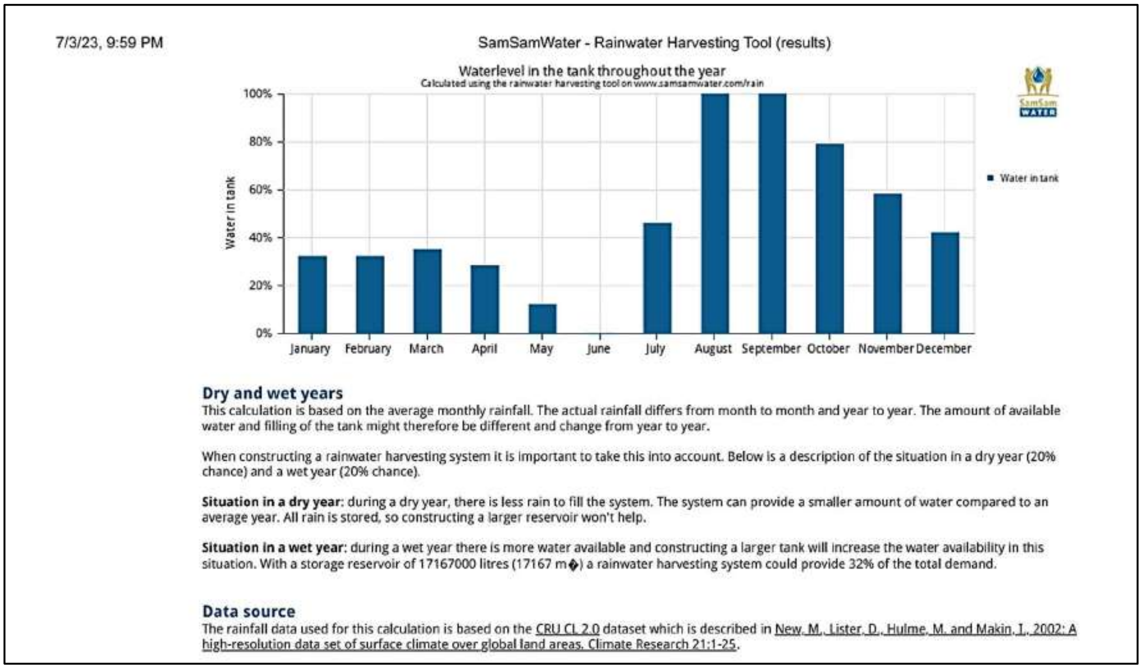
Required storage

The total amount of water that can be collected from this roof, 45734700 litres, is not enough to fulfil the total yearly water demand of 207502500 litres However, it might still be worthwhile to construct a rainwater harvesting system. With a storage reservoir of 12992200 litres (12992.2 m�) a rainwater harvesting system could provide 125301 litres of water per day, which is 22% of the total demand.

The storage reservoir will be full in and then slowly drain until it is (almost) empty at the end of June.

https://www.samsamwater.com/rain/step4.php?lat=33.76177&lng=72.73271&zoom=17&roofarea=69021&roofoption=1&rooftype=flat&runoffcoef=... 1/2

Figure C- 1: SamSam Model Report Output (Page-1)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SamSamWater - Rainwater Harvesting Tool (results)

Dry and wet years

This calculation is based on the average monthly rainfall. The actual rainfall differs from month to month and year to year. The amount of available water and filling of the tank might therefore be different and change from year to year.

When constructing a rainwater harvesting system it is important to take this into account. Below is a description of the situation in a dry year (20% chance) and a wet year (20% chance).

Situation in a dry year: during a dry year, there is less rain to fill the system. The system can provide a smaller amount of water compared to an average year. All rain is stored, so constructing a larger reservoir won't help.

Situation in a wet year: during a wet year there is more water available and constructing a larger tank will increase the water availability in this situation. With a storage reservoir of 17167000 litres (17167 m�) a rainwater harvesting system could provide 32% of the total demand.

Data source

The rainfall data used for this calculation is based on the CRU CL 2.0 dataset which is described in New, M., Lister, D., Hulme, M. and Makin, I., 2002: A high-resolution data set of surface climate over global land areas. Climate Research 21:1-25.

Figure C- 2: SamSam Model Report Output (Page-2)