



Dissertation

Master in Civil Engineering - Building Construction

***Water Efficiency Analysis in the Classroom Building
and Hydraulics Laboratory of the Faculty of
Engineering, Physical Sciences and Mathematic –
Central University of Ecuador***

Carlos Andrés Valenzuela Portilla

Leiria, July of 2018

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Carlos Andrés Valenzuela Portilla

Dissertation developed under the supervision of Doctor Ricardo de Jesus Gomes, Professor at the School of Technology and Management of the Polytechnic Institute of Leiria and co-supervision of Doctor Armando B. Silva Afonso, full Professor at the University of Aveiro (retired) and Master Freddy Muñoz Tobar, Professor at the Faculty of Engineering, Physical Sciences and Mathematic of the Central University of Ecuador.

Leiria, *July of 2018*

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Dedication

To my beautiful wife, Karla...

To my mother, Inés...

To my father, Carlos.

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To God, for giving me this opportunity, the life and strength necessary to achieve this goal.

To all, my greatest feeling of gratitude...

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Resumo

O Equador, localizado no meio do mundo, é um dos menores países da América do Sul com o maior número de recursos de água doce superficiais e subterrâneas. O impacto global que afeta as reservas mundiais desse recurso natural também afeta os países da região devido ao acelerado crescimento populacional, às mudanças climáticas, ao obsoleto da tecnologia e à falta de hábitos sobre a necessidade de reduzir o consumo excessivo e o desperdício de bebida. água.

A maior taxa de consumo de água potável entre os países da América do Sul é do Equador, com mais de 237 litros/(habitante.dia). Este número alarmante é uma das razões pelas quais é importante reduzir o consumo de água potável em edifícios não residenciais sem afetar o conforto dos usuários. O principal objetivo deste trabalho é analisar a eficiência hídrica de edifícios universitários em Quito através da aplicação do modelo de cálculo sugerido pela Associação Nacional para a Qualidade nas Instalações Prediais - (ANQIP).

Diferentes estratégias e técnicas são aplicadas para cumprir este objetivo, entre elas, a caracterização arquitetônica e hidro-sanitária dos edifícios, a avaliação de cada dispositivo sanitário e sua eficiência hídrica, bem como a determinação de vazões volumétricas nas instalações dos edifícios. que fazem parte do estudo de caso.

A escassez gradual de água potável gera a necessidade de encontrar fontes alternativas para o fornecimento deste recurso. O projeto de um sistema de coleta de água da chuva se torna a solução integral proposta para fornecer água para usos não potáveis, reduzir o consumo de água potável, reduzir custos de faturamento e transformar edifícios em projetos hidráulicamente sustentáveis.

Conclui-se que os sistemas de captação de água da chuva fornecem volumes importantes de água para fins não potável em edifícios como estabelecimentos universitários.

Palavras-chave: Eficiência; SAP; edifícios; sustentabilidade; rotulagem.

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Abstract

Ecuador, located in the middle of the world, is one of the smallest countries in South America with the largest number of surface and underground freshwater resources. The global impact that affects the world reserves of this natural resource, also affects the countries of the region due to an accelerated population growth, climate change, the obsolescence of technology and the shortage of habits about the need to reduce excessive consumption and waste of drinking water.

The highest rate of drinking water consumption among the countries of South America is from Ecuador, with more than 237 liters/(inhabitant.day). This alarming figure is one of the reasons why it is important to reduce drinking water consumption in non-residential buildings without affecting the comfort of users. The main objective of this work is to analyze the water efficiency of university buildings in Quito through the application of the calculation model suggested by the Portuguese Association for Quality in Building Services Installations (ANQIP).

Different strategies and techniques are applied to fulfill this objective, among them, the architectural and hydro-sanitary characterization of the buildings, the evaluation of each sanitary device and its water efficiency, as well as the determination of volumetric flows in the facilities of the buildings that form part of the case study.

The gradual shortage of drinking water generates the need to find alternative sources for the supply of this resource. The design of a rainwater harvesting system becomes the integral solution proposed to supply water for non-potable uses, to reduce consumptions of potable water, to reduce billing costs and to transform buildings into hydraulically sustainable projects.

It is concluded that rainwater harvesting systems provide important volumes of water for non-drinking purposes in buildings such as university establishments.

Keywords: *Water-efficiency; R.H.S.; buildings; sustainability; labeling.*

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List of acronyms

ANQIP: Associação Nacional para a Qualidade nas Instalações Prediais

ASTM: American Society of Testing Materials

BEPAC: Building and Environmental Performance Assessment Criteria

BREEAM: Building Research Establishment Environmental Assessment Method

C: Roughness Coefficient according with Hazen-Williams

CASBEE: Comprehensive Assessment System for Building Environmental Efficiency

Di: Internal diameter [mm]

EPMAPS: Empresa Pública Metropolitana de Agua Potable y Saneamiento

f: Friction Coefficient according with Moody's Diagram

hb: Pressure drop due to broadening effect (steel pipes)

hr: Pressure drop according with Darcy-Weisbach

hn: Pressure drop due to narrowing effect (steel pipes)

i: Maximum Rainfall Intensity [mm/h]

INAMHI: Instituto Nacional de Meteorología e Hidrología

INEN: Servicio Ecuatoriano de Normalización

IWA: International Water Association

J: Head loss according with Hazen-Williams [m/m]

LEED: Leadership in Energy & Environmental Design

m.a.s.l: Meters above sea level

MDQ: Metropolitan District of Quito

NASA: National Aeronautics and Space Administration

PE: Polyethylene

PP: Polypropylene

PVC: Polyvinyl chloride

Q: Volumetric flow rate [l/s]

RHS: Rainwater Harvesting System

S: Flow Speed inside the pipeline [m/s]

SUDS: Sustainable Urban Drainage Systems

UWC: Urban Water Cycle

WHO: World Health Organization

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1. Introduction

1.1. Framework

Water has been, is and will be one of the most important non-renewable natural resources available for the existence of life on planet earth. This resource is essential for living beings, humans, fauna, flora, nature and even for the socioeconomic development of all nations in the world. Currently, one of the main problems facing the world is the shortage of fresh water used to meet the consumption needs of the population due to a set of factors that have caused this situation. The rapid population growth, increased consumption of drinking water, lack of consumption's regulation and control mechanisms, global warming, climate change, uncontrolled exploitation of natural freshwater resources, the pollution of water resources, dependence on energy resources and lack of awareness to reduce the waste of this natural resource, are part of those factors that have produced the reduction in water availability.

In Latin America, especially in Ecuador, the concept of water preservation is still not well known or very little practiced. One of the aspects that cause this lack of social awareness and the application of regulatory measures has to do with the abundance of water that some countries have (at the moment) and that have not developed plans that conserve this resource to guarantee their quantity and quality to future generations. The population growth in Ecuador is indirectly proportional to the volumes of water available in existing water fields; reason enough to begin by changing the current situation related to the excessive and uncontrolled consumption of drinking water in buildings.

The obligation to preserve this natural resource taking into account the population growth of the country is one of the most special motivations to implement measures of consumptions reduction. For example, the installation of devices that improve the water efficiency of buildings, the use of another type of water (rainwater) as an alternative to water supply systems for buildings can be analyzed in order to preserve water and even to give other types of solutions related to urban flooding. Water supply is a basic need of the world population, which is why it is important to establish actions to ensure the availability of this resource for

future generations, through the implementation of measures at local and global level in order to achieve short, medium and long-term results.

With regard to local and specific solutions within Civil Engineering alternatives, it is proposed as an object of study in the present research, the analysis of measures of Water Efficiency that can be applied to buildings, with the aim of contributing to the reduction of consumption and waste of water. Although this type of research or study does not guarantee the availability of water in the future, it promotes and motivates the use of good and responsible practices for the conservation of this resource in public and private facilities, where the awareness of the users can be tested in the daily water expenditure.

Based on the current situation in Ecuador and the city of Quito, which will be detailed in the following points, this research work focuses mainly on the application of alternative systems or resources such as the use of rainwater that can be captured in the building studied. Heavy rains lasting from September to May each year in the city cause severe flooding due to its topography and deficiencies in the public drainage system. This is one of the most important reasons to take into account the use of alternative resources that allow to reduce the consumption of water from public water supply systems and therefore to reduce the energy consumptions that are required to provide this service to buildings from the city.

For the present case study, the basic considerations and characteristics of the rainwater harvesting system that could be implemented in the building, the area and volume of water collection, the treatment system and the storage system are analyzed. Through a thorough study of the water cycle, efficient use of water in water supply systems, urban sustainability of drainage systems and water efficiency in buildings related to measures, technologies, loss reduction devices, certifications and water balances. Based on the solutions, technical suggestions presented, and the development of the model that improves the water efficiency of the building under study, the aim is to reduce the consumption of drinking water, also reducing energy consumption and associated production costs. Taking into consideration that in Ecuador water efficiency in buildings is a completely new and necessary case study, it aims to raise social awareness about the need to preserve water as a natural resource from buildings, with the simple and planned implementation of systems that contribute to the improvement of the sustainability of the new constructions of today. To fulfill this objective, all materials and devices in the Ecuadorian market will be taken into consideration.

1.2. Topic Overview

In order to understand the need to preserve water as a natural resource for the population and as an essential basic service, it is important to analyze and evaluate the current situation through official figures or statistics, which describe reality in a better way.

According to UNESCO reports (United Nations Educational, Scientific and Cultural Organization), only 2.53%¹ of the total water on the planet Earth is fresh water, that is, only this percentage can be used for consumption of living beings considering that the difference of percentage is saline water.

Certainly, one of the most important and up-to-date indicators that can contribute to identifying today's problem with the availability of fresh water in the world is the growth of the world's population. Official figures reveal that the total population in millions is 7,433 by 2016².

While it is true that fresh water reserves are sufficient to meet the needs of the current population as shows the Figure 1.1, exaggerated consumption and waste water, do not guarantee that this capacity will be maintained for future generations.

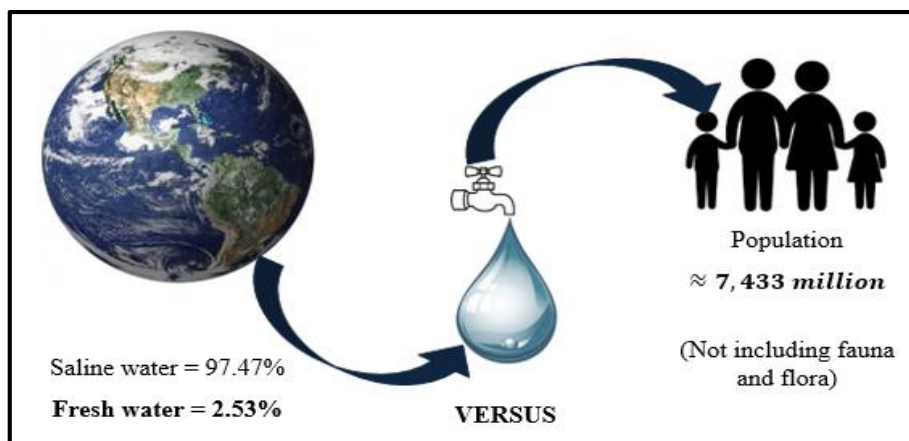


Figure 1.1 – Water Reserves vs Current Population (2016)

Source: Author's compilation

¹ United Nations Educational, Scientific and Cultural Organization – UNESCO, (2015)

² United Nations Population Fund - UNFPA, (2016)

To have a clearer idea of the quantity of fresh water available on Earth, it is essential to review the official figures of some bibliographical references, in order to understand the need to establish control over water consumption. It is also important to analyze the use of water at a global level in order to identify the most common activities for which this resource is intended.

As shows Table 1.1 and Figure 1.2, the availability of fresh water is very small compared to the total volume of water that exists on Earth and is mostly unfit for human consumption. Due to the dramatic global warming and permanent climate change, glaciers and ice caps suffer a slow melting process due to the intensification in the ambient temperature, which causes an increase in the level of the sea and in turn that this type of fresh water resources disappear completely. In the last decades, the world has witnessed the radical change in the morphology of glaciers in the two poles and in the loss of glaciers present in volcanoes and mountains all over the world. Ecuador is one of the countries that has lost much of its glaciers located in volcanoes and mountains in recent years because of this climate change.

Table 1.1 - World Water Distribution

WORLD WATER DISTRIBUTION			
Type	Water Volume (million km³)	Percent of fresh water (%)	Percent of total water (%)
TOTAL WATER	1386		100
Fresh water	35.0	100.0	2.53
Glaciers and ice caps	24.4	69.70	1.76
Groundwater	10.5	30.00	0.76
Lakes, rivers, atmosphere	0.1	0.30	0.01
Saline water	1351		97.47

Source: Food and Agriculture Organization of the United Nations – FAO, (2002)

One of the resources with more fresh water after glaciers is under surface (groundwater) however in many places of the world it is very difficult to exploit these resources because of the depth to which they are located and the costs generated by this activity. This type of resource contains high quality water in most cases but its extraction seems to be the next step to cover the water demands that will be required in 2050. The freshwater resource offered by rivers and lakes is very limited compared to other types of resources, but this resource is one of the most exploited currently by the extraction facilities it provides. The

surface resources are not only used to capture the water and provide this service to the cities, but also as a generator of electric power, which is why its availability is always threatened.

Of these 35 million km³ of fresh water, is satisfied not only the consumption needs of the population, of animals and plants, but also of the socioeconomic activities to which the inhabitants of the earth are dedicated. In general, fresh water is destined for three important sectors: urban (human consumption), industrial (commercial - economic) and agriculture.

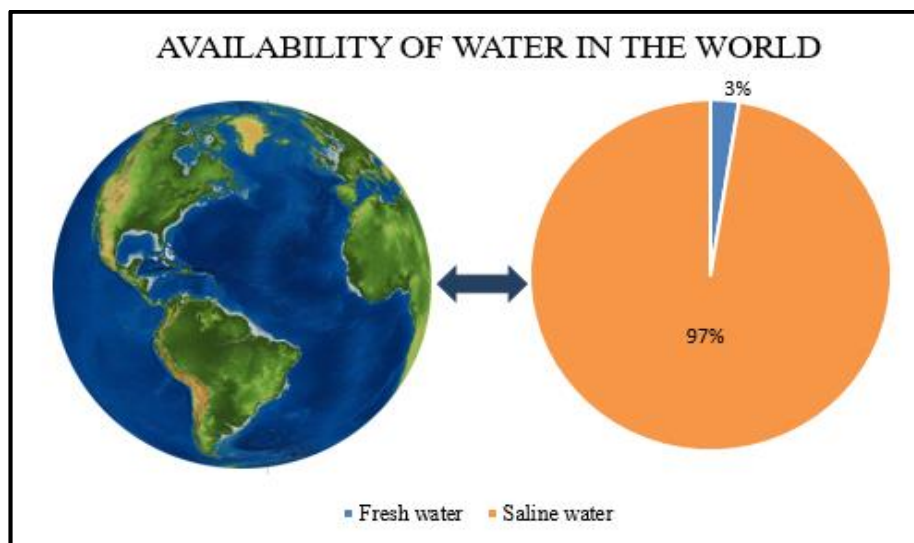


Figure 1.2 – Availability of water in the World

Source: Author's drawings

As shows the Figure 1.3, global withdrawals and water consumption are directly related to the sectors mentioned above. Water efficiency in buildings is then associated to reducing water consumption and waste water at the urban level. While it is true that municipal water consumption and waste water is not the largest compared to other activities in which water is used, it is important to reduce water consumption and waste water, to ensure the availability of this resource in the future.

As can be seen, it is paradoxical that municipal waste water is higher (8%) than municipal water consumption (3%), reason for which it is important to pay attention to the concept of saving water. Maybe, the infiltration of rainwater in domestic drainage system has an effect about this.

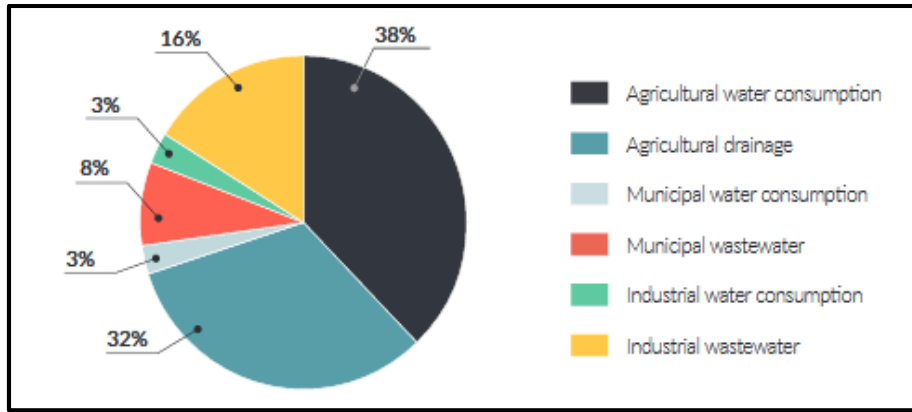


Figure 1.3 – Fate of global freshwater withdrawals

Source: The United Nations World Water Development Report 2017, (2017)

It is very important to distinguish the percentages presented in the Figure 1.4 to differentiate between the water being withdrawn and the water consumed. Most of the water withdrawn for domestic consumption returns to rivers and aquifers as waste water often without treatment.

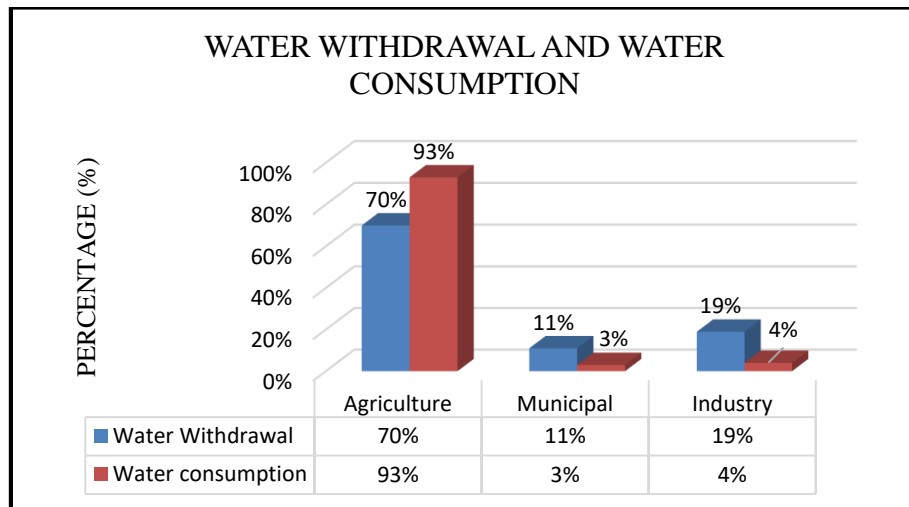


Figure 1.4 – Water withdrawal and water consumption

Source: The United Nations World Water Development Report 2017, (adapted)

It is also important to analyze the variation of the availability of fresh water through rainfall or precipitations according to the geographical location of each country. For example, Figure 1.5 shows that the total renewable water resources per capita for Ecuador varies between 15000 and 50000 m³. This data is very important for the present research project,

considering that the case study takes into account the use of rainwater as an alternative resource of water supply for buildings according to the concept of water efficiency.

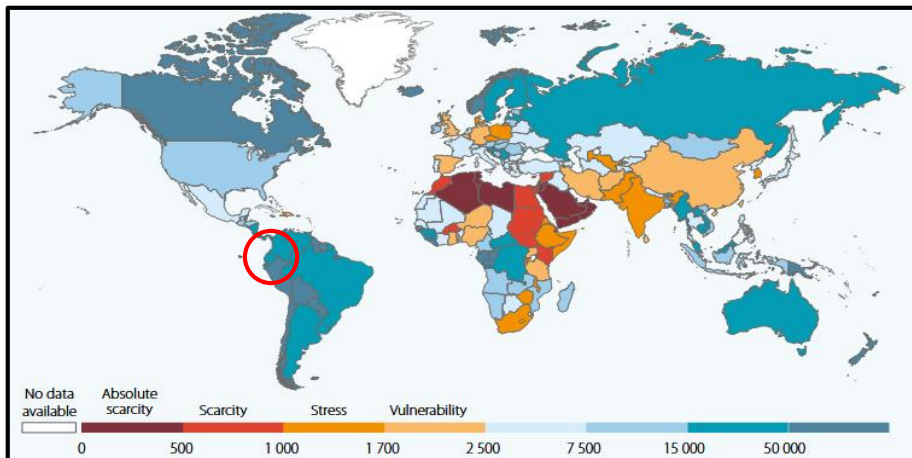


Figure 1.5 - Total renewable water resources per capita, (2013)

Source: UNESCO – The United Nations World Water Development Report 2015

“The average annual rainfall over land amounts to 119000 km³, of which some 74000 km³ evaporate back into the atmosphere. The remaining 45000 km³ flow into lakes, reservoirs and streams or infiltrate into the ground to replenish the aquifers. This represents what is conventionally called "water resources". Not all of these 45 000 km³ are accessible for use because part of the water flows into remote rivers and during seasonal floods. An estimated 9 000 - 14 000 km³ are all that are economically available for human use, a teaspoon in a full bathtub compared to the total amount of water on earth. ...” (p. 1)³

The figures presented above allow to understand the current and the global situation of water as a nonrenewable resource and emphasize the importance of establishing a control point that regulates the consumption levels of this resource in buildings, which would be classified within the municipal use of water (for human consumption). As for the sector of industry and agriculture, it is important to establish other water efficiency research to reduce water consumption.

Information about water availability in Latin America is scarce or at best has not been updated. However, it is important to know the current situation of the region that Ecuador is located. After Asia, South America has one of the largest water availabilities. One of the

³ Food and Agriculture Organization of the United Nations - FAO, (2002)

advantages of South America is that it has this great concentration of fresh water and a population to serve very small compared to other regions of the world. Due to its geographical location, climatic conditions and extensive jungle regions, fresh water in South America is very abundant (Table 1.2). The problem is fundamentally, in spite of not having overpopulation, there is no control or mechanisms in place for the preservation of water in these reserves.

Table 1.2 – Fresh water availability compared to population

AVAILABILITY OF FRESH WATER IN THE CONTINENTS		
Continent	Population (%)	Fresh water Availability (%)
Africa	13	11
Asia	60	36
Australia & Oceania	< 1	5
Europe	13	8
North & Central America	8	15
South America	6	26

Source: Amigos de la Tierra América Latina y el Caribe, (2016)

“The estimated extension of the water supply in South America is 13,555 km³...” (p. 16)⁴

Another important factor that contributes with this amount of fresh water for South America is the number of rivers that have their countries, among them the Amazon River which is the largest river by volume of water in the world and that alone concentrates a fifth part of fresh water in the liquid state of the planet. The orographic influence of the countries of South America and especially of those that are crossed by the Andes Mountains like Ecuador, possess high availability of water in comparison to its surface and population.

The largest amount of water is concentrated in the central zone of South America, in one of the largest jungle extensions in the world located in Brazil. For this reason, water stress levels are different throughout the region.

This unequal distribution of water in the regions of South America can be perceived in some countries more than in others, due precisely to the lack of mechanisms, norms and

⁴ Amigos de la Tierra América Latina y el Caribe, (2016)

regulations that allow to control the consumption of water of the inhabitants through a responsible administration of this one resource.

As can be seen in Figure 1.6, the availability of the resource does not mean that it is accessible to the entire population.⁵ This implies that the majority of countries with high availability levels experience declines in levels of drinking water coverage for their populations, as is the case in Ecuador. According to the source, between 71% and 80% of the population in Ecuador has access to potable water, that is, in the worst case, approximately 29% of its inhabitants do not have this basic service, or are victims of their scarcity or poor quality.



Figure 1.6 - Tribunal Latinoamericano del Agua, (2017)

Source: Population with access to drinking water in Latin America and the Caribbean

This fact is another element that justifies applying water efficiency systems in buildings, since despite having the necessary reserves of water, not all the inhabitants of the country have access to this natural resource. Contributing to reduce current water consumption, can contribute to more people who are beneficiaries of the potable water service.

⁵ Tribunal Latinoamericano del Agua, (2017)

1.2.1. Natural resources available in Ecuador

Located in the northwestern part of South America, Ecuador is a country with an area of 283'560 km² and an approximate population of 16.4 million inhabitants. Its capital Quito, becomes one of the most important and outstanding cultural heritages of humanity. Ecuador has four natural regions, Costa, Sierra, Orient or Amazon and the region of the Galapagos Islands located in the Pacific Ocean.



Figure 1.7 - Continental Ecuador

Source: Google Earth v7.1.8.3036

Privileged for being located in the center of the world, Ecuador becomes a small country with one of the most abundant biodiversity in the world, with innumerable climates of tropical characteristics and an enormous natural resource heritage that become today, in the main economic and energy engine of the country. These natural resources are essential for the development of the population; they supply raw materials, food, energy and water for consumption as well as agriculture and industries. Ecuador has a set of renewable natural resources such as fauna, animals, water and soil and non-renewable as minerals, metals, petroleum, natural gas and inexhaustible ecological time resources, as sea wave energy, wind, sunlight, among others.

The concept of renewable water in Ecuador is very questionable. In order to adopt this statement as such, it is necessary to have a very rigorous control of its use, treatment, and, circulation, otherwise it becomes a non-renewable resource. For this reason and considering all the demographic and economic background, it is very difficult to guarantee that in Ecuador this resource will remain as renewable within a few years.

Because of its geographical location and the natural action of the Andes Mountains, Continental Ecuador has a diverse orography that give rise not only to three well-defined natural regions but also to a large number of rivers whose origin comes precisely from these

mountains, being the country with more rivers per square meter in the world. Its freshwater reserves are not only concentrated in these rivers, but also in the aquifers of the eastern region, which are the most abundant in the country. It is impossible to forget the volcanoes and mountains of “perpetual” snow and glaciers, which give rise to large rivers that are the main resource for the withdrawal of water for consumption, agriculture and industry (energy generation).

As shown in the Table 1.3, the water availability of the Pacific slope is high in view of the 2000 m³/inhabitant/year, which is considered to be scarce especially in times of low precipitation. However, it is important to note that this value is not very far from the critical level.

According to the Diagnosis of Water Statistics in Ecuador and the study carried out by SENAGUA (Secretaría Nacional del Agua – Ecuador), the following statistical results are considered as starting data:

- Under conditions of natural water regime and without regulation dams the availability of fresh water through natural slopes is as follows:

Table 1.3 – Fresh Water availability in Ecuador

FRESH WATER AVAILABILITY IN ECUADOR		
Natural slope	Resources of water (GUARANTEE OF 90%) (Hm³/year)	m³/inhab/year
Pacific	60563	4600
Amazonas	228917	340000
Total Continental Ecuador	289480	21067

Source: Comisión Económica para América Latina y el Caribe - CEPAL, (2012)

Of course, this amount of freshwater considered as the current reserve of Ecuador varies with respect to the factors that determine the consumption of this resource: population growth, economic development, water demand and its uses, water management and policies established to preserve this natural resource. Considering the expectation of population growth worldwide of approximately 9 billion inhabitants by 2050, it is necessary to start applying water efficiency criteria that contribute to a uniform and responsible distribution of this resource to 100% of inhabitants in Ecuador during this period.

These natural resources are distributed as follows. Within the wide range of hydrological resources conditioned by the physical and climatic diversity of the country thanks to its geographical location, the Esmeraldas and Guayas River in the coast are important hydric references of the natural resources of Ecuador.

In the mountain range, thanks to the extensive mountain range that crosses the country from north to south, there is an extensive amount of rivers that drain preferentially towards the eastern slope and whose bottoms are different sized aquifers. The difference of level between the zone of the mountain range and the zone of the east (Amazon region), generates an abrupt descent of these rivers that in the majority of the cases is used for the generation of electricity. The eastern region is one of the Amazon River basin; therefore, there is a large number of rivers and the largest reserve of underground aquifers in Ecuador, thanks to the abundance of rainfall, with areas of deficient flooding and drainage. All these natural resources are distributed in the watersheds as detailed in the Table 1.4.

Table 1.4 – Watersheds areas in Ecuador

WATERSHEDS AREAS	
Natural slope	Watersheds
Pacific	72
Amazonas	7
Total Continental Ecuador	79

Source: Secretaría Nacional del Agua - SENAGUA, (2011)

Figure 1.8 shows the hydrographic division of Ecuador according to the drainage of its water bodies to the west and east of the Andes Mountains. As can be seen, the red line is precisely the line that separates neighboring drainage basins with opposite drainage directions. This mountainous chain exerts a significant influence on the water behavior, the drainage of rainwater and the country's current freshwater reserves.

Despite the large number of tributaries and underground aquifers, much of Ecuador's population can not be supplied with potable water in their homes. This problem is very common in the area of the Ecuadorian coast, especially in the province of Manabí, where the Esmeraldas and Guayas River basins exclude it, making it largely desert.

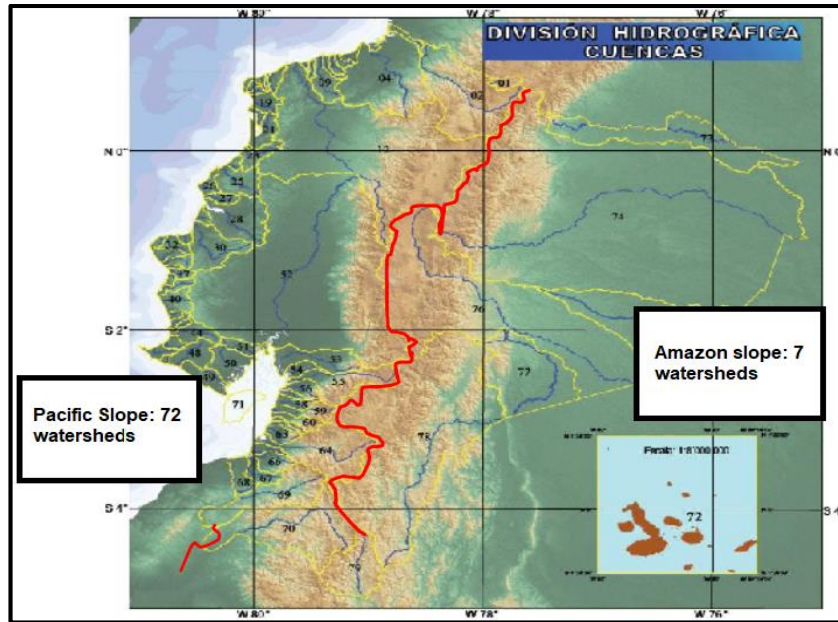


Figure 1.8 - Hydrographic division of Ecuador

Source: Secretaría Nacional del Agua - SENAGUA, (2011)

As shows Figure 1.9, the country's water potential is concentrated in the Amazon region where water resources are more abundant due to permanent rainfalls and the confluence of mountain rivers, however, the lowest percentage of Ecuador's population is concentrated in this region. This is another factor that obstructs an equitable distribution of water in the regions of the country.

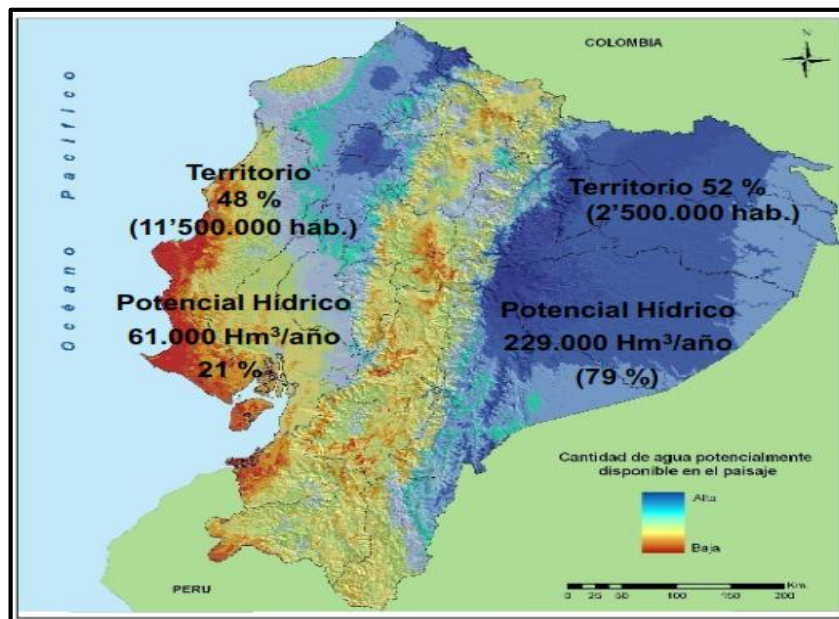


Figure 1.9 - Water potential of Ecuador

Source: Secretaría Nacional del Agua - SENAGUA, (2011)

As shows Table 1.5 and Figure 1.10, for water management as a natural resource in Ecuador there are nine hydrographic demarcations, which are terrestrial and marine zones composed of one or several neighboring watersheds and the underground and coastal transition waters associated with these basins. *“The total of these hydrographic demarcations include 740 hydrographic units distributed in these associated basins and micro-basins. The Galapagos Islands are located within the Guayas hydrographic demarcation”... (p.10)⁶*

Table 1.5 – Hydrographic Demarcations of Ecuador

HYDROGRAPHIC DEMARCATION OF ECUADOR			
Nº	Hydrographic Demarcation	Number of hydrographic units	Area (km²)
1	Guayas	419	43'181.86
2	Manabí	57	11'933.39
3	Napo	6	65'206.18
4	Puyango – Catamayo	46	10'859.97
5	Esmeraldas	147	32'078.27
6	Jubones	2	11'409.29
7	Mira	58	6'847.54
8	Pastaza	12	32'154.88
9	Santiago	11	34'445.91
	Galápagos	1	8'225.71
	Total	740	256'370.00

Source: Comisión Económica para América Latina y el Caribe - CEPAL, (2012)

For the case study of the present investigation, it is important to note that Quito is located within the Esmeraldas hydrographic demarcation (No. 5), which is attributed the general water administration for this case. However, Quito has a public institution, which is responsible for managing and controlling the drinking water supply system (Empresa Pública Metropolitana de Agua Potable y Saneamiento - EPMAPS), in other words, to regulate the municipal water service in the country's capital.

⁶ Comisión Económica para América Latina y el Caribe - CEPAL, (2012)

It is also important to analyze that Quito has as its main resource of supply, the waters of Micacocha located in the moorlands of the Antisana Ecological Reserve, important natural "factories" of this precious resource. Due to the climatic conditions and its geographical location, this reserve becomes an essential resource of fresh water for the inhabitants of Quito.



Figure 1.10 - Hydrographic Demarcations of Ecuador

Source: Secretaría Nacional del Agua - SENAGUA, (2011)

These figures allow to conclude that the Amazon region is the area with the most important water resources that the country has for its supply. At present, there are no inspections, surveys or surveys that allow updating information on the volumes of water that exist in these resources, which is why plans and strategies to encourage the care of these natural resources and to recharge these reserves through systems and techniques that prevent their disappearance.

On the other hand, and based on the grouping of hydrographic basins with similar climatic and spatial characteristics (homogeneity), Ecuador has 31 hydrographic systems totaling an area of 131726 km² that correspond to 51% of the total area of the country.⁷ The hydrographic systems of Ecuador, are defined in the Table 1.6.

⁷ Consejo Nacional de Recursos Hídricos del Ecuador - CNRH, (2002)

Table 1.6 – Hydrographic Systems of Ecuador

HYDROGRAPHIC SYSTEMS OF ECUADOR			
Nº	Watershed	Name	Area (km²)
1	Pacific	Carchi	372
2	Pacific	Mira	6555
3	Pacific	Mataje	237
4	Pacific	Cayapas	6421
5	Pacific	Verde	1904
6	Pacific	Esmeraldas	21553
7	Pacific	Muisne	3136
8	Pacific	Jama	2243
9	Pacific	Chone	2696
10	Pacific	Portoviejo	2505
11	Pacific	Jipijapa	2680
12	Pacific	Zapotal	5738
13	Pacific	Guayas	32218
14	Pacific	Taura	2449
15	Pacific	Cañar	2414
16	Pacific	Naranjal - Pagua	3395
17	Pacific	Jubones	4361
18	Pacific	Santa Rosa	1062
19	Pacific	Arenillas	653
20	Pacific	Zarumilla	831
21	Pacific	Puyango	3682
22	Pacific	Catamayo	7178
23	Pacific	Puná	923
24	Pacific	Galápagos	8010
25	Amazonas	San Miguel - Putumayo	5604
26	Amazonas	Napo	59505
27	Amazonas	Cunambo	8757
28	Amazonas	Pastaza	23190
29	Amazonas	Morona	6588
30	Amazonas	Santiago	24920
31	Amazonas	Chinchiipe	3162

Source: Consejo Nacional de Recursos Hídricos del Ecuador - CNRH, (2002)

As shown in Table 1.6, 24 of Ecuador's 31 hydrographic systems flow into the Pacific's natural watershed. The hydrographic system number 6 called Esmeraldas is where the case study of this research work is located.

Several studies have been developed over the last decade in Ecuador, to determine the conditions of water resources and their main characteristics. According to the available information, the main characteristics of renewable water resources are detailed in Table 1.7.

Table 1.7 – Renewable water resources

RENEWABLE WATER RESOURCES (RWR) OF ECUADOR			
Long-term average annual rainfall	Year	Value	Unit
Intensity		2274	mm/year
Volume		583	km ³ /year
Long-term average RWR	Year	Value	Unit
Internal		442.40	km ³ /year
External		0	km ³ /year
Total		442.40	km ³ /year
Dependency rate		0	%
RWR per person	2014	27403	m ³
Usable underground resources	Year	Value	Unit
Potential		10.40	km ³ /year
Water supply of rivers from neighboring countries			
Incoming (+)	Country	Value	Unit
Water supply		0	km ³ /year
Outgoing (-)	Country	Value	Unit
Water leak	Colombia	35.00	km ³ /year
Water leak	Peru	128.76	km ³ /year

Source: Food and Agriculture Organization of the United Nations - FAO, (2015)

The renewable water resources of Ecuador for each inhabitant guarantee a value of 27403 m³/inhabit according with the Table 1.7. This figure differs from that cited by CEPAL in Table 1.3, since in this case the insular region is also considered, and not only the continental one. In addition, the source of consultation has been updated through the latest water studies conducted in the country. It is very important to consider that in the case of Ecuador, there is no water contribution from neighboring countries, quite the opposite, there is the exit of water that originates from natural resources located in the country and that through certain rivers allow the water flows to Colombia and Peru. This lack of water supply is a disadvantage for the availability of the resource in the future.

1.2.2. Uses of water in Ecuador

Water demand and consumption are two very different terms. Their close relationship allows to understand the need and quantity with which water resources are used in each country.

- **Demand:** is the amount of water that is needed to supply a specific use.
- **Consumption:** the physical loss of water (in volume), that the specific use produces.

It is important to classify freshwater uses as consumptive and non-consumptive. Within the first group is the water consumption in quality and quantity such as domestic supplies, volumes of water for industry and of course for agriculture. In this case, the water that is used is not returned to the medium where it was captured nor with the same characteristics that was extracted. In contrast, non-consumptive uses include volumes of water intended to cover other types of activities such as navigation, power generation and water dams. In this case, the water used is returned to the medium from which it was extracted, although it is not always returned to the same place. In addition, this volume of water can present alterations in its physical, chemical and biological characteristics. Ecuador is one of the richest countries in water resources in the region. In the country, the uses of water to meet the requirements of the population focus on the areas according to SENAGUA.

A. CONSUMPTIVE WATER USE

As can be seen in Figure 1.11, the country's water is mostly used for agricultural purposes. However, it is logical that residential and public use represents one of the most significant percentages, since all inhabitants require this natural resource for their consumption and for the tasks that they perform daily.

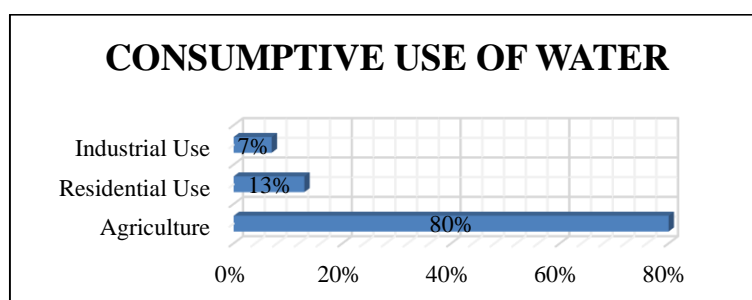


Figure 1.11 - Consumptive water use in Ecuador

Source: SENAGUA 2011 (adapted)

Table 1.8 shows the amount of water that the consumptive uses require. For this reason, it is very important to regulate or to control the consumption of water at the residential level, that is, to guarantee the expenditure of water exclusively necessary in homes, buildings, institutions, schools, among others. Although it is true that the study of water efficiency in a particular sector will not guarantee the existence of this resource in future years, at least it will allow to use the water that is really required in a specific building and therefore, will contribute to preserve this natural resource.

Table 1.8 – Water extraction for consumptive uses

WATER EXTRACTION FOR CONSUMPTIVE USES			
By Sector	Year	Value	Unit
Agriculture		8.076	km ³
Residential Use (Municipal)		1.293	km ³
Industrial		0.549	km ³
Total		9.918	km ³

Source: Food and Agriculture Organization of the United Nations - FAO, (2015)

B. NON-CONSUMPTIVE WATER USE

These types of uses are those that demand the most volume of water. However, it is also important to consider non-consumptive uses within this analysis.

b.1) DAMS – HYDROPOWER

These types of uses are those that demand the most volume of water. One of the clearest examples of this situation is the hydroelectric, which require large amounts of water volume to generate electricity through the movement of the turbines.

At present, Ecuador has experienced one of the most notable growths in this aspect, mainly due to the creation and construction of important projects for the generation of hydropower. Table 1.9 summarizes the hydroelectric growth that the country has experienced throughout its history.

Table 1.9 – Hydroelectric growth in Ecuador

HYDROELECTRIC GROWTH IN ECUADOR				
Name of Dam	River	Operational since	Reservoir capacity (million m³)	Power (MW)
El Ambi	-	1925	-	485
Cumbayá	-	1961	-	40
Azúcar	-	1967	5	-
Pisayambo	-	1967	100.7	-
Poza Honda	Portoviejo	1971	100	-
Pucara - Pisayambo	Tambo	1977	-	76
Guangopolo	-	1977	-	31.2
Daniel Palacios (Paute)	Paute	1983	120	1100
Tahuin	Arenillas	1987	210	-
Agoyán	-	1987	3.6	156
Chongón	Chongón	1991	280	-
Daule Peripa	Daule	1992	6300	-
La Esperanza	El Carrizal	1996	450	-
La Mica (El Carmen)	-	1997	50	-
Salve Faccha	-	2002	12.5	-
San Vicente	Javita	2003	60	-
Abanico	Abanico	2005	-	-
San Francisco	Pastaza	2007	-	230
Pasochoa	-	2012	-	4.5
San Miguel	Caldera	2015	-	44.4
Manduriacu	Guayllabamba	2015	10	65
Coca-Codo Sinclair	Napo	2016	1.2	1500
Sopladora	Paute	2016	10	487

Source: Food and Agriculture Organization of the United Nations - FAO, (2015)

The last three dams are part of the new energetic matrix program developed by the Ecuadorian Government and China, in order to increase and improve the energy capacity and to solve the current demands. The total capacity of these dams to store water and ensure the availability of this resource in drought stations is 7.69 km³.

b.2) WATER FOR IRRIGATION

The use of water for the agricultural activity through irrigation systems in Ecuador, as well as in other Latin American countries, is a priority. The official figures reveal that 80% (8.076 km³) of fresh water is destined to the agricultural sector per year, as the main economic activity of the country. The demand of this resource for the agricultural sector is significant due to the natural conditions of Ecuador, where a great variety of products are cultivated in order to be available for consumption of the national population and also, the international market. This percentage is distributed as shows the Table 1.10, through irrigation systems located in the Sierra, Coast, Amazon and Insular Regions of Ecuador.

Table 1.10 – Irrigation Surface according to type

IRRIGATION SURFACE TYPES IN ECUADOR			
N°	Description	Value	Unit
	Total surface equipped for irrigation	1'500,000	ha
1	Surface irrigation	663,900	ha
2	Sprinkler irrigation	170,100	ha
3	Localized irrigation	19,400	ha

Source: Food and Agriculture Organization of the United Nations - FAO, (2015)

Of all non-consumptive uses, hydropower is the activity that requires the most volume of water in the country. It is important to emphasize that these figures consulted correspond to the data obtained from the last decade (2010 - 2017) since not all these indicators are updated. The estimated flow for non-consumptive uses is summarized in Figure 1.12.

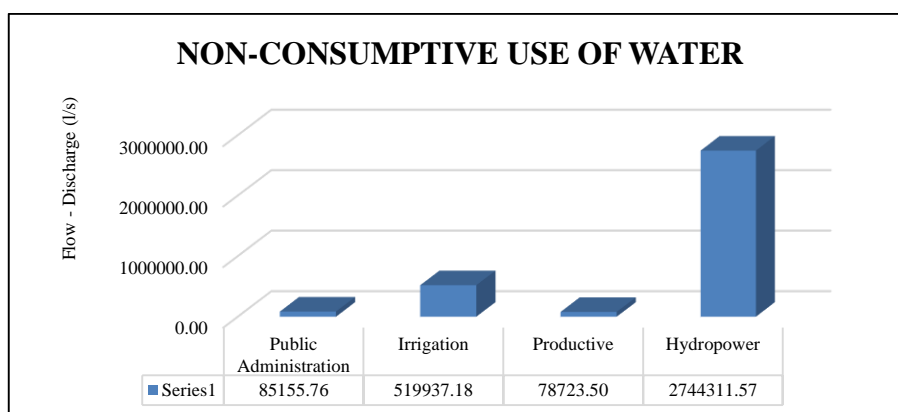


Figure 1.12 - Non- Consumptive water use in Ecuador

Source: Comisión Económica para América Latina y el Caribe - CEPAL, (2012) (adapted)

1.2.3. Uses, figures and rates for potable water in Quito - Ecuador

Quito, as the capital of Ecuador, is the most important city in the country. Its political, social and economic importance make this city the main strategic axis for the development of the population. Located at 2800 meters above sea level and with the water resources described in literal (1.1.1), Quito has a permanent water supply service in the majority of its population.

According to the sustainability report prepared by the “Empresa Pública Metropolitana de Agua Potable y Saneamiento (EPMAPS -2016)”, the key performance indicators on the administration of this company in addition to the uses and rates are described in the following tables.

Table 1.11 summarizes the systems from which Quito is supplied with water to later make it drinkable and distribute it through the conduction networks to the different sectors of the city. These 7 water supply systems, become the most important and necessary resources for the contribution of 259.65 m³ of water, captured in an average of 8.21 m³/s.

Table 1.11 – Systems that provide water for Quito

SYSTEMS THAT PROVIDE WATER FOR QUITO				
Nº	System	Resource	Millions m³	%
1	Papallacta	Superficial	91.76	35.3
2	La Mica	Superficial	39.59	15.2
3	Oriental pipelines of conduction	Superficial	77.86	30.0%
4	Western pipelines of conduction	Superficial	27.74	10.7%
5	Rural	Superficial	3.37	1.3%
6	Wells	Underground	4.78	1.8%
7	Water springs	Superficial	14.56	5.6%
TOTAL			259.65	100.0%

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

On the other hand, Quito has 20 treatment plants that on average produce 7.87 m³/s of drinking water for the consumption of the inhabitants of this city. Table 1.12 shows the

volume of water that these plants must make drinkable according to each natural system of water supply.

Table 1.12 – Volume of treated water in Quito

VOLUME OF TREATED WATER IN QUITO				
N°	System	Resource	Millions m³	%
1	Papallacta	Superficial	92.43	37.1%
2	La Mica	Superficial	38.77	15.6%
3	Oriental pipelines of conduction	Superficial	68.90	27.7%
4	Western pipelines of conduction	Superficial	26.19	10.5%
5	Rural	Superficial	3.37	1.4%
6	Wells	Underground	4.78	1.9%
7	Water springs	Superficial	14.56	5.8%
TOTAL			249.00	100.00%

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

As for the number of reserve tanks available in Quito to store drinking water and distribute it later, is 333 units as shows Figure 1.13. The 51.7% of this total corresponds to tanks that allow the distribution of drinking water to the entire city of Quito and the remaining 48.3% of tanks, distribute drinking water to the neighboring parishes of the city.

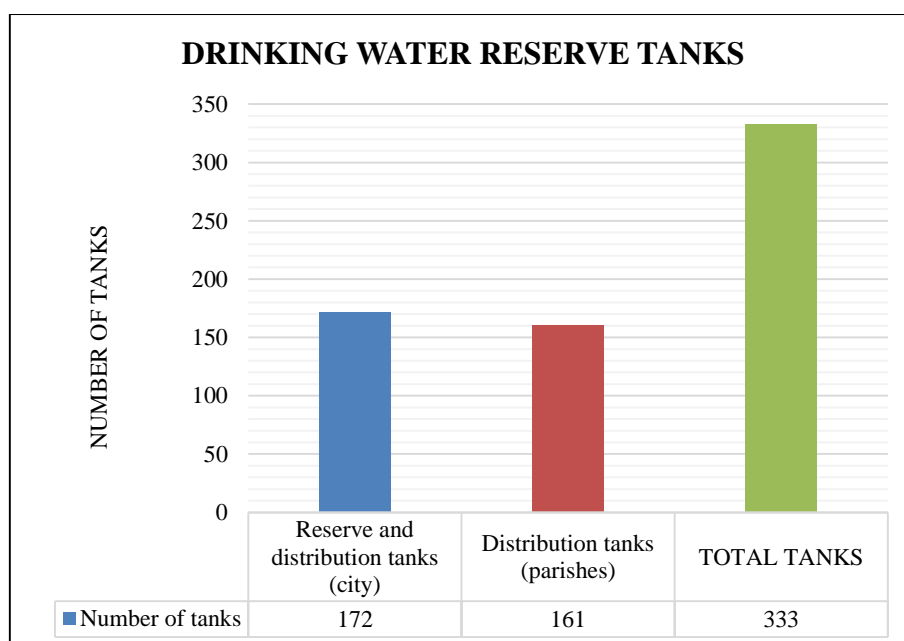


Figure 1.13 - Drinking water reserve tanks

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

The distribution of drinking water for the city of Quito is made through two networks: the transmission lines with a total of 602 km and the distribution pipelines with a total of 5,803.59 km. The Table 1.13 shows the amount of water coming from natural resources that is distributed in the city of Quito. On average, the water distributed is 7.73 m³/s.

Table 1.13 – Distribution of drinking water in Quito

DISTRIBUTION OF DRINKING WATER IN QUITO				
Nº	System	Resource	Millions m³	%
1	Papallacta	Superficial	89.69	36.7%
2	La Mica	Superficial	38.31	15.7%
3	Oriental pipelines of conduction	Superficial	68.19	27.9%
4	Western pipelines of conduction	Superficial	25.70	10.5%
5	Rural	Superficial	3.30	1.4%
6	Wells	Underground	4.78	2.0%
7	Water springs	Superficial	14.56	6.0%
TOTAL			244.52	100.00%

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

The use of tools to improve the performance of a Water Management Company through the application of pioneering practices (Benchmarking), can be evaluated through different quality indicators. This type of tools has substantially improved the quality of service that EPMAAPS provides to the inhabitants of Quito. Thanks to its efficiency, the following indicators are currently guaranteed.

According to the Figure 1.14, 98.61% of the Metropolitan District of Quito has drinking water coverage at the residential, municipal, commercial and industrial levels. The remaining 1.39%, usually lacks the service due to geographical inconveniences that prevent distributing the water coming from the reserves by gravity. These sectors in most cases correspond to new neighborhoods settled in the highest areas of the city. From experience, the continuity of the water service in Quito is indeed satisfactory. Its discontinuity is usually due to maintenance tasks in the network, operational factors or inconveniences in the collection, driving and distribution works that may occur throughout the year. Thanks to the 20 treatment plants in the city, the evaluated quality of drinking water meets all the requirements and standards required by the current Ecuadorian standard NTE INEN 1108.

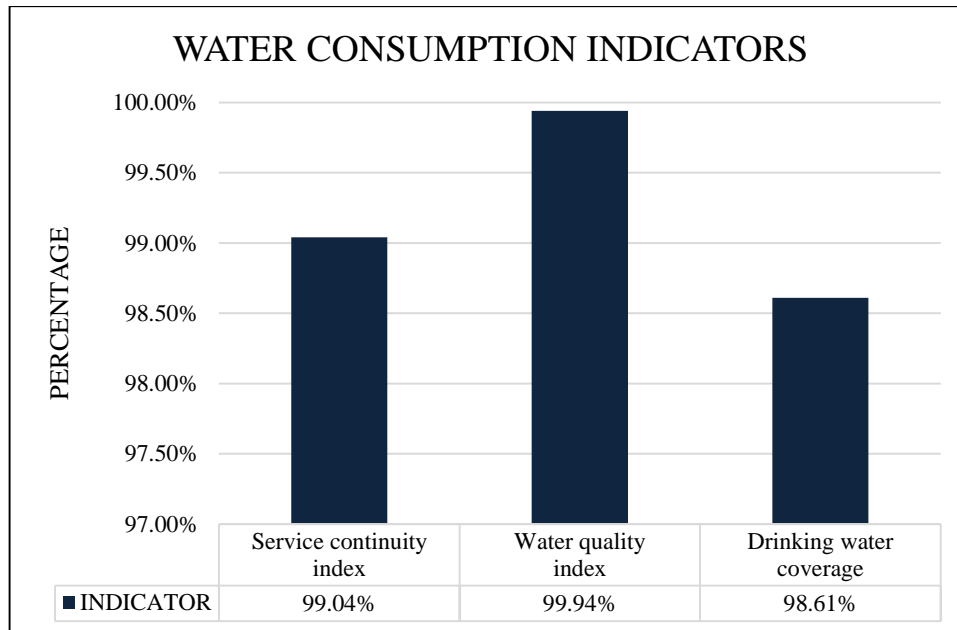


Figure 1.14 - Water Consumption Indicators by EPMAPS - Quito

Source: Author's own drawing

With regard to potable water rates and considering the increase of the demand for the service due to the population growth in the city of Quito, as well as other economic and social factors due to its capital category, it has one of the highest water rates per cubic meter (m³) of the region.

As can be seen in Table 1.14, the rates per cubic meter of drinking water vary significantly among some capitals of South American countries. This economic variation is caused by the costs of producing drinking water that each country invests, the availability of existing natural resources, the number of inhabitants in each city and obviously the economic capacity or payment that each city has. The economic income and the financial situation of the population of these cities is different from each other, therefore it is logical to set the rates according to socio-economic and even political aspects in some cases.

Making a thorough comparison between existing data from the last decade, it is clear to note that Quito has the second highest fixed rate of drinking water per cubic meter of the region. In this case, the Drinking Water Management Companies may feel disadvantaged with the reduction of consumption at domestic (home) and municipal level since their billing would decrease. It is important, however, to find a balance between the interests of these companies

in the administration and control of drinking water and the natural resources available in Ecuador to prevent waste or misuse. Precisely, this economic indicator allows to understand the costs associated with the production of one cubic meter of drinking water in Quito, which reflects that this process is quite complex and expensive at least, in the capital despite having abundant resources.

Table 1.14 – Comparison of Drinking Water Rates in Capitals of South America

COMPARISON OF DRINKING WATER RATES IN CAPITALS OF SOUTH AMERICA - RESIDENTIAL, DOMESTIC AND MUNICIPAL LEVEL

Country	Capital	Fixed Rate / Average (\$ USD)	Year 2005			
			Variable Rates (\$ USD)			
			0 - 30m ³	31 - 150m ³	151 - 300m ³	> 300m ³
Bolivia	La Paz	\$ 0.45	\$ 0.22	\$ 0.44	\$ 0.66	\$ 1.19
Chile	Santiago	\$ 0.77	\$ 0.35	\$ 0.35	\$ 0.35	\$ 0.35
Colombia	Bogotá	\$ 2.61	\$ 0.17	\$ 0.69	\$ 0.69	\$ 0.69
Ecuador	Quito	\$ 1.93	\$ 0.54	\$ 0.66	\$ 0.72	\$ 0.72
Paraguay	Asunción	\$ 0.87	\$ 0.26	\$ 0.29	\$ 0.29	\$ 0.29
Perú	Lima	\$ 1.41	\$ 0.26	\$ 0.26	\$ 0.26	\$ 0.26

Source: The World Bank, (2010)

Country	Capital	Fixed Rate / Average (\$ USD)	Year 2016 - 2017			
			Variable Rates (\$ USD)			
			0 - 30m ³	31 - 150m ³	151 - 300m ³	> 300m ³
Bolivia ⁸	La Paz	\$ 1.45	\$ 0.72	\$ 1.45	\$ 1.45	\$ 1.45
Chile ⁹	Santiago	\$ 1.01	\$ 0.56	\$ 1.63	\$ 1.63	\$ 1.63
Colombia ¹⁰	Bogotá	\$ 3.53	\$ 0.65	\$ 0.76	\$ 0.76	\$ 0.76
Ecuador ¹¹	Quito	\$ 2.10	\$ 0.43	\$ 0.72	\$ 0.72	\$ 0.72
Paraguay ¹²	Asunción	\$ 1.20	\$ 0.28	\$ 0.33	\$ 0.39	\$ 0.39
Perú ¹³	Lima	\$ 0.88	\$ 0.31	\$ 0.69	\$ 1.18	\$ 1.18

Source: Drinking Water Companies of South America

The analysis of the information consulted can be better understood, through Figure 1.15, which allows to more easily identifying the changes produced in the fixed and variable rates

⁸ Los Tiempos, (2016)

⁹ Gobierno de Chile, (2017)

¹⁰ Acueducto Agua y Alcantarillado de Bogotá, (2017)

¹¹ Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

¹² Empresa de Servicios Sanitarios del Paragua S.A., (2017)

¹³ La República, (2017)

of drinking water per cubic meter in the capitals of South American countries. The conclusions obtained are the following:

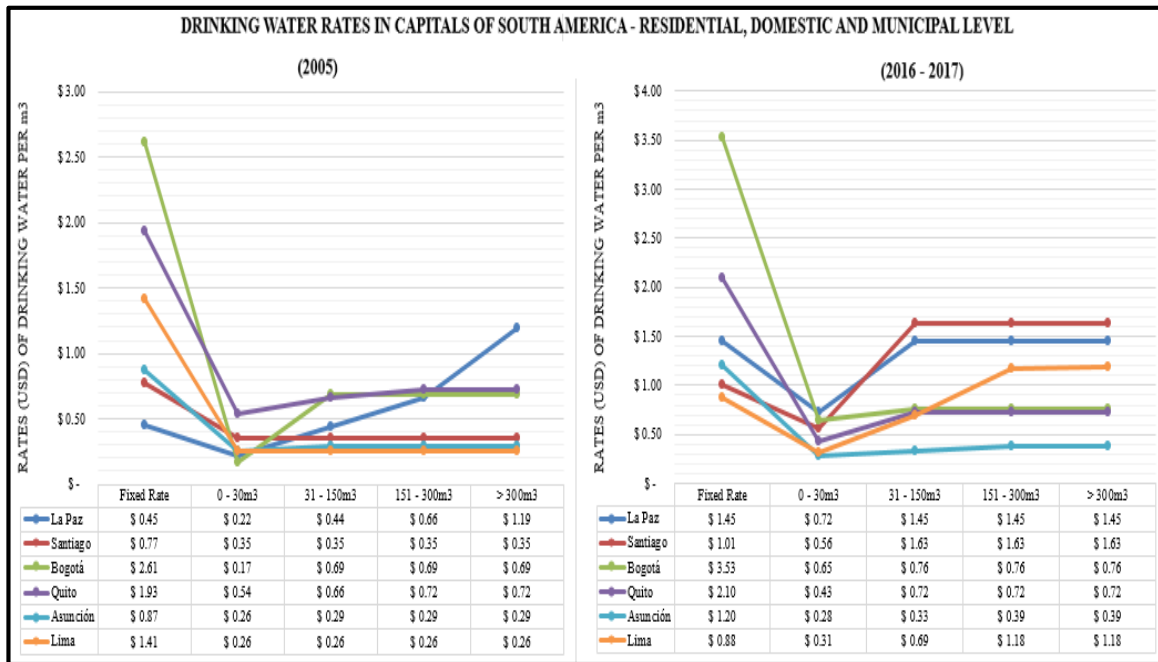


Figure 1.15 - Drinking water rates in capitals of South America

Source: Author's own drawing

Fixed Rates: The fixed rates of domestic, residential and municipal consumption of all the capital cities consulted have increased since 2005. For example: **a)** La Paz has a current increase of 322.22% in its fixed rate per cubic meter of drinking water. **b)** Santiago, one of the capitals with more natural drinking water resources in the world, increases its fixed rate per cubic meter of drinking water by 131.17%. **c)** Bogotá has increased by 135.08% its fixed rate per cubic meter of drinking water; in addition, it has the highest fixed rate of all the capitals consulted. In the same way, Colombia has one of the largest reserves of drinking water; however, the costs of producing potable water are considerably high. **d)** In the case of Quito, the tariff plan for potable water that is between 2005 and 2015 without modifications has experienced an increase in the fixed rate per cubic meter of water by 108.81%. Its rate does not stop being one of the highest in the region. It should also be noted that Quito has the smallest increase in the fixed rate of drinking water service provided to its citizens, with respect to the other capitals consulted. **e)** The current increase of the fixed rate of Asunción is 137.80% for each cubic meter of drinking water, with respect to the year 2005. **f)** Lima is the only capital within the cities analyzed, which has achieved a reduction

in the cost of its fixed rate with respect to the value of each cubic meter of drinking water. It is important to emphasize that this city presents a reduction of 37.59% in the cost of drinking water compared to 2005, besides that it invests in strategic plans for the control of its resources, economic incentives for the inhabitants that reduce the consumption of drinking water in their homes, among others.

Variable Rates: Once the user exceeds the minimum consumption established by each drinking water company, there are different rates recognized for each consumption range per cubic meter that will be charged and billed. For all the cases analyzed, variable rates have been increasing at present. The variable rates that have increased the most (almost tripling) are those of Santiago de Chile and those of La Paz in certain ranges. It is important to note that currently, the variable rates stabilize from 30m³ with the exception of Lima where this continuity is given from 150m³.

It is very important to add that the rate policy of the EPMAPS grants subsidies in the invoicing of consumptions for potable water and sewerage services to more than 40,000 inhabitants according to their figures in 2016. Table 1.15 details the number of beneficiaries according to the type of subsidy.

Table 1.15 – Number of subsidized beneficiaries

IRRIGATION SURFACE TYPES IN ECUADOR			
N°	Subsidy	# Beneficiaries	USD
1	Disabilities	3128	50,423.00
2	Elderly	37249	1'815,723.00
TOTAL		40377	1'866,146.00

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

Similarly, for users at the residential or municipal level, there are discounts for consumption up to 20 m³ of water per month conforming to the socioeconomic condition and to the sectorization of urban land in the Metropolitan District of Quito. These discounts range from 5% to 22% for the middle and lower sectors respectively.

1.2.4. Statistical information of water losses in Quito – Ecuador

Water losses are one of the problems of operational deficiency in urban supply systems, which represents a permanent problem for companies that sell drinking water. It is important to note that water losses occur during different phases: in the source, conduction, in the purification processes and in the distribution through the networks installed in the cities. One of the biggest water losses occurs precisely there, in the distribution phase due to different causes that usually result from illicit connections, leaks or poor quality facilities. Water losses and the unbilled authorised water consumption are counted as an annual final volume of water that is not billed. In this group it is important to differentiate the types of losses to understand their possible causes and mitigate their effects. According with: **Gomes, R. (2016)** in his analysis of the water balance, it can be clearly identified that water losses are due to two important groups: Apparent Losses and Real Losses as can be shown in the Figure 1.16.

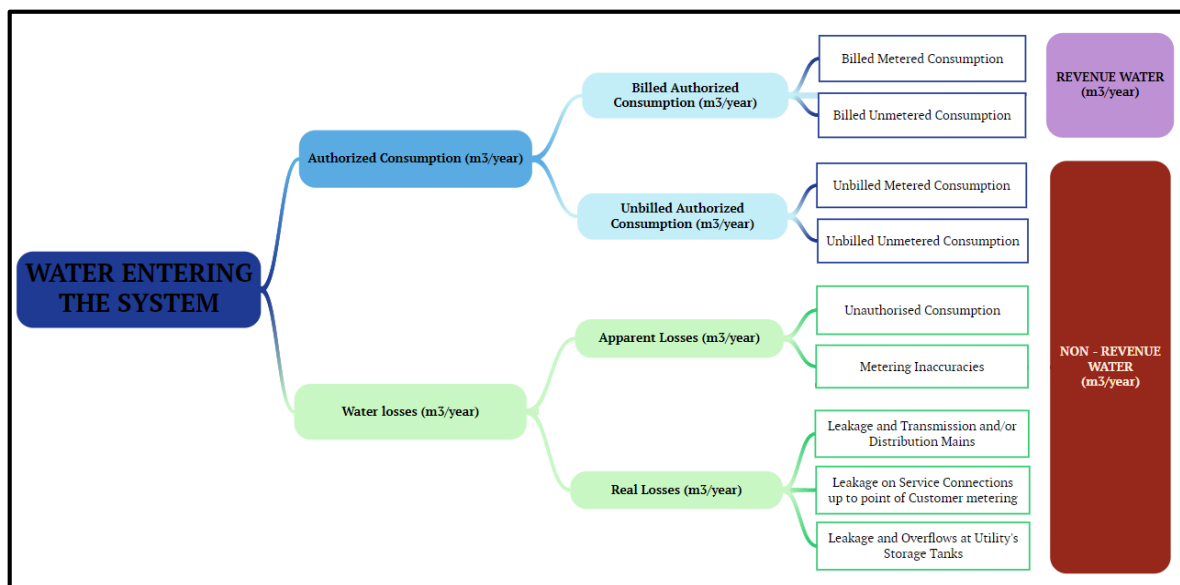


Figure 1.16 - Water at entry point system

Source: Gomes. R, (2016) (adapted)

“In Ecuador, an important obstacle to achieving integrated water resources management is the problem of the lack of hydro meteorological information and of water statistics in general, which does not allow adequate and reasonable decisions to be made for water

allocation, planning their uses and the organization of the use of the territory, nor does it enable a good performance of the functions monitoring, control and regulation”... (p. 4) ¹⁴

The Metropolitan Public Company of Drinking Water – EPMAPS (Empresa Pública Metropolitana de Agua Potable y Saneamiento) in 2016, defines the Index of Unaccounted Water (I.U.W) as the indicator of the percentage of unbilled water as can be showed in the Figure 1.17. For this calculation, the EPMAPS uses the Equation 1 to determine the Index of Unaccounted Water in Quito.

$$I.U.W. (\%) = 1 - \left(\frac{\text{Volume of commercialized drinking water}}{\text{Volume of water distributed from treatment plants, springs and wells}} \right) \times 100$$

[Equation 1]. Index of Unaccounted Water in Quito

As can be seen in Figure 1.17, non-revenue water in Quito during these years varies between 23.90% and 31.74%, which represents practically one third of the total volume of drinking water commercialized.

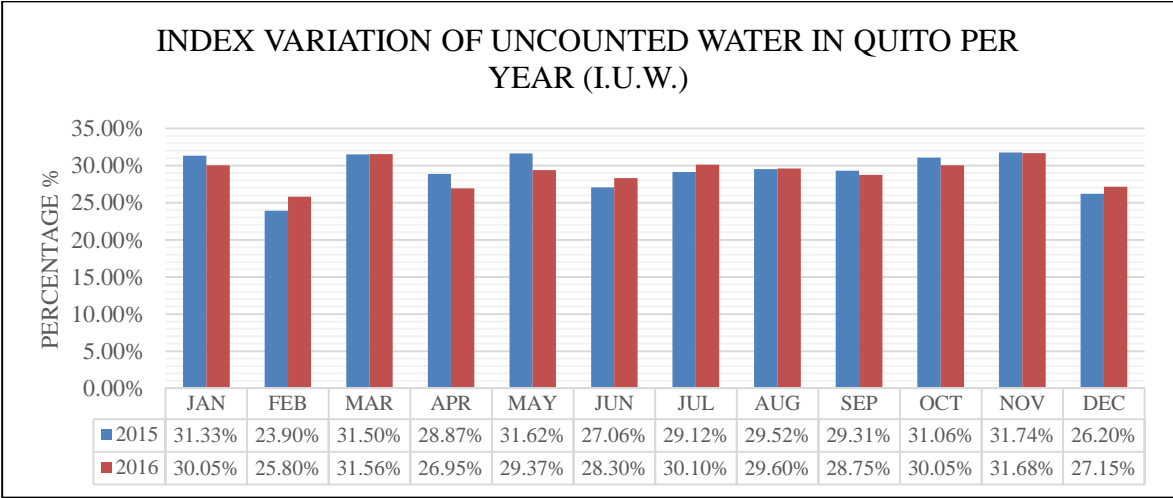


Figure 1.17 - Index Variation of Unaccounted Water in Quito City per month
 Source: Gobierno Abierto de Quito, (2017) - Author’s own drawings (adapted)

This means that in addition to the unbilled authorised consumption of water that exists in the city (public institutions for example), there is a large percentage of water losses that reflect a serious and permanent problem for the economic sustainability of the Water Company. In

¹⁴ Comisión Económica para América Latina y el Caribe - CEPAL, (2012)

this sense, it is important to determine with greater precision the percentage of water losses that exist and their most common causes, to identify the most appropriate solutions to minimize its impact.

The company EPMAPS - Quito, determines that: *“The real and apparent losses of the distribution system have an average annual value of 20.63% in the metropolitan area and 42.30% in parishes. According to the company, the index is in the international optimal values, which has been achieved due to the permanent execution of commercial actions, such as installation of micrometers, detection of clandestine connections, illicit consumption, etc., and operational actions such as hydraulic sectorization, decrease of overpressures, reduction of overflows in tanks and the timely detection and repair of leaks”...*¹⁵

The Figure 1.18 details the variation of the index of unaccounted water in Quito according to the political division. In the first case, the analysis (blue color) shows the index variation of the Metropolitan District of Quito, reason for which the percentage of unaccounted for water is greater than considering only the urban part of the city (red color). As expected, the surrounding parishes are the most affected as this is where the unaccounted for water index is higher due to the common existence of leaks, clandestine connections, deficiency in facilities, lack of economic resources, among others.

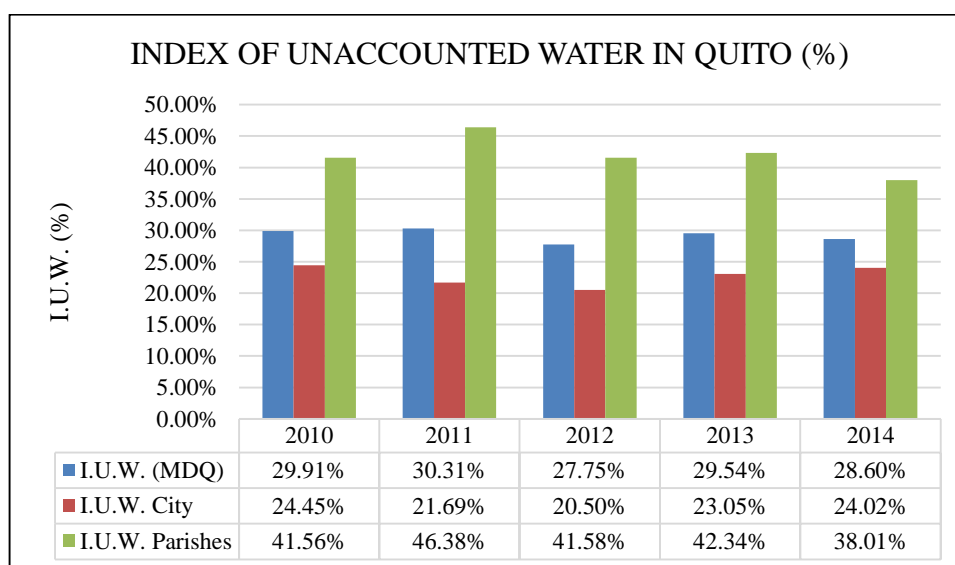


Figure 1.18 - Index of Unaccounted Water in Quito City per year

Source: Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

¹⁵ Empresa Pública Metropolitana de Agua Potable y Saneamiento, (2017)

1.3. Justification and objectives

1.3.1. Justification

The project “Analysis of Water Efficiency in Buildings” determines the requirements, strategies, tools, devices and obligations that must be met by the users of drinking water systems for an adequate control over the consumption of this important natural resource. The importance of the study of Water Efficiency in Buildings is to guarantee the technical conditions of the hydraulic operation about drinking water systems through the networks installed in the buildings, but with a responsible and controlled consumption that motivate permanently, the hydraulic and energetic sustainability.

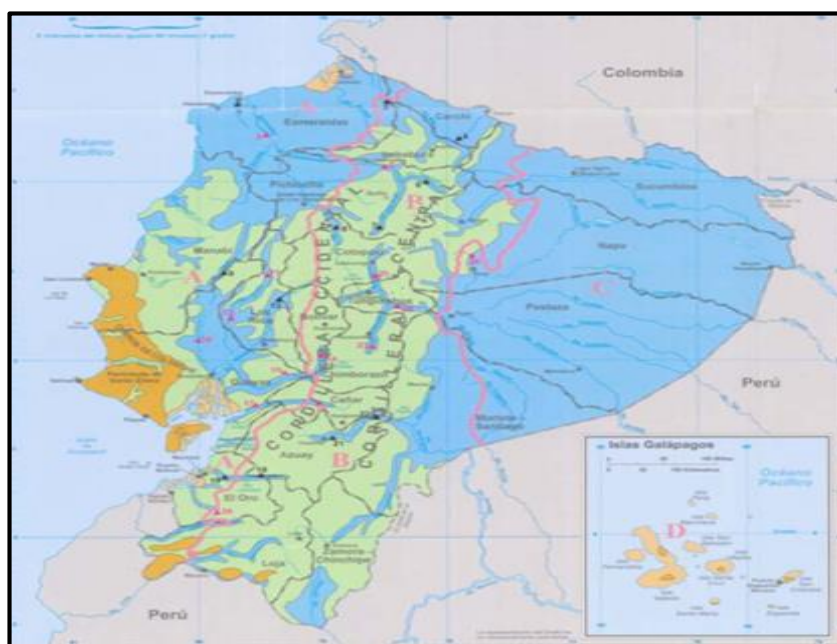
The need to design efficient systems that reduce the current consumption of drinking water is one of the fundamental reasons for the development of this project based on the technological and scientific mechanisms available from other countries in the world, where this topic has been widely developed and studied. Defining a set of technical requirements related to the proposed study case, this project will be written at a design level that will take into account the geographical, hydrological, hydraulic and structural factors that influence the selected building to improve its performance and water efficiency.

The lack of water efficiency systems in Ecuador and the countries of the region is one of the most important reasons that justify this project. On the other hand, the accelerated population growth, the current demands for drinking water, the contamination of water resources, in addition to the undoubted ecological and environmental damage, an inclement climate change and a dramatic reduction of natural resources of drinking water are some factors to motivate the research’s development. One of the best options to implement this study is precisely a public building of Quito that is part of the “Universidad Central del Ecuador”, since it is essential to improve the water efficiency of this type of buildings where the concurrence of people is massive and where the consumption of drinking water increases considerably during each day. The lack of water efficiency systems in the country and self-sustainable buildings in this field, can stop being a disadvantage and become a strength to

contribute to the change of this productive matrix, construction processes, materials and supply systems of drinking water in buildings.

The main problem between the availability of water in the country and the population location is precisely that the country's greatest water potential (88%) is located on the Amazon slope, where only 4% of the country's total population lives. By contrast, the other 96% of the population is located in the central and coastal region of the country, where water resources are not abundant.

As shown in Figure 1.19, the greatest availability of water is in the Amazonian region of the country, however, the underground resources are little known, and due to the difficulty in access to these places, there is limited information to develop a more accurate database of the current condition of the country's natural resources. As can be seen, the main cities of the country are located geographically in places where water resources are not abundant and where there is greater concentration of population.





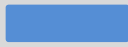
COLOR	SPATIAL DISTRIBUTION
	Scarce or poor water
	Seasonally abundant water
	Permanently abundant water

Figure 1.19 - Spatial distribution of water sources

Source: Comisión Económica para América Latina y el Caribe - CEPAL, (2012)

For this reason, it is essential to raise awareness about the importance of preserving this natural resource and giving it good use with respect to water consumption. For the present research project, emphasis will be given exclusively to hydraulic efficiency in buildings (residential – public level). Figure 1.20 details the total area of the case study buildings.

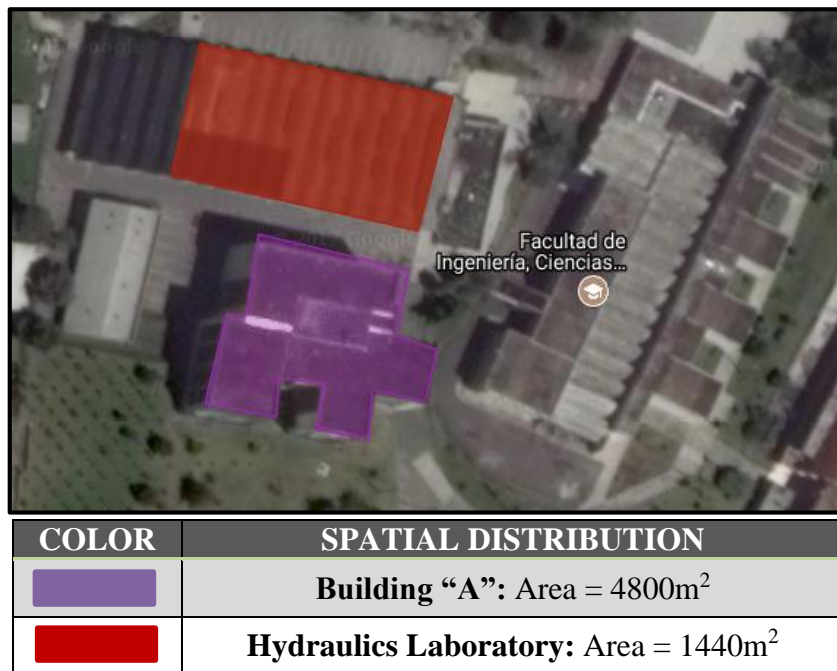


Figure 1.20 - Area where hydraulic efficiency analysis would be applied

Source: Author’s own drawings

The second factor that justifies the development of this research is precisely the current conditions that support the infrastructure of the Faculty and that due to its antiquity presents functional disadvantages. Although the Faculty has obtained the quality accreditations in terms of education, infrastructure and teaching staff that place it within the most competitive in the country, there are certain deficiencies in the main buildings that are related to the current state of these structures and especially of the hydro sanitary elements and accessories which do not have an adequate performance or operation. The large number of students entering to the “Building A” and the Hydraulics Laboratory as shows the Figure 1.20, causes that these type of installations and accessories work each day of more than 14 hours, which is why there is a premature wear of the materials in addition to the excessive and uncontrolled consumption of water that is not automated and that cannot limit the consumption of this resource. It is clear that there is no awareness on the part of users about the drinking water resource they have and even worse about the need to regulate consumption.

CURRENT WEATHER CONDITION: The strong and intense rains in Quito during the last year (2017) have caused the collapse of the drainage system, especially in this part of the city, where by geographical location the water from the mountains accumulates on flat land. Such is the currently case, where the Building A and parking areas have been flooded by heavy-long rains. As shows the Figure 1.21, the areas that are susceptible to flooding due to the low capacity of current sewer systems are the following detailed:

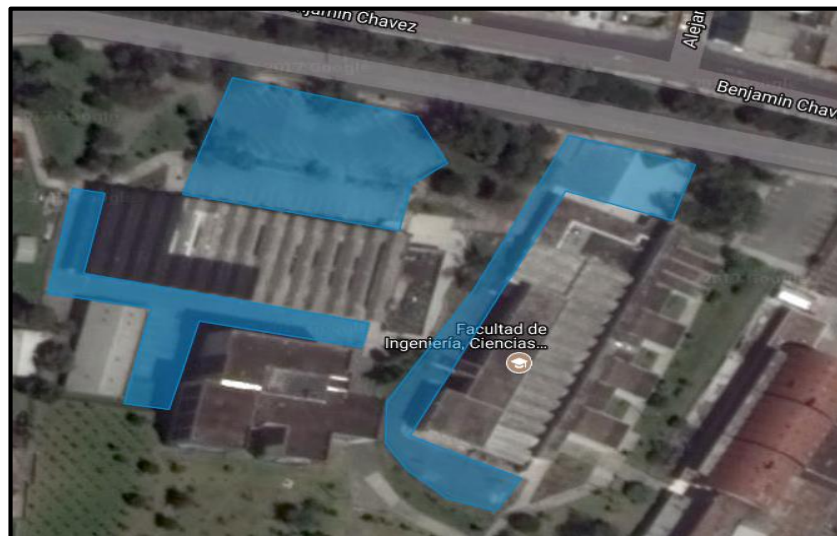


Figure 1.21. Floods in the areas near “Building A”

Source: Google Earth Pro v. 7.3.0.3832

This essential and common factor during all the years in Quito motivates to install systems and apply techniques of rainwater harvesting in order to use this natural resource in the hydraulic lab and sanitary facilities of “Building A” analyzed in the present plan of thesis. This type of consideration, in addition to improving the sustainability of these buildings and their functionality, can have two key advantages:

1. The first one is to use rainwater in toilets or in the hydraulic models that are designed in the Laboratory.
2. And the second one, is to contribute to the reduction of the flood areas detailed in Figure 1.21.

This measure can improve the current conditions where the academic activities are developed and rainwater can be used in specific devices to reduce also the consumption of drinking (potable) water that now are not controlled.

1.3.2. Objectives

Due to the scarcity of water worldwide and the daily activities in which this natural resource is used, it is important to look for the most efficient strategies and alternatives to change with this reality by reducing it as much as possible. In this particular case, the use of rainwater is one of the most convenient alternatives to alleviate this problem, considering the factors described in the justification of the present project. The objectives described in this project try to motivate the conservation of drinking water and natural resources, so that they do not become a resource of risk for the health of the users, but on the contrary, to install systems that improve the quality of the service that is provided in the facilities reducing consumptions and billing costs. This thesis has the following specific objectives:

1. GENERAL PURPOSE:

The general objective of this project is to analyze and evaluate the feasibility of reducing the current drinking water consumptions at levels of optimal use, by means of rainwater for hydro-sanitary facilities (non-potable consumptions) in the Classroom Building and the Hydraulics Laboratory of the Engineering Faculty, through the design of a continuous system that can be used as an alternate supply mechanism and as a water reserve in times of low rainfalls.

2. SPECIFIC OBJECTIVES:

- ✓ Collect practices, techniques, strategies and systems for the use of rainwater for non-potable uses for buildings, based on others already developed abroad.
- ✓ Reduce the percentage of water losses in the building currently.
- ✓ Reduce consumption, avoiding waste in the use of water by activities and/or consumer devices.
- ✓ Evaluate the potential and obstacles of the use of rainwater in non-potable uses based on the current devices and specifications that may be applied in Ecuador.
- ✓ Contribute to the reduction of floods around the building that is part of the case study, through the design of a small reserve lagoon located on the grounds of the Faculty.

- ✓ Design a continuous supply system that feeds on rainwater collected in the artificial lagoon and also, on the roofs of the building.
- ✓ Evaluate the need to design a rainwater treatment system before its use in the current hydro-sanitary networks.
- ✓ Carry out the hydraulic and hydro-sanitary design of the proposed system that contributes to the reduction of drinking water consumption in the building.
- ✓ Promote a new culture of water, through the strategies and techniques proposed in this thesis.
- ✓ Contribute to new scientific research topics that may be developed in the future by Ecuadorian students for the benefit of this country and society.

1.4. Methodology

The writing of this thesis is developed, justified and evaluated throughout five chapters that seek to share with the readers a logical, systematic and comprehensible process on the Analysis of Water Efficiency in Buildings, applied to a case study in Quito, Ecuador.

In this chapter, **Chapter I: Introduction**, the subject and the most representative aspects of the country where the thesis is developed are presented, its main characteristics and some statistical figures to understand the availability of resources and the importance of water in the city of Quito. The objectives are also defined and the work methodology is described.

In the second chapter, **Chapter II: Background and Literature**, a bibliographic review is made on the most relevant technical aspects of conventional urban hydraulics: such as water cycles, components of water supply and drainage systems, the efficient use of water in supply systems, performance indicators, district metered areas, pressure management, SCADA systems, sustainable urban drainage systems, and the structural and non-structural systems for flood prevention. As a fundamental part of this work, the efficient uses of water in buildings, the components of water installations in buildings, the reduction of water and energy losses are also described. It is important to emphasize that in order to achieve the sustainability of a building through hydric efficiency, an evaluation must be carried out on audits in this area, the technologies available for the reduction of water losses, the

certification and labelling of water efficiency devices and indicators of performance of these alternative. This must be developed to maintain the quality control in the buildings water distribution facilities.

In the third chapter, **Chapter III: Rainwater harvesting systems**, the components of these systems, the water losses and the consumption of energy that can be admitted, the quality and the rain water treatments existing specially in the capture of water by middle of the roofs, a cost/benefit analysis and the certifications with their respective technical specifications are analyzed. In summary, this chapter studies the most important mechanism considered for the present case study, the techniques and systems developed for the use of rainwater.

In the fourth chapter, **Chapter IV: Case study**, the gathering of information on the evaluated building, the climatic factors and conditions, the consumption and losses in this building are carefully evaluated to propose the most adequate solutions for the reduction of drinking water consumption and the use of rainwater. To achieve this purpose, the current situation of the selected building, its geographical location, topography, architectural information, the hydro sanitary analysis of the building, water consumption, water losses and solutions and measures to mitigate these problems are studied. Finally, a cost / benefit analysis corresponding to the solution proposed for the proposed study case is carried out.

Finally, in the fifth chapter, **Chapter V: Conclusions**, the results obtained for the case study are discussed. The design of the proposed solution is analyzed and all the final technical criteria that support the devices, tools and systems used to reduce consumption and improve the building's hydraulic efficiency are established. The summary of this methodology can be consulted in the Figure 1.22.



Figure 1.22. Methodology

Source: Author’s own drawings

2. Background and Literature

2.1. Introduction

Following the analysis made on freshwater resources worldwide in Chapter I, it is important to emphasize in this chapter, the most important concepts about the water cycle and the urban water cycle to analyze the natural process of water circulation on the Earth and its circulation influenced by the activities of the people in the cities. The importance of the components that make up water supply systems and urban drainage systems is essential to analyze their influence on the urban water cycle.

Subsequently, the study of the efficient use of water in water supply systems is carried out through the description of performance indicators, leakage reduction methods of water systems such as **the District Metered Area DMA, pressure management and the SCADA system.**

Considering as part of the present work the use of a rainwater harvesting system and the reduction in current floods in the vicinity of the building corresponding to the case study, the analysis of sustainable urban drainage systems is carried out, detailing the structural and non-structural measures for flood prevention.

The literature to be consulted also focuses on the study of the efficient use of water in buildings, for which the components that make up the plumbing installations of buildings, conventional resources and water alternatives are analyzed, as well as water losses and reduction of energy.

One of the most important parts of this chapter is undoubtedly the previous description of the current strategies on evaluation of hydraulically efficient buildings through the application of audits, technology to reduce losses, certifications and labeling of efficient water devices, among others.

2.2. Water Cycle and Urban Water Cycle

2.2.1. Water cycle

The water cycle or the hydrological cycle describes the process of water circulation through and on the Earth. The water on Planet Earth is always in motion and presents a constant change of state: liquid, gaseous and solid. This cycle of water occurs from the origin of the planet and its main engine is the sun's energy and wind, without them and the force of gravity, it would not be possible the constant transformation of water in its different states.

According to the Earth Observatory - NASA, (2017): “The water, or hydrologic, cycle describes the pilgrimage of water as water molecules make their way from the Earth’s surface to the atmosphere and back again, in some cases to below the surface. This gigantic system, powered by energy from the Sun, is a continuous exchange of moisture between the oceans, the atmosphere, and the land”.

The Figure 2.1 clearly describes the water cycle on Planet Earth. As can be analyzed, the Earth is composed of different types of reservoirs that accumulate and transfer water to keep it in constant movement such as rivers, lakes, lagoons, oceans, underground aquifers, glaciers, polar ice caps and the same soil where infiltration of water occurs.

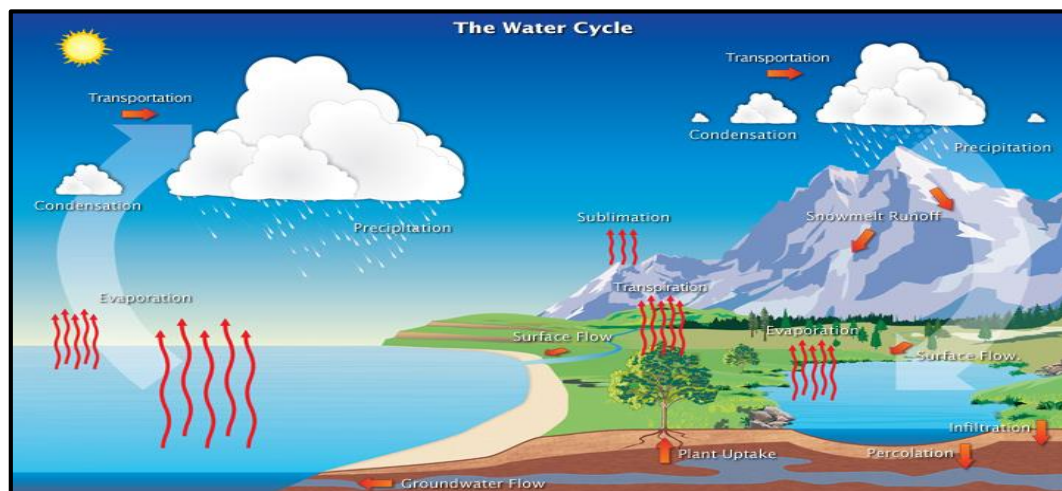


Figure 2.1 - Water Cycle

Source: Earth Observatory – NASA, (2017)

Another definition of the water cycle given by Marsalek, J. et al., (2006) defines this process as: “A conceptual model describing the storage and circulation of water between the biosphere, atmosphere, lithosphere, and the hydrosphere”. (p. 2).

It is considered that the water cycle originates in the oceans, where thanks to the heat of the sun and the wind, the water heats up and evaporates into the air as water vapor. The water vapor is transported to the upper layers of the atmosphere through updrafts, in this place and with the influence of low temperatures, the water vapor condenses forming clouds that return to the earth to later, fall in the form of rains, hail or snow. In this way, fresh water waters the land again feeding the oceans, lakes, rivers, aquifers, forests and of course generating the necessary resources for the sustenance of human beings, plants and animals.

The water that falls in the form of precipitation is concentrated in different places: one part of the water infiltrates the soil, another drains through the surface of the Earth to finally reach the hydric bodies and the last part of the water in the form of rain evaporates. This cycle is the fundamental sustenance of life.

The movement of the water has a particular behavior, the water that by runoff reaches the rivers is transported back to the oceans; the water that, on the contrary, flows towards the surface, concentrates in lakes or lagoons and also feeds on the water that drains into these "natural reservoirs of fresh water". Another part of the water that falls in the form of rain infiltrates the soils, the water that is found in the superficial layers returns to the hydric bodies; the water that is in deeper layers can even be discharged to the oceans through sub-terrestrial structures; another part of this infiltrated water finds openings in the terrestrial surface and emerges due to the internal pressure in the form of springs of fresh water. The water that infiltrates is very important because the one that remains in the most superficial layers serves as sustenance to the vegetal species, to the animals and even to the human beings by means of its extraction.

This is the importance of the water cycle on life on Earth; its effect allows the recharge of underground aquifers and fresh water resources that are the basis for water supply to the inhabitants of each city, town or country. Another factor to consider in the cycle of water and that is very important is the speed with which water completes this cycle, which depends mainly on the role-played by vegetation. The vegetation influences the elements of the

hydrological cycle in a different way; it is known that the forest reduces the flows caused by the downpours, cause of avenues and floods, thanks to the retention of rainwater. (García, Torrent, López, & Del Campo, 2011).

The increase in temperature caused by climate change that is currently experienced by the entire Earth causes the accumulated snow and glaciers to melt, greatly increasing the level of the oceans and causing flooding. The indiscriminate felling of trees is among the main aspects that affect the alteration of the hydrological cycle. This activity carried out by people makes the soil more susceptible to erosion, smaller amounts of carbon dioxide are captured, the production of oxygen decreases and therefore the water resources that are protected by a green vegetation cover, become contaminated or lost.

In the other hand, a special process can take place in the water cycle, the salt water intrusion in groundwater. This process details the intrusion of salt water into fresh water aquifers due to different causes such as soil-water interaction. On many occasions, the rocks found on the coast are fractured, allowing the passage of salt water to the soil strata where the confined fresh water is found. The Figure 2.2 explains the process of salt water intrusion in the ground, especially where the aquifers are located and where the influence of freshwater extraction systems exists.

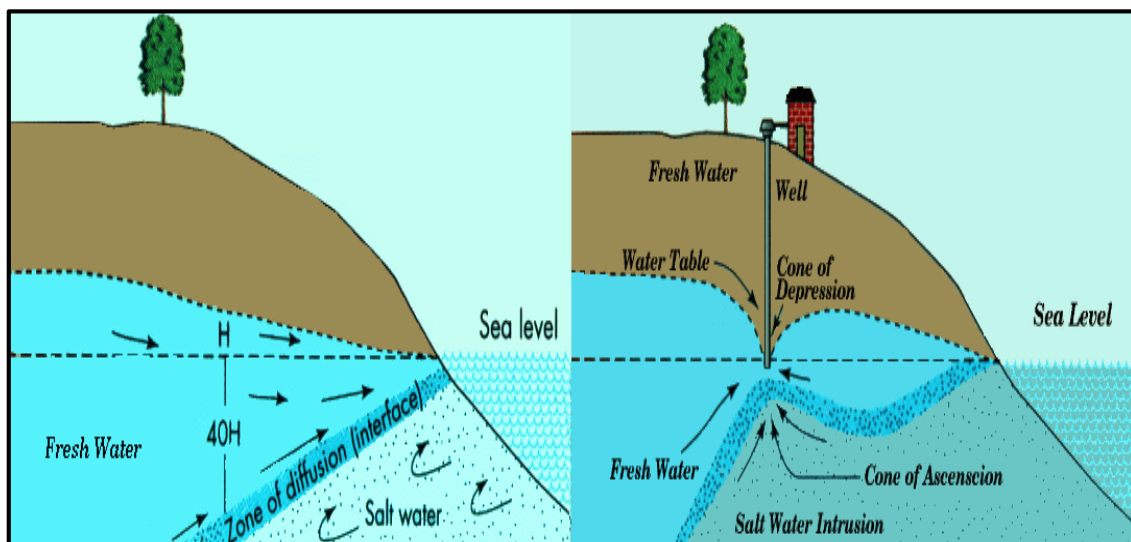


Figure 2.2 - Seawater Intrusions in Groundwater Phenomenon

Source: LENNTECH, (2017)

The importance of the hydrological cycle in this phenomenon is key. When the rains are scarce or when there is an uncontrolled extraction of fresh water, the underground aquifers are emptied little by little. This decrease in water causes, on the contrary, the creation of the salt water pressure cone that tries to penetrate through the diffusion zone or interface. When the salt water enters the aquifers, the physical-chemical characteristics of the fresh water change completely, making it practically impossible to occupy for consumption. For this reason, the continuity of the water cycle plays a fundamental role in underground freshwater reserves such as aquifers.

The irresponsible attitudes of both the inhabitants of the world and the Water Administration Companies have caused that uncontrolled consumption, contamination of water resources and population growth cause serious problems to the water cycle, being evident the shortage of this resource for the supply. Not only the quantity of fresh water is a problem nowadays, but also its quality, since the activities of the population provoke a great environmental impact that contaminates the water resources and reduces its possibility of treatment due to the high costs that are they require.

Soil waterproofing is another of the most common problems that are currently encountered, as it decreases the ability to infiltrate rainwater through soil strata. This inability of natural drainage causes an increase in the volume of water, in other words, floods appear. This problem, however, has a very close relationship with another cycle, the urban water cycle. The EPMAPS currently holds workshops and seminars where it shows the water cycle to raise awareness about its care and importance. In this sense, the Ecuadorian Public Enterprise aims to insert the message of the importance of water in the Metropolitan District of Quito, through lessons on the water cycle and its subsequent transfer from natural resources, their treatment and distribution in each house. According to Espinosa, C. (2016) Operations Manager of EPMAPS, “each inhabitant of Quito, uses an average of 200 liters of water per day, although other cities such as Bogotá and La Paz use an average of 150 liters per capita per day. This shows the importance of saving water and respecting the hydrological cycle”.¹⁶

¹⁶ EL COMERCIO, (2016)

2.2.2. Urban water cycle

Generally, the urban area is characterized by having a population that lives permanently within a physical and geographic limitation and that appeal to the natural resources available to supply itself and to guarantee its social, economic and political development.

In this sense, the capitals of each country tend to host a large number of inhabitants that in most cases usually exceed one million people. Urban areas reflect a markedly higher economic growth compared to rural areas, have a higher price per square meter, are equipped with all the infrastructure required for both the public and private sectors and thus offer greater options of resources so that its inhabitants can develop their daily activities. While it is true and there are "smart" cities that take better advantage of the natural resources available, there are also common cities that demand exaggeratedly large water consumption and in which there is no responsible culture on the management of these survival mechanisms.

Within the urban environment, water is essential to comply with domestic and industrial consumption. The worldwide trend reflects an agglomeration in urban areas of people and their need to be supplied by water. This type of needs create aquatic ecosystems that are managed through companies in charge of the supply and sanitation services. Thus arises the obligation to create proportionally to population growth, measures that improve efficiency levels of supply and drainage systems, adequate control of resources and quality management.

According to Marsalek, J. et al. (2006): “An urban population demands high quantities of energy and raw materials, and removal of waste, some of which turns into environmental pollution. Indeed, all key activities of modern cities: transportation, electricity supply, water supply, waste disposal, heating, supply of services, manufacturing, etc., are characterized by the aforementioned problems”. (p. 1).

In effect, urban activities have an impact (often negative) on urban ecosystems, including urban waters and their aquatic ecosystems, for this reason it is essential to manage urban

processes to maintain adequate control over the demands of the inhabitants. The analysis of the urban water cycle will then allow the efficient use of urban water.

Urban areas stand out for their industrial development and for the provision of different types of services to society in general. Water then becomes one of the indispensable resources for its growth, for the supply of its inhabitants, for the development of life in its different facets. It is precisely here where the water that is used to supply a limited urban area, cross-different processes or stages in a cyclical way. The most simplified way to summarize this cycle is composed of three important stages: Supply, Consumption and Sanitation - Treatment.

The Urban Water Cycle (UWC) is a more complex modification of the water hydrological cycle thanks to the impacts produced by the urbanization of a certain area and the need to provide basic services for its inhabitants through water supply systems, drainage systems and waste water systems. In urbanized environments, that is, at local levels such as cities, the urban water cycle is clearly governing compared to the water cycle or hydrological cycle. The Urban Water Cycle is one of the processes that has more relation with the **water balance**; therefore, its study is one of the main sources to understand one of the traditional methods for the management of water losses. According to the Figure 2.3, the urban water cycle is analyzed as the set of steps described below and repeated in a cyclical way:

1. To meet the needs of drinking water at the urban level, it is important to locate the natural resource that will allow water to be captured as raw material. Currently the water resources that supply large cities do not necessarily have to be located in nearby areas. Thanks to population growth, water consumption, climate change and many other urban factors that influence the hydrological cycle, it is essential to look for more distant resources that offer water in quantity and quality required.
2. The water collected from the natural resource is transported to the treatment plants through conduction networks that can include pumping processes. In the treatment plants, the water in its natural state receives the necessary physical, chemical and microbiological treatments according to current regulations, including a disinfection phase based on chlorine. The treatment processes can be quite complex, depending on the amount of water to be treated, its level of contamination, the existing demand in the urban area, among others.
3. Once the water has been treated and has the characteristics to be considered as drinking water, it is distributed through the water mains to the different buildings,

houses, schools, industries, that is, to all the users that require the service. During this process, it may be noted that there are leaks, which may be real or apparent.

4. Rainwater falls on the urban area, but crosses the polluted layer of air before running off through the waterproofed surface (streets), in conjunction with the domestic and industrial waste water transported through the sewer system. A small portion of the rainwater infiltrates the ground that has not been paved (green areas).
5. The drainage system allows the waste water to be transported to Septic Tanks in some cases and in others directly to Waste water Treatment Plants where the original characteristics of the water can be recovered at certain levels before being returned to the water bodies.
6. From waste water treatment plants, you can obtain different products or organic compounds ideal for agriculture and even certain types of energy based on biogas.
7. Finally, the treated water can be used for irrigation activities or simply discharged to receiving bodies such as rivers, aquifers, lakes and reservoirs. These water bodies will again lead the water to the ocean. Another part of the water returns to the atmosphere through evaporation and transpiration.
8. Some of the water that is filtered through permeable strata or through different types of losses can reach underground aquifers before receiving an adequate treatment, which can lead to the contamination of said subterranean aquifers. Paradoxically, the human being extracts water for its consumption from this type of underground resources as an alternative resource of supply.
9. This procedure is repeated again and again in urban areas becoming a permanent cycle whose main protagonists are water and human beings.

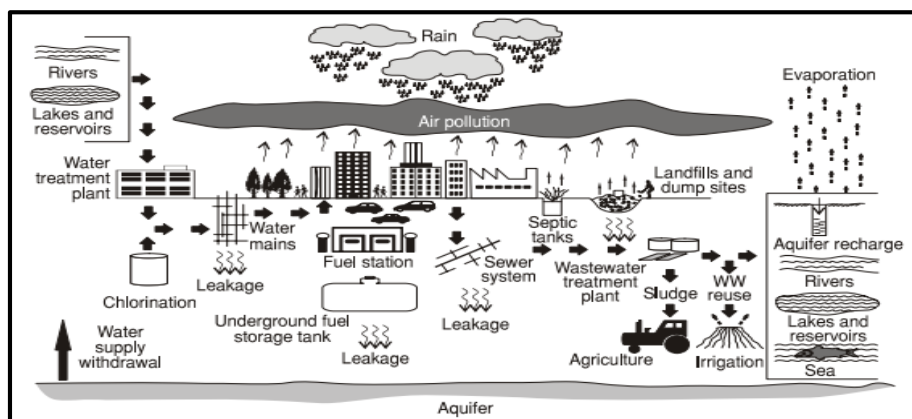


Figure 2.3 - The Urban Water Cycle shown pictorially

Source: Marsalek, J. et al., (2006)

Not all cities have the same water treatment system from the collection or worse, the waste water treatment system. In many cases the waste water is not even treated, but is discharged directly to the receiving bodies without any consideration of the negative impact that occurs in the environment.

In the same way, Ballina Shire Council, (2017) graphically describes the stage at which raw water (extracted directly from the source) is transformed into drinking water, recycled water and waste water. As can be seen in Figure 2.4, recycled water can also be used for domestic use (such as non-potable water), that is, for the operation of sanitary devices. This type of water can also be used within the industrial sector, for certain recreational activities where extensive areas are created as artificial lakes such as golf fields, or more commonly for agriculture. Every responsible urban water cycle must have a system of water treatment plants for purification and, at the same time, waste water treatment plants that guarantee the sustainability of the supply system and permanent respect for the planet's natural resources.

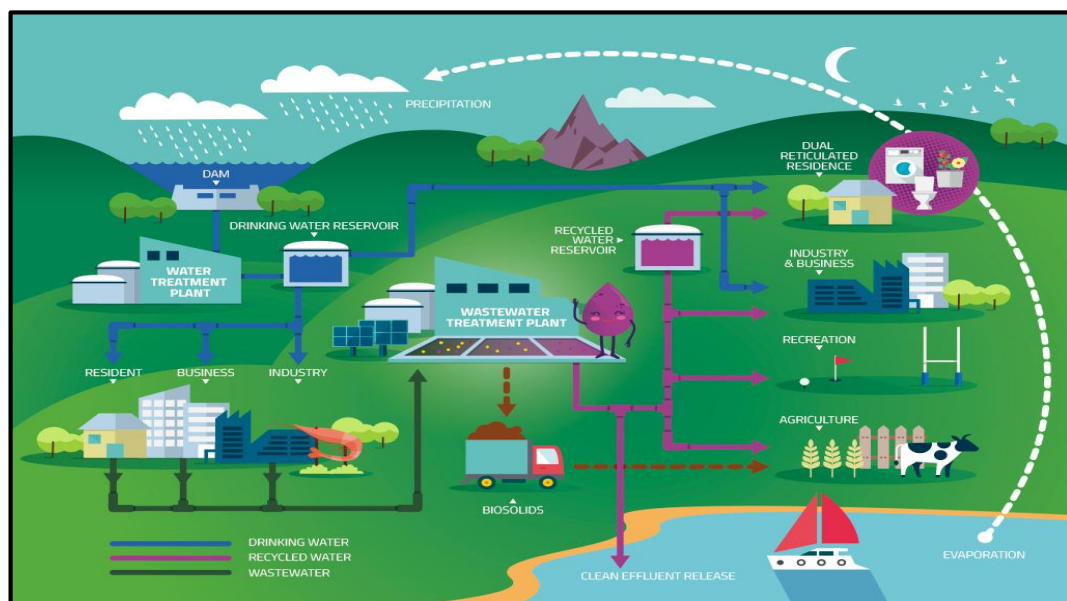


Figure 2.4 - Drinking, Recycled Water and Waste water

Source: Ballina Shire Council, (2017)

The difference present in the Figure 2.4 is that it is considered a structural measure for flood prevention. As can be observed, there is a dam that allows regulating and controlling the flow and volume of water to be distributed in an urban area. This measure greatly controls the flooding of urban areas, but its materialization is costly, in addition to suffering drawbacks in its structure can cause catastrophic flooding.

The urban water cycle is made up of important components that ensure its occurrence and that directly influence the water cycle. Its main components are: water supply systems, urban drainage systems, waste water collection as can be shown in Figure 2.5. From each of these components arise processes that must be managed by specialized entities to ensure the proper functioning of available resources.

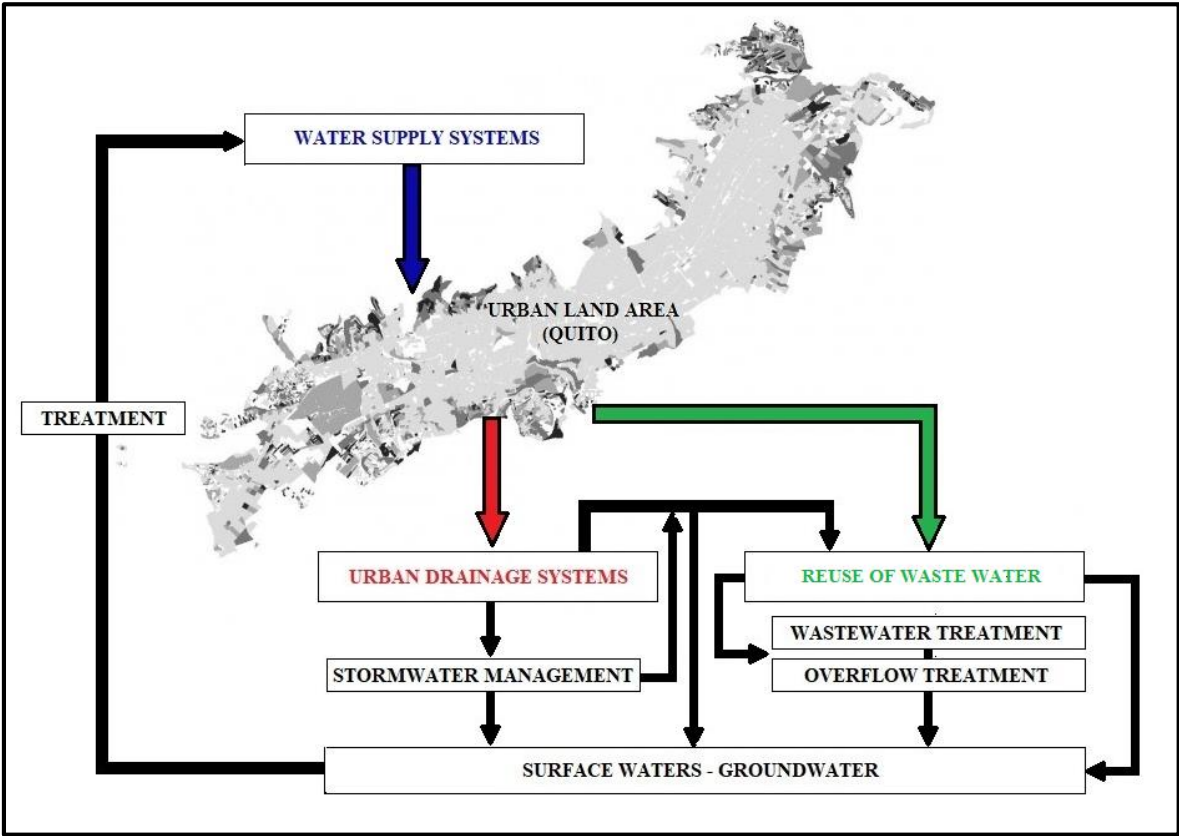


Figure 2.5 - Main Components of Urban Water Cycle
 Source: Author’s own drawings

2.2.3. Components of water supply systems

The water supply systems are formed by a set of components, pipes, facilities and accessories that serve to drive water from natural resources to the places where the populations are located (residential, industrial, commercial level). These water supply systems make it possible to satisfy the drinking water consumption needs of the inhabitants who reside in a certain urban area. In order to guarantee the quantity of water necessary according to the existing consumption demand, it is necessary to study in detail the characteristics of the

resources that must be used for the collection of water. In this sense, it is important to determine with precision its geographical location, water volume, water quality, among other technical details that must be evaluated.

According to the natural resource of water used for the supply system, the source can be classified as follows:

- **Surface water:** the water that will feed the supply system is originally formed by lake waters, rivers, reservoirs, springs and even rainwater.
- **Groundwater:** water is extracted from aquifers (through wells).
- **Non-conventional resources:** in this type of resources, there are those that are not common due to the high costs in the production of fresh water. Among the most important are the processes of desalination and reuse.

The main objective of a water supply system is to efficiently deliver water according to established quality and quantity standards. To achieve this goal, it is important that the water quality once the treatment phase passes, does not change during its distribution in the pipes. In most of the hydraulic designs, it is sought to use water supply systems that transport the water under the action of gravity (through the difference in level between reservoirs and homes), however in places as large as capital cities, this principle is almost impossible to fulfill. The systems use pumps to impulse the water in order to supply the service to neighborhoods or sectors that are in topographic levels higher than those of the main reservoirs.

In order to analyze the components of the water supply systems, it is important to define the functionality and applicability of the system; these components vary if the supply system is applied for an urban area or for a rural area. In the case of urban areas, the components of a water supply system are more complex, since they require a high efficiency performance due to their frequency of use. In the cases of rural areas, water supply systems (at least in Latin America) omit several important components that are often not considered important, due to lack of knowledge on the subject or economic resources that make it impossible to installation. In these systems, the raw water treatment plants and waste water treatment plants are practically scarce. In any case and as can be reflected by the Figure 2.4, *the urban water cycle has a direct relation with the components of water supply systems.*

The components that make up the typical water supply systems for urban areas are the following:

- 1. Natural Resource (Source):** it is defined as the physical area delimited geographically from where the water that is considered within a hydraulic study is extracted to satisfy the existing demand of drinking water by a population. It is important that the hydrological, geological and hydraulic study conclude that the resource is suitable in quantity and quality, that its volume is permanent and sufficient to meet the design parameters considered based on the number of inhabitants as shows the Figure 2.6.



Figure 2.6 - Natural resources of water extraction

Source: Author's own compilation

- 2. Catchment:** These structures are built in the natural resource of water, with the aim of deriving part of the flow of that resource based on the existing demand for a specific city. The catchment structures have water intakes protected by grids through which the water enters. In some cases, along with the catchments, there are sand interceptor or sedimentation structures from which pipes that transport water by gravity or by pumping to treatment plants are derived.

Figure 2.7 is the example about how these structures can catch the water from the bottom, side, or the most common at present are the dams.



Figure 2.7 - Natural resources of water extraction

Source: Author's own compilation

- 3. Treatment Plants:** According with the Figure 2.8, these components are conformed by a set of structures, devices and monitoring systems that allow purify the water collected from the resource to comply with the quality standards required for human consumption. The applied processes may vary according to the physical, chemical and microbiological characteristics of the water from the natural resource. Among the most common are coagulation, flocculation, filtration, membrane processes, chemical disinfection, oxygen application, adsorption systems, ion exchange, solar radiation, among others.



Figure 2.8 - Treatment Plants for Water in Quito

Source: Author's own compilation

At the moment, these first three components are "communicated" to each other through **adduction or impulsion pipes** that allow transporting the water flows from the catchment to the treatment plant. The hydraulic design of these pipelines is essential to ensure the correct operation of the pipes and the transport of water from one point to another. For this, it is essential to consider a variety of necessary devices such as purge valves, pressure-ruptured tanks, pressure regulating valves and the different accessories according to the

geometrical layout of these pipes according to the topography. The pipes and accessories can be metallic (steel, cast iron, copper), polyethylene (PE), polyethylene manufactured by the peroxide method (PEX), polypropylene (PP), polyvinyl chloride (PVC), or multilayer, among others.

- 4. Reservoir:** These are structures with different geometric configurations that allow to store drinking water from the treatment plants. Its characteristics must comply with quality standards at all times to ensure that the water contained will not be contaminated or change its physical, chemical and microbiological characteristics. They are generally located in the higher areas as shows the Figure 2.9, to serve most of the cities through water mains based on gravity principle. However, the expansion of cities means that over time it is impossible to provide water to certain sectors, causing problems in the distribution of water. Its hydraulic purpose is to compensate for variations in consumption and have a double function: to serve in case of emergency such as fires, breakdowns or breaks repair.

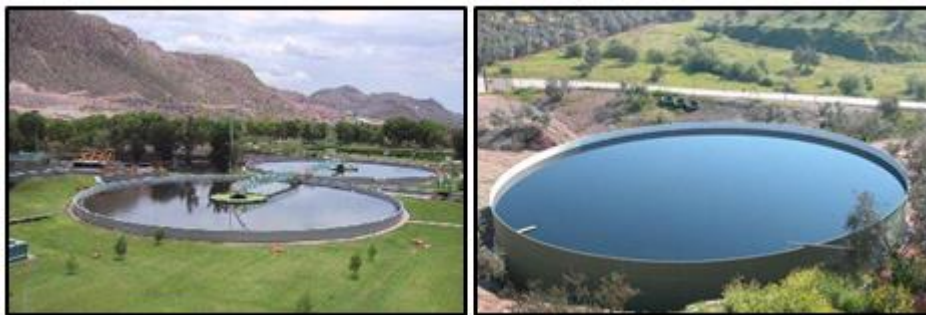


Figure 2.9 - Drinking Water Reservoirs in Quito

Source: Author's own compilation

After the reservoirs are installed the water mains, which have the function of transporting the water from the storage components (reservoirs) to the distribution pipes that are located along the streets of the urban area. The distribution pipelines are connected to the typical residential water service connection. The general scheme that details the components of a conventional water supply system is summarized in Figure 2.10. As can be analyzed, the optimal functioning of each component of a water supply system is key to guarantee the continuity and quality of the service since the water is captured in the natural resource until its arrival in each home as drinking water.

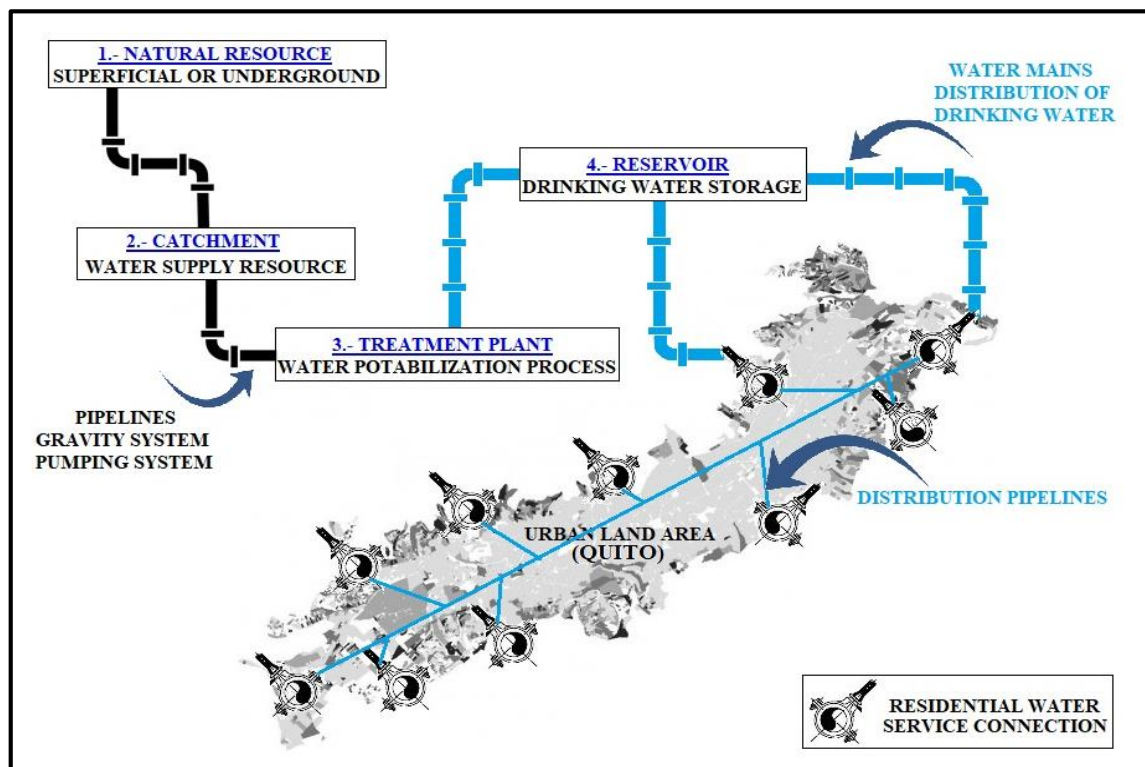


Figure 2.10 - Water Supply System Components

Source: Author's own drawings

Finally, a potable water supply system could not fulfill its function completely if the components that will treat the residual water product of the use of drinking water have not been considered. It is important that the potable water supply systems consider in their structure, the implementation of elements that treat waste water at residential and industrial level. Although it is true and the water is not returned with the original conditions to the water resources, it is important to reach the levels established by the regulations to discharge the water that was already used in the rivers or lakes. This is how cities have sewerage systems that are made up of pipes that transport waste water. These systems are formed by receivers (channels), wells and other types of structures that make it possible to administer this type of water technically until their arrival at the respective treatment plants. In these plants, different types of strategies are applied to purify water and to produce compounds based on organic matter. Figure 2.11 illustrates precisely the process that occurs at the urban level due to the use of drinking water. It is important to understand that these components are part of another system, but in turn directly influence the operation and functionality of the components of water supply systems.

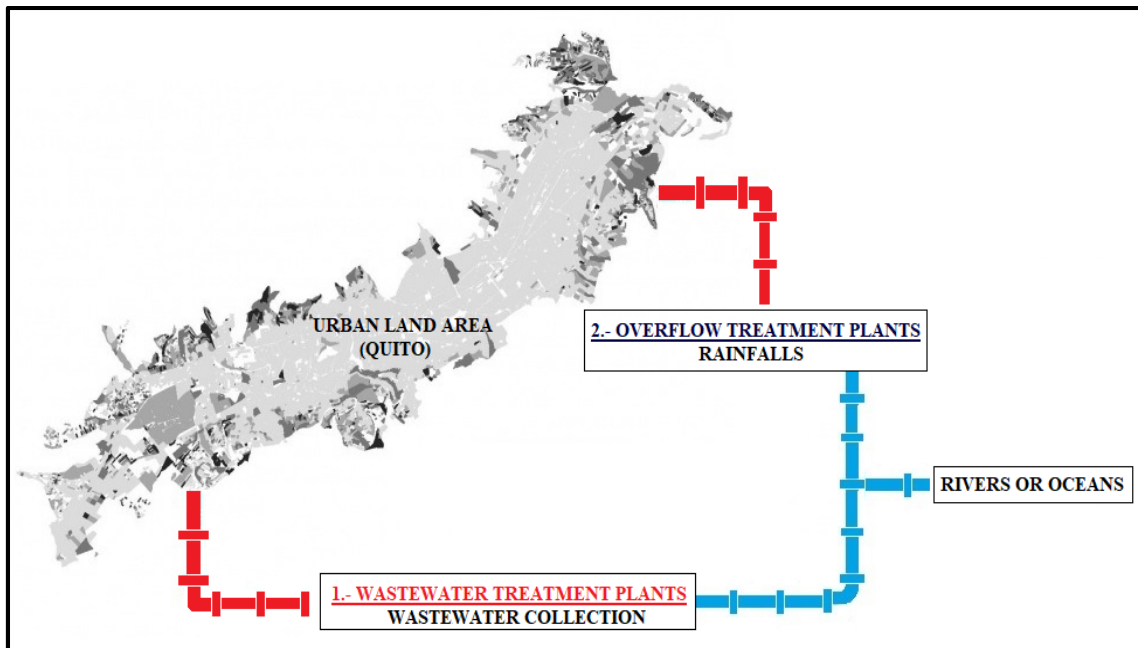


Figure 2.11 - Sewerage System Components

Source: Author's own drawings

2.2.4. Components of urban drainage systems

The drainage of cities due to rainwater has a great importance for the development of the urban water cycle. Considering the daily volumes of water that must be evacuated from a city due to the emergency flows (overflow – major system) and the concentration of water on the surface of the streets and covers by the rains (minor system), it is important to consider the design of systems to transport, treat and dislodge these waters to receiving water bodies.

The proper design of urban drainage systems guarantees that cities are protected from floods that can occur due to different frequencies, intensities and rainfall durations. For the sizing of its components, it is necessary to have technical information such as maximum rainfall flows, topographic information, and runoff slopes. The main function of drainage systems is precisely to evacuate the water that, due to topographic conditions (in most situations) accumulates in the ground. The effect of urbanization in large cities currently causes problems related to the increase of floods in relatively short times. The most influential cause in this problem is the replacement of green coverings (vegetation, grass) by concrete surfaces or any other impermeable material that makes it difficult to drain the water through the permeable strata of the soil.

These systems must collect rainwater that runs off the slopes that make up the streets and that fall directly onto the urban area. To achieve levels of efficiency in these systems it is important to take advantage of the action of gravity on the water to be transported through channels. Talking about efficiency, it is important to carry out periodic maintenance on urban drainage systems to prevent them from being blocked or for water to return to the streets and increase flooding. The principal hydraulic components in the urban drainage system are described according to the Figure 2.12.

- 1. Collecting Network:** This system is made up of a series of components that allow collecting and transporting rainwater from the street surface to the treatment systems or discharge resources.. In this group are the main and secondary channels which are cemented to lower levels compared to the level of the land to be served. Its sections, geometric characteristics vary according to the design proposed to evacuate the amount of water that runs down the streets.
- 2. Manholes:** These structures collect the storm water through the pipelines installed at its entrance. Inside the water can be retained or stored, however it is very important that there is not the overflow of water.
- 3. Protective structures:** These structures that are placed in the curves to avoid the scour and erosion of the margins of the channels.
- 4. Pumping Stations:** Where, due to topographic conditions, the drainage system can not evacuate water by gravity, it is important to install pumping stations to transport the water collected at those points to areas with higher elevations for proper operation.

According to Mays, L. (2001): "...minor systems include gutters, pipes, small ditches, culverts, and storm drains, detention ponds, and small channels. Major systems include the streets and the urban streams, floodways, and flood fringe areas..." (p. 1.18).

The components of an urban drainage system consist of subcatchments in which is produced the overland flow based on the excess rainfall. Therefore, on the top is the sewage (from combined systems) which collects the rain and the snowmelt. Both of them, the major and minor systems transport the water to the storm water treatment plants through the interceptors.

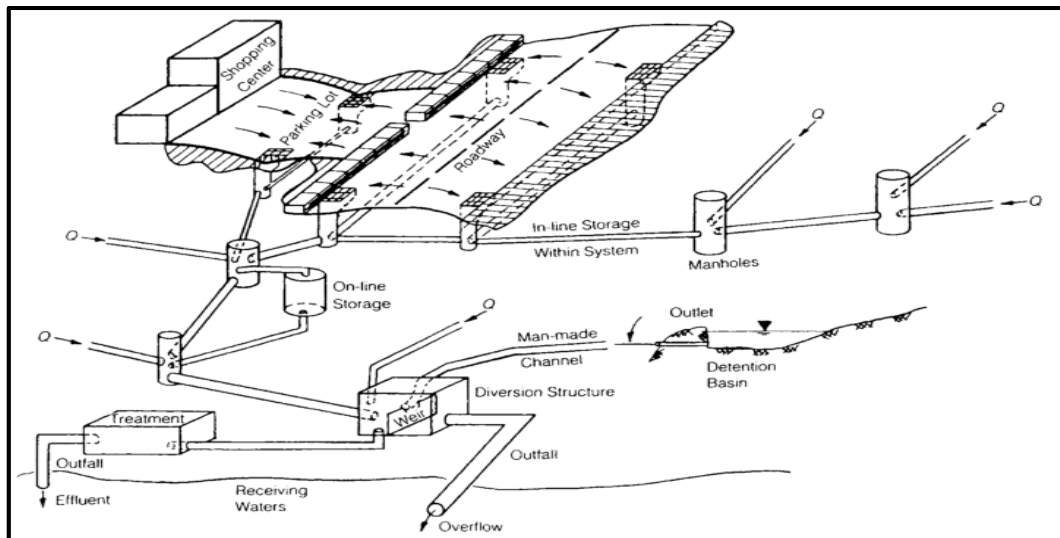


Figure 2.12 - Components in urban drainage system

Source: Mays, L. (2001)

Currently, the concept of urban drainage has been modified to sustainable urban drainage, which is characterized by reducing the amount of water pollutants by trickling down the streets. In this way, not only is the water drained through the system's components, but it is returned to nature, water with better characteristics. In the other hand, the Figure 2.13 illustrates the urban combined sewer system (waste water and storm water systems).

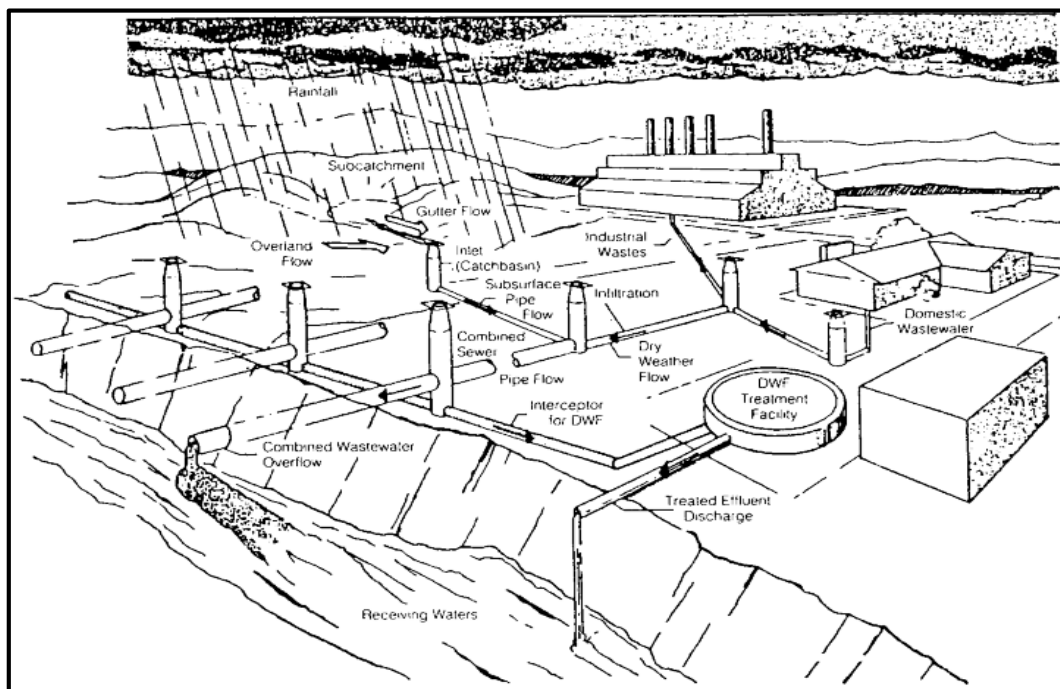


Figure 2.13 - Components in urban drainage system

Source: Mays, L. (2001)

2.3. Sustainable urban drainage systems

The waterproofing created by humans in urban areas reduces the possibility of rainwater infiltrating through the soil and increases the risk of flooding. This reality, added to the lack of drainage systems in many cities, increases the possibilities of imminent floods in the low areas. The effects of climate change and accelerated population growth play a fundamental role in the need to implement Sustainable Urban Drainage Systems, because the frequency and intensity of rainfall is increasing and because the increase in population causes the need to physically expand the limits of urban areas waterproofing soils as shows the Figure 2.14.

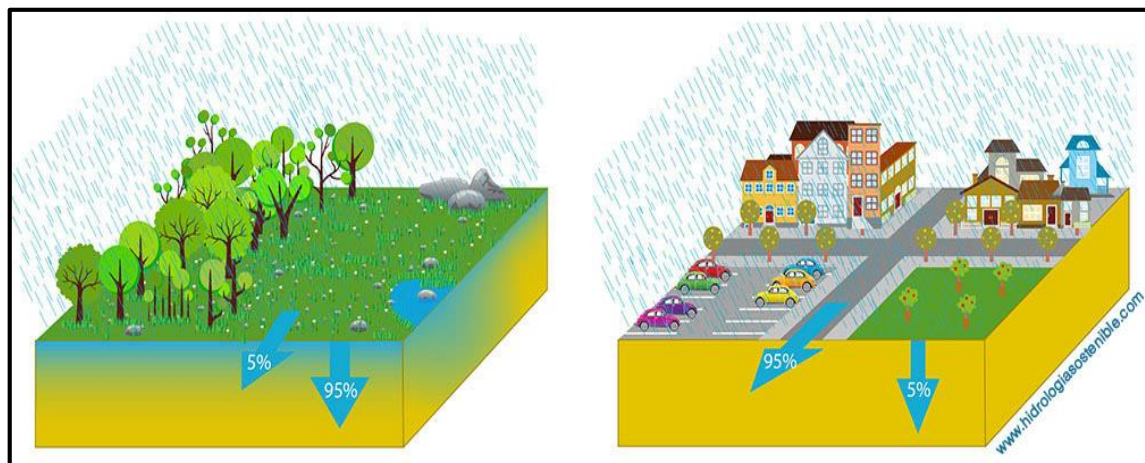


Figure 2.14 - U.W.C. modification by surface waterproofing (Before and After)

Source: Hidrología Sostenible, (2018)

The existence of evidence that the rains are and will be more intense over the years is a fact. According to the (World Health Organization, 2017), the frequency and intensity of rainfall increases and it is expected that this variation will continue throughout the century causing terrible floods. Its effect is not only related to the inability to drain from urban areas but also the contamination of fresh water resources, the risk of diseases, the proliferation of carriers of diseases, human losses, economic losses due to damage to urban infrastructure, damage to water supply and drainage systems, among others.

Sustainable Urban Drainage Systems (SUDS) are design alternatives that propose the implementation of models based on natural drainage systems over urban areas. Its main objective is to provide an unconventional alternative to drainage in urban areas and reduce

the risks of flooding. At the same time, they intend to use rainwater for different purposes, which reduces the consumption of drinking water from public networks. Its sustainability focuses precisely on saving water, reducing costs, reducing waste water, and using rainwater as a way to alleviate existing drainage systems.

The design of Sustainable Urban Drainage Systems must consider different iterative stages to guarantee its efficiency and functionality as shows the Figure 2.15. Other factors will affect the urban water management as floodplains occupation, coastline occupation, deforestation, low performance of urban drainage and natural systems, social and cultural changes.

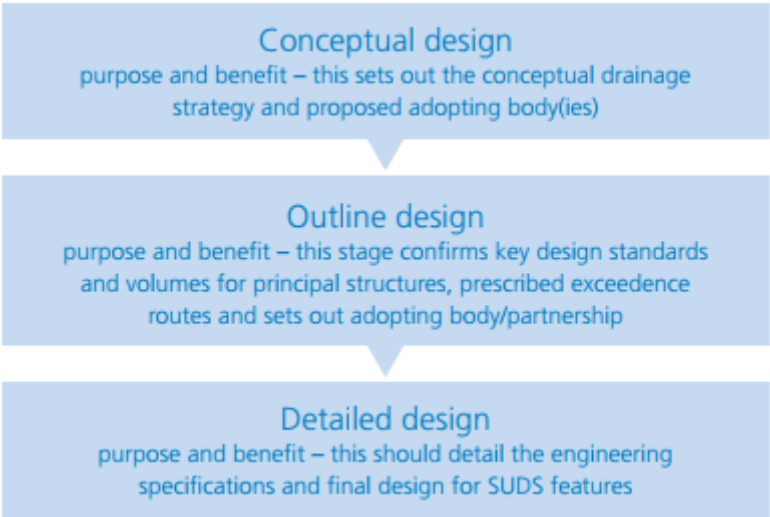


Figure 2.15 - Iterative Stages to develop site level drainage designs
Source: Anglian water, (2018)

Currently, families take measures at the individual level to prevent urban flooding through the construction of walls or floodgates that are operated in the event of heavy rains to protect the interior of homes. However, at urban levels, the measures that must be applied for the prevention of floods require the control of enormous quantities of water, which can be regulated through structural and non-structural measures to prevent urban flooding.

2.3.1. Structural measures to prevent urban flooding

The structural measures are formed by all the constructions conceived by Civil Engineering to avoid the risk of possible flooding in a given area. In fact, this type of measure represents an option for flood control very effective; however, its main disadvantage is in the economic aspect since its production costs are quite high. Another problem that usually arises in these measures is that unexpectedly exceed the values of the estimated rainfall intensities and threaten to cause the collapse of these structures.

Structural measures for the prevention of urban floods can be classified into three groups: Retention Structures, Protection Structures, Drainage Systems and Artificial Retention Basins.

2.3.1.1. Retention structures

As its name implies, this type of structure allows the retention of water to prevent flooding downstream of a certain area. The dams are a clear example of this type of structural measure as shows the Figure 2.16. Its main function is to regulate large flows.

- **DAMS:** This type of structures can be made up of different construction materials such as: reinforced concrete, stone with clay cores, among others. Its objective is to retain the water that is stored in a specific area and that usually comes from a river. In addition this structural measure can be used for drinking water, irrigation, and electric power production purposes. They also serve as flow regulators to prevent flooding in low areas to its place of construction.

However, this type of structure becomes a potential resource of danger that can cause even larger floods if there are faults in it. For this reason, there is a sense of extreme security that is clearly wrong, because these structures are susceptible to collapse due to the strong water pressure experienced or by the great magnitude of seismic events.



Figure 2.16 - Coca Codo Sinclair Dam – Napo, Ecuador

Source: Ministerio de Electricidad y Energía Renovable, (2017)

Some advantages and disadvantages are detailed in the Table 2.1 about the use of dams. The environmental impact generated by the construction of these structural measures is very negative, since thousands of hectares of nature are destroyed during construction, during the flooding of the reservoir. In addition, the displacement of animal species is another effect.

Table 2.1. Dam’s advantages and disadvantages

DAM’S ADVANTAGES AND DISADVANTAGES	
Advantages	Disadvantages
<ul style="list-style-type: none"> • Creation of recreation spaces, aquaculture and navigation. 	<ul style="list-style-type: none"> • Accidental pollution (normal water use).
<ul style="list-style-type: none"> • Reserves of water for human consumption, agriculture and fire-fighting. 	<ul style="list-style-type: none"> • Seismicity (related to dam breaking and flooding of downstream sites).
<ul style="list-style-type: none"> • Regularization of flood and drought flows (floods and prolonged periods of drought). 	<ul style="list-style-type: none"> • Interruption of sediment transit in water courses (coastal erosion).
<ul style="list-style-type: none"> • Production of hydroelectric power. 	<ul style="list-style-type: none"> • Alteration of the microclimate of the region, which may lead to the extinction of the most sensitive habitats.
<ul style="list-style-type: none"> • Use of other renewable energy sources (wind energy). 	<ul style="list-style-type: none"> • Upstream flooding, instability of slopes and overloading of the reservoir.
	<ul style="list-style-type: none"> • Obstruction of migration of fish species.

Source: Author’s own analysis

2.3.1.2. Protection Structures

This type of structure is built near cities that are located at lower levels with respect to sea level. Its function is to offer permanent protection to cities or urban areas avoiding the entry of water into these areas.

- **DYKES:** This type of structural measure prevents flooding due to water ingress. Its structure can be reinforced concrete, earth or natural stone. Its main function is to prevent flooding in areas near rivers or seas, in addition to channeling the bodies of water (rivers) to change their direction. These structures are designed to reduce the energy coming from the waves produced by the seas or the currents of rivers, in such a way that they provide protection to the surrounding areas as shows the Figure 2.17.



Figure 2.17 - Dyke of Barcelona's Port

Source: Diario Qué!, (2011)

2.3.1.3. Urban Drainage Systems

Undoubtedly the most common structural measures at the urban level. This type of system requires different components: channels, tunnels, pipes, among others as shows the Figure 2.18. Its main function is to drain the water that flows through the surface of the urban area to the rivers. In this way, rainwater is prevented from accumulating in the streets and in the lower areas of the cities. Without these types of systems, the proliferation of floods, diseases and damage to urban infrastructure is imminent. This measure needs to be connected to rainwater harvesting structures, such as culverts, which become the water entrance to the drainage system.



Figure 2.18 - Urban Drainage System

Source: Diario Qué!, (2011)

2.3.1.4. Artificial Retention Basins

Like the natural retention lagoons or ponds, this type of structure is constructed with the objective of capturing the surface runoff, without the (temporarily) stored volume will be infiltrated through the subsoil. This basic design principle allows the reduction of the maximum flow that is subsequently conducted to the downstream drainage system, decreasing the flood peak. Large reservoirs are usually built in the underground due to the lack of physical space on the surface. According with the Figure 2.19, polyethylene pipes can be used.



Figure 2.19 - Artificial Retention Basin

Source: Enviropipes, (2018)

2.3.2. Non-structural measures to prevent urban flooding

This type of urban flood prevention measures is closely related to sustainable urban drainage systems, because they seek solutions or unconventional alternatives to drain the runoff water in a natural way which is, contributing positively to the environment. Its main characteristic is that this type of measures are designed to minimize the damage of the floods, do not avoid them. The investment cost of these systems is considerably lower than in comparison with structural urban flood prevention systems; however, their results are very efficient when applied on a large scale.

The "ecological" concept of these measures positively influences the environment with the implementation of systems that behave as natural mechanisms under the use of rainwater, improve the drainage infrastructure maintenance and encourage resilient construction.

- **GREEN ROOFS:** The global population growth and the lack of enforcement in environmental protection laws have produced changes in climatic conditions and increased pollution. As shown in Figure 2.20, green roofs reduce the impact of flooding by storing water in their structure.



Figure 2.20 - Green Roofs in Quito

Source: El Universo, (2015)

The green roofs have become one of the best solutions for solving these problems and to prevent urban flooding due to its low investment and other benefiting such as:

1. Visual improvement;
 2. Improves thermal comfort;
 3. Creation of recreational space in confined spaces;
 4. Restored the water cycle by the stored water in the substrate;
 5. Improved air quality by the elimination of gas emissions in urban areas;
 6. Decreased of CO₂ product of the burning of fossil fuels;
 7. Possible creation of micro-enterprises related to the sale of natural crops and construction of gardens;
 8. Use of recycled materials.
- **NATURAL STORAGE / INFILTRATION BASINS:** Retention lagoons are also natural structures at the surface level in order to store rainwater for a certain period. The vegetation of these natural storages is fundamental for the treatment of water and the elimination of pollutants. When these areas are not flooded, these non-structural measures can be used for other purposes such as sports areas (skate parks), car parking, among others, as shows the Figure 2.21.



Figure 2.21 - Natural storage - Multifunctional artificial storage (Skate Park)

Source: ZUT Skateparks, (2011)

- **INFILTRATION TRENCH:** They are uniformly graduated sections of the soil (filter strips) designed to collect runoff water from the roofs or floors and eliminate contaminants by filtering, by vegetation or infiltration. For this type of non-structural

measures, coarse aggregate (gravel) is used as filtering material. As a secondary objective, they can store water before the excess is transported to conventional drainage systems through connections with these measures as shows the Figure 2.22.

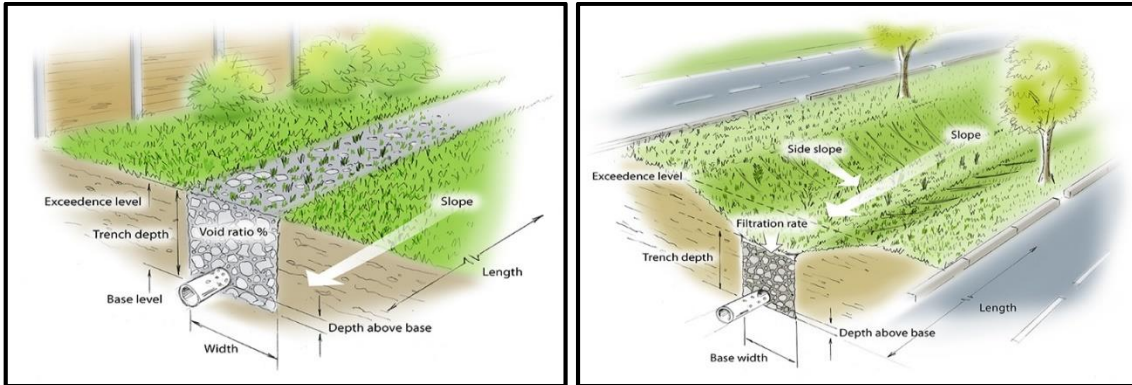


Figure 2.22 - Infiltration Trench

Source: Innovyze, (2016)

- **RENATURATION OF THE URBAN WATER CYCLE:** As shows the Figure 2.23, the process of applying green roofs is essential to return the property of impermeability to the floors that were covered by concrete or asphalt layers, making it difficult to infiltrate the water. During the process of soil waterproofing, there is a high risk of collapse due to the excessive withdrawal of water in urban areas.



Figure 2.23. Recovery of green spaces in Quito

Source: Innovyze, (2016)

The possibility of renaturation of the urban water cycle allows the recharge of aquifers, the reduction of flow peaks in drainage systems and contributes to the increase of green areas and spaces for recreation purposes in cities where these spaces have been practically

eliminated. To comply with this measure, plants or native vegetation of the sector under study can be reinserted or reforested.

- FLOODPLAINS OCCUPATION:** It is very important to create a culture of flood prevention in places that are potentially prone to suffer this type of even. In these cases, it is necessary to consider resilient constructions that allow to reduce the risk of collapse or damage of structures due to water as the houses proposed in the Figure 2.24.



Figure 2.24 - Models of Resilient Constructions
 Source: Government Technology, (2014)

- INFILTRATION WELLS:** They are wells that serve as temporary rainwater storage structures. Its main objective is to reduce the flow peaks in the drainage system through the partial storage of the volume of water that precipitates in an urban area. It is important that in the construction process the structure is surrounded with a geomembrane as shows the Figure 2.25.

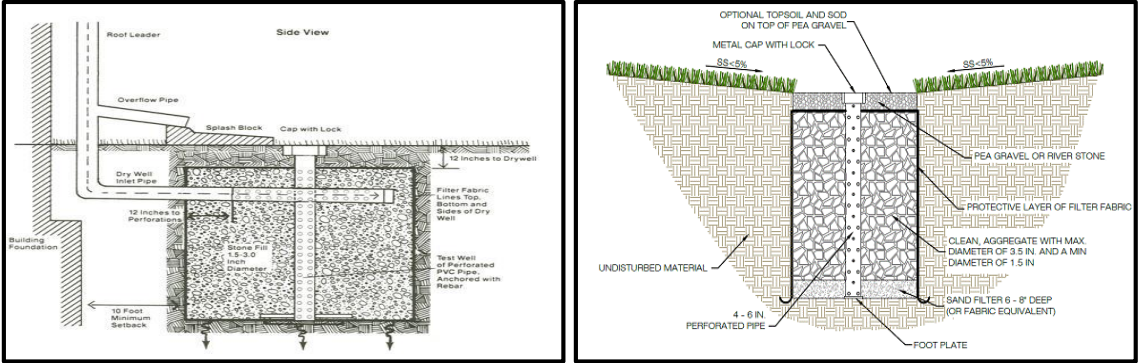


Figure 2.25 - Infiltration Wells
 Source: Keep Our Earth Now, (2012)

- **PERMEABLE PAVEMENTS:** In this case, rainwater infiltrates through the pavement and can be stored in lower layers of soil or there may be pipes connected to the main drainage system for the transport of infiltrated water through the pavement. Open-graded mixes use only crushed stone (or gravel) as shows the Figure 2.26.

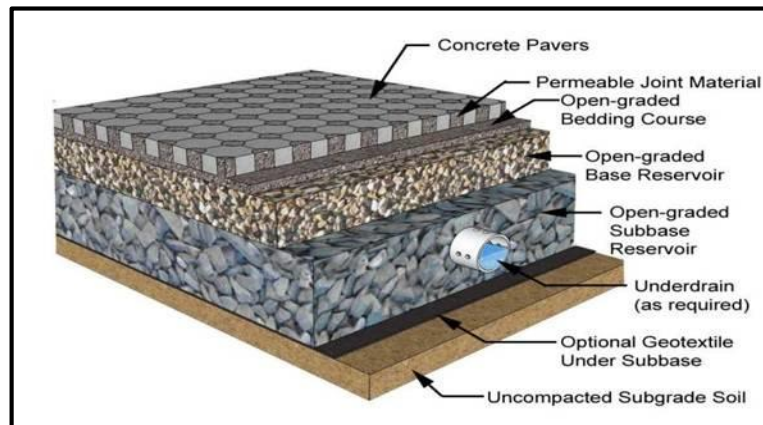


Figure 2.26 - Typical Detail of Permeable Pavements

Source: VIRGINIA DEQ STORMWATER DESIGN SPECIFICATION No. 7, (2011)

- **URBAN AFFORESTATION:** With a concept very similar to the renaturation of the urban water cycle, the Urban Afforestation is a non-structural measure for flood prevention that aims to reforest places in urban areas to intercept rainfall as shows the Figure 2.27. Among its advantages, the thermal improvement of the area, the renewal of air quality, the reduction of noise and the aesthetic improvement of the area stand out.



Figure 2.27 - Urban Afforestation in Quito

Source: La Hora, (2018)

- **VERTICAL GARDENS OR LIVING WALLS:** They are walls constituted by vegetable layers that are used as facades of buildings. They can also be installed in buildings and their main objective is the water retention in their layers, improve thermal confort in open urban spaces, renewal of air quality, creation of vertical ecosystems, guarantee the preservation of plant species, among others. This type of measures is designed to withstand the different conditions and factors of the climate as well as aesthetically contribute to the structure. In quito this is a new concept applied in Shopping Centers as shows the Figure 2.28.



Figure 2.28 - Living wall in the Mall of Quito

Source: DISEÑO EN ECUADOR - haremos historia, (2014)

- **REUSE OF RAINWATER:** For the present research work, this non-structural measure is the most important of the analyzed ones. The use of the resource that is naturally obtained due to the water cycle, can be used in a way that not only contributes to improve the water efficiency of a building but also reduces the risk of flooding. In the case study of this thesis, it is tried to demonstrate this benefit precisely with the supply of an alternative system that works based on the collection of rainwater.

Among its innumerable benefits are the: reduction of drinking water consumption and water resources conservation for buildings. Generally, drinking water is wasted and rainwater is not considered as an extra resource of water for the execution of certain activities and the operation of sanitary devices. It is demonstrated that these systems contribute efficiently as non-drinking water reserves for the increase of water efficiency in buildings as shows the Figure 2.29.

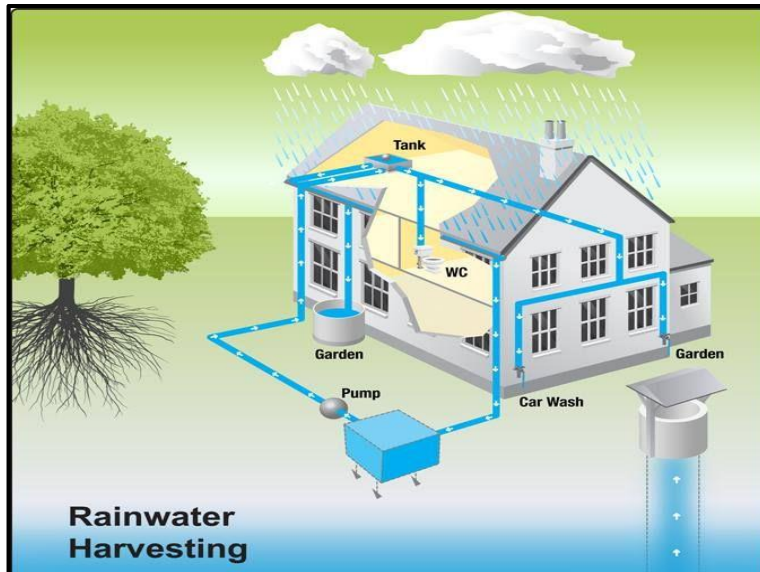


Figure 2.29 - Rainwater Harvesting system for Houses

Source: Solar Geo, (2011)

Figure 2.29 shows a typical rainwater harvesting system for a residential house and Figure 2.30 details a rainwater system for a building of (n) number of stories.

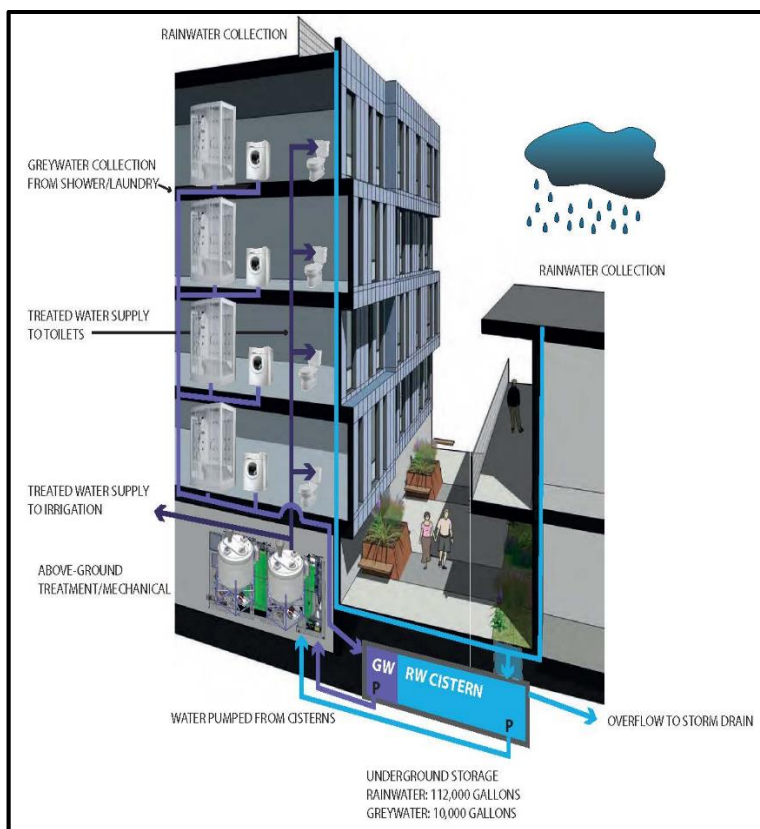


Figure 2.30 - Rainwater Harvesting system for Buildings

Source: Ecological Concerns Incorporated, (2016)

2.4. Efficient use of water in buildings

The efficient use of water in buildings is directly related to the importance of water as a natural resource and all the factors that justify the application of measures to guarantee its conservation and good use through practices and quality processes. In Latin America, the efficient use of water in buildings is not a common practice that is regulated based on current technical and design demands. However, there are worldwide referents such as Brazil and Portugal for example, which execute not only water efficiency projects in buildings, but also that apply efficient water use policies.

According to the Ministry of the Environment of Brazil (2018) the policy of the 5 R's is applied to partially solve the environmental problems related to the reduction of consumption and the reuse of materials through recycling as shows the Figure 2.31.



Figure 2.31 - Policy of the 5 R's

Source: Ministry of the Environment of Brazil, (2018)

The assigned name (5 R's) refers to five actions that must be applied as a fundamental step for changing habits at the urban level. Applied to the hydraulic efficiency in buildings, these policies could be understood as follows:

1. **To Reduce:** The amount of drinking water (consumptions and water losses) that are spent daily in buildings. Techniques, mechanisms, devices or strategies can be applied to reduce consumption as much as possible and avoid water losses that have an impact on high economic costs and the indiscriminate expenditure of natural resources.
2. **To Rethink:** It is necessary to think about all that can still function and that in this specific case can be used as a new way of water supply even at the level of non-potable water. Millions of cubic meters of potable water are unnecessarily wasted in the world for each year, which allows to understand that natural resources suffer an accelerated wear.
3. **To Reuse:** All the volume of water that can be reused for non-potable consumption. In this case, the reuse of rainwater becomes an essential policy to guarantee the hydric efficiency of a building.
4. **To Recycle:** The water that was already used in the buildings. This policy allows the disposal of residual water (gray water) with a previous treatment, as an option to replace the non-potable consumption of the users, reducing the consumption of drinking water.
5. **To Refuse:** Uncontrolled consumption in the system of drinking water supply in buildings. Part of this policy must be assimilated and applied by users. Their compromise should avoid wasting drinking water and contamination of this resource.

These policies are considered to raise society's awareness of the need to change negligent routines with respect to the care of the environment and the efficient use of natural resources.

In the specific case of Quito (Ecuador) and based on the information published by the Secretaría de Territorio (2017), several urban projects have already been approved. They have met Eco-Efficiency parameters such as collection and reuse of rainwater, treatment and reuse of water grays, generation and use of solar energy, terraces and green walls. The adoption of these measures contributes to the public space (delivery of frontal removal to the public space), diversity of uses in the building (housing, offices and commerce), adequate debris management plans and solid waste based on good construction practices, among others. In addition to the approved projects, more than ten projects are being followed up, since its expedition, which seek greater buildability in the areas of mass transit influence.

This global trend related to the efficient use of water in buildings is becoming a necessity and a requirement to be met. The objective is to obtain the certification and labeling for buildings on water efficiency, which is achieved with a high commitment of responsibility, the increase in the quality of processes and decision making, the implementation of policies for the reuse of natural resources as systems alternative supplies, etc. On the other hand, the lack of attention in the sanitary and hydraulic design of buildings and their operating processes, combined with the wasteful patterns in the use of water, result in high levels of inefficiency.

However, the technologies to increase the water efficiency of buildings has allowed this concept to be developed in a broader and more innovative way. That is how Das *et al.*, (2015) establish the definition of green buildings. They refer to structures that are designed to be environmental friendly making the minimal and efficient use of resources. The need to create this type of structures has to do directly with the extinction of natural resources and the high consumer demand that exists. The accelerated population growth means that 64 trillion cubic meters of fresh water per year are required to satisfy the current demand.

A wide variety of methods has been developed to evaluate green structures or water efficient structures built:

1. **BREEAM:** Building Research Establishment Environmental Assessment Method based in Watford England.
2. **Green Star:** Applied in Australia.
3. **CASBEE:** Comprehensive Assessment System for Building Environmental Efficiency developed in Japan.
4. **BEPAC:** Building and Environmental Performance Assessment Criteria (Canada).
5. **LEED:** Leadership in Energy and Environmental Design developed in The United States.

One of the main objectives of the efficient use of water in buildings is to protect the quality of this resource. In the same way that the structure of a building is designed for a certain period of useful life, there must be an adequate design of the water supply system that should consider the supply of an alternative unconventional resource (rainwater harvesting) and another of waste water reuse. Both strategies must be used for the consumption of non-potable water exclusively.

2.4.1. Components of the buildings water distribution facilities

The efficiency in the distribution of water in a building must be characterized by providing the resource to all users who are part of the structure regardless of the number of floors. To achieve this goal, it is important to install high quality components that distribute water from the public system with the required pressure to each water point. The water distribution facilities in the building can have a combined system (gravity + pumping) that allows them to supply users more efficiently as shows the Figure 2.32.

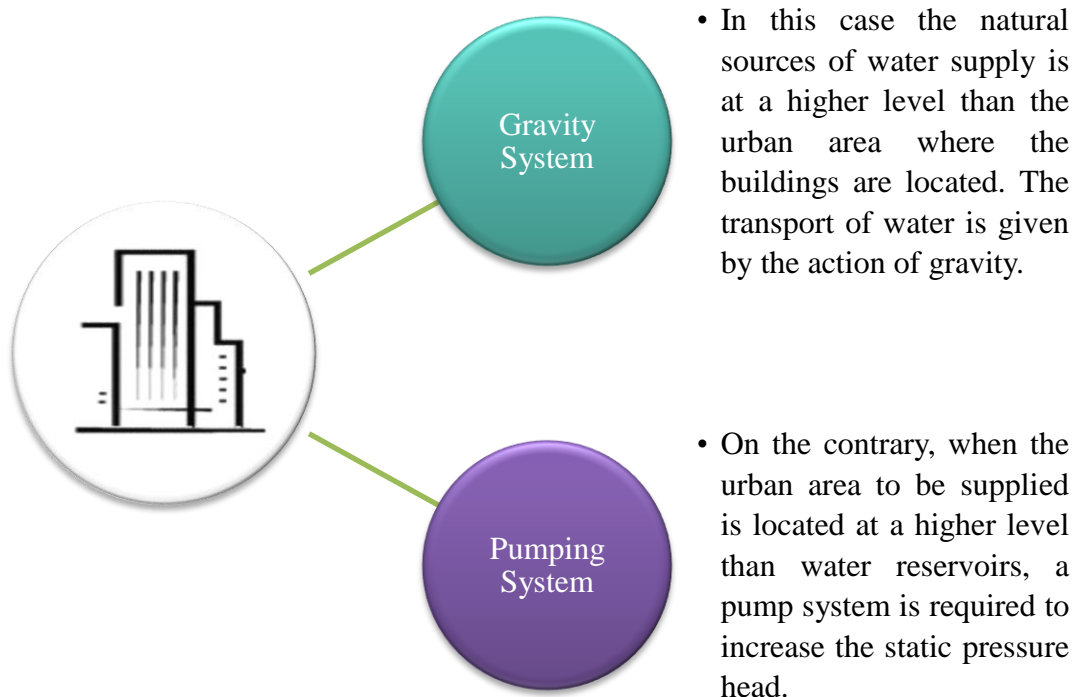


Figure 2.32 - Distribution system for water supply in buildings

Source: Author's own drawings

Within the basic principles of water supply for buildings is important to comply with the following:

- The quality of the water coming from the public distribution system should not be modified in the building's distribution system. The pipes must comply with the current quality standards and their materials must meet the demands related to the action of pressures.

- The water distribution facilities in the building must have the capacity to supply the water to all the connection points with the minimum pressure required for the service to be continued.
- The water distribution facilities in the building must consider the implementation of safety nets to solve emergencies such as fires.
- The water distribution facilities in the building must consider the design of bypass systems so that no user remains without water supply during repairs or maintenance of specific sections.
- The design criteria established in current regulations must be met so that the water distribution facilities are properly separated from the sanitary-sewer facilities.
- The water distribution facilities in buildings must consider the supply of hot and cold water through their respective systems.

The components that make up the most common water distribution facilities in buildings are the following:

STRUCTURAL COMPONENTS: They are structures generally built in reinforced concrete that have the function of regulating and storing volumes of water for the supply of the building. Its location can be in the subsoil, at the level of the building, or in the upper part of it. Its design will depend exclusively on the volume of water required, the number of users and the characteristics of the building.

- **Cisterns:** are structures that catch and store water from the public water supply system or rainwater, to provide the supply to buildings through its connection with pipes.
- **Feed cistern:** in various systems, it is common that there are structures that store water to provide this resource to other systems, such as electric/gas apparatus for heating water.
- **Water line – Ball Valve:** they are usually found on the walls of the tanks to identify the level of water in which the ball valve must be activated and suspend the entry of water into the structure.
- **Overflowing level:** it is the minimum level of water with which this resource can be distributed from the cistern to the different connection points in the building without affecting the pressure.

HYDRAULIC COMPONENTS: The hydraulic components of water distribution facilities in buildings are all those elements by which water is transported from the public system to the water points installed in the different spaces of a building. Depending on their function, they can be classified as follows:

- **Service pipe:** all pipes that connect to the public system and transport the water to any installation of the water system in the building as cisterns.
- **Distributing pipes:** It is the pipeline responsible for transporting the water from the cistern to all the water points installed in the building.
- **Warning pipes:** An emergency pipe that evacuates water immediately from the building.
- **Communication pipes:** Are all the pipes that connect the main distribution pipes in the building with the stop valves.
- **Meter:** It allows measuring the consumption of water in the building by users. This component is essential to quantify the water flow required by each building on an annual average.
- **Meter control valve:** It is important to install a control valve in order to regulate the water consumption in buildings. This measure avoids wasting water and regulates consumption based on peak hours during the day.
- **Pump:** The pumps allow to raise the water from lower levels to all the floors that make up the building. Pumps can be installed to distribute the water through the building or to feed a cistern located at the top of the building and so that through the action of gravity, the water can be distributed from this point.
- **Check valve:** Is a valve that normally allows water to flow through it in only one direction. Its function is aimed at regulating the passage of water from one point to another.
- **Riser:** This a pipe that extends one full story or more to distribute water to branches.

The scheme of the connection between the public water supply system and the water distribution facilities in the building is detailed in Figure 2.33 through the communication and supply pipes. The components (accessories) of this connection are a collar between municipal pipeline and communication pipe, a gooseneck pipe, the stop valve and a domestic water meter.

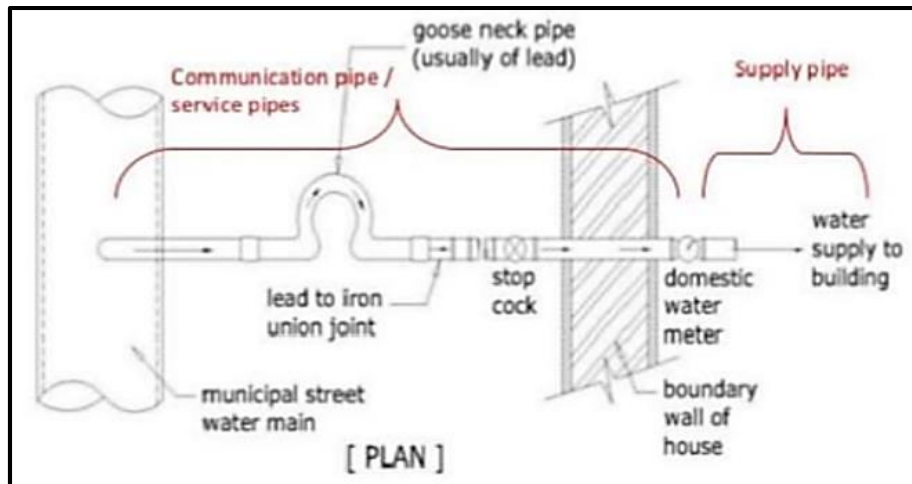


Figure 2.33 - Schematic Water Supply of a Building

Source: SlideShare, (2018)

WATER SYSTEMS: For the most part, it is important that the buildings have facilities that allow the distribution of hot water and cold water at all connection points. These components guarantee the comfort of the users and allow them to satisfy the consumption needs; especially for the personal hygiene activities that are constituted as a daily routine and that in cold cities necessarily contemplate the use of hot water.

- **Cold Water System:** This system provides water to satisfy different purposes: drinking, cooking, cleaning, sanitary, washing, emergency (fire system) and gardening. They can supply water directly (upward distribution) through pumps that transport water to all floors (maximum two) of the building. On the other hand, they can also supply water indirectly (down take supply) through a tank that is fed by pumps and which is located at the top of the building distributing the water by gravity (for a building of more than two floors).
- **Hot Water System:** The interaction of a building with its environment is permanent, which is why there is a thermal exchange according to the external conditions that surround it. The hot water system must contemplate the integrated installation of heating and sanitary hot water supply through a set of elements that properly installed offer high levels of comfort to users and energy efficiency to the building. This system must compensate for heat losses and provide an adequate temperature for domestic hot water. This system uses pipes resistant to high temperatures. In most cases, CPVC (post chlorinated polyvinyl chloride) or thermofusion.

Figure 2.34 lists the components of the water distribution facilities in a building with two cisterns. The lower part can be operated by a pump to convey water to all levels of the building if it has only two floors. On the contrary, the cistern located in the upper part of the building allows the distribution of water by gravity to all the floors. In both cases, it is necessary to install a pump that allows to raise the water in both mechanisms.

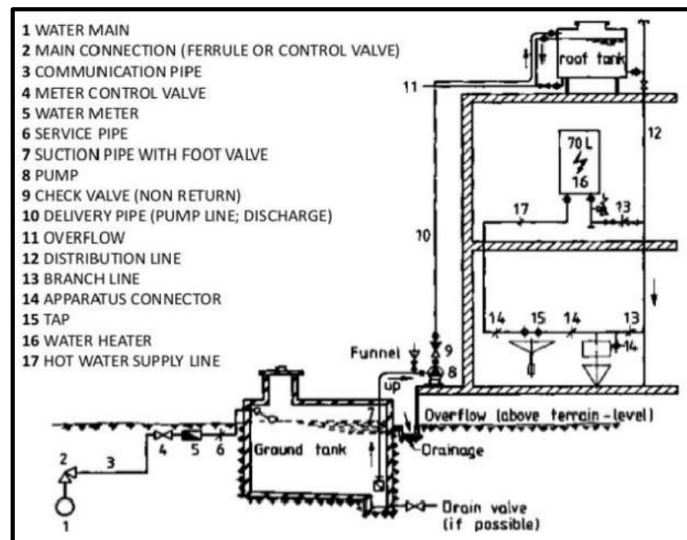


Figure 2.34 - Detailed Components of Water Supply in a Building

Source: SlideShare, (2018)

Figure 2.35 shows the typical components of different water distribution facilities in buildings. In all cases, the meter is essential to record the consumption in the building.

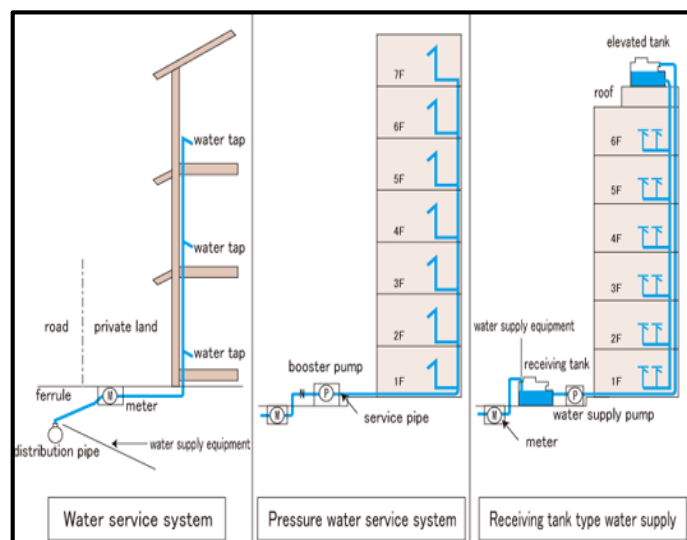


Figure 2.35 - Schematic Components of Water Supply in a Building

Source: SlideShare, (2018)

As can be seen in the water service system for buildings with a maximum of two floors, it is not necessary to install pumps, because the pressure of the system is sufficient to supply the water service inside the structure. This condition also depends on the topographic level where the building is located in relation to the reservoir of the water supply system.

2.4.2. Conventional and alternative water resources

The increase in population density, the vertical growth of cities (in buildings and skyscrapers) and the high consumption of drinking water, motivate the use of alternative water resources to meet the demand required in the urban area.

The extreme dependence of cities on superficial and underground resources decreases the availability of the resource for future generations. It is important to consider that the effects of current climate change play a fundamental role in the natural recharge of these freshwater resources that are essential for the development of life on Earth. For these reasons, the global trend is aimed at finding non-conventional or alternative resources to supply the demand for water that is needed both for human consumption and for other types of activities (agriculture and industry). While it is true, water is classified as a renewable resource, there are different studies that ensure its scarcity in future years. This denomination must be responsibly analyzed and consider its reform, since the demand for water is so great that at any moment the natural resources can be extinguished.

2.4.2.1. Conventional water resources

According to Murad (2010), conventional resources of water depend exclusively on the amount of rainfall, since they originate all types of surface and ground water that are known. Conventional water resources can be classified as follows:

- 1. SURFACE WATER:** Probably it is the most widely used conventional resource not only for the supply of water for consumption, but also for agriculture through irrigation,

navigation, electricity production, recreation, tourism, among other purposes. Its recharge depends fundamentally on the intensity and frequency of rainfall, which makes it possible for this resource to be considered as "renewable". Surface waters are classified into two large groups: lotic waters or streams and lentic waters.

The lotic waters or streams make reference to the volume of water that is in constant movement and whose sense is always given in only one direction. In this group are rivers, springs, streams, streams, ravines and waterfalls as shows the Figure 2.36.



Figure 2.36 - Lotic Water – Conventional Resources

Source: Author's compilation

The lentic waters are volumes of water that remain retained or stagnant. In this group are the lagoons, lakes, swamps, wetlands, among others as shows the Figure 2.37.



Figure 2.37 - Lentic Water – Conventional Resources

Source: Author's compilation

- 2. UNDERGROUND WATER:** This natural resource of water is one of the most important for water supply and the development of different activities in terms of

consumption, irrigation and industry. Due to their physical, chemical and microbiological characteristics, they are practically uncontaminated resources of water. These resources tend to be abundant, however, and with the uncontrolled exploitation of underground sources, they are considerably reduced over the years. The emptying of these underground resources causes in many occasions the collapse of the soil by the excessive extraction of water.

In this group are the aquifers, whose recharge is mainly a function of the intensity and frequency of rainfall and the percentage of infiltration of runoff water through the permeable strata of the soil. The Figure 2.38 gives important examples of this case.



Figure 2.38 - Underground Water – Conventional Resources

Source: Author’s compilation

The statistics on the availability of water resources according to their type of resource can be analyzed through Figure 2.39.

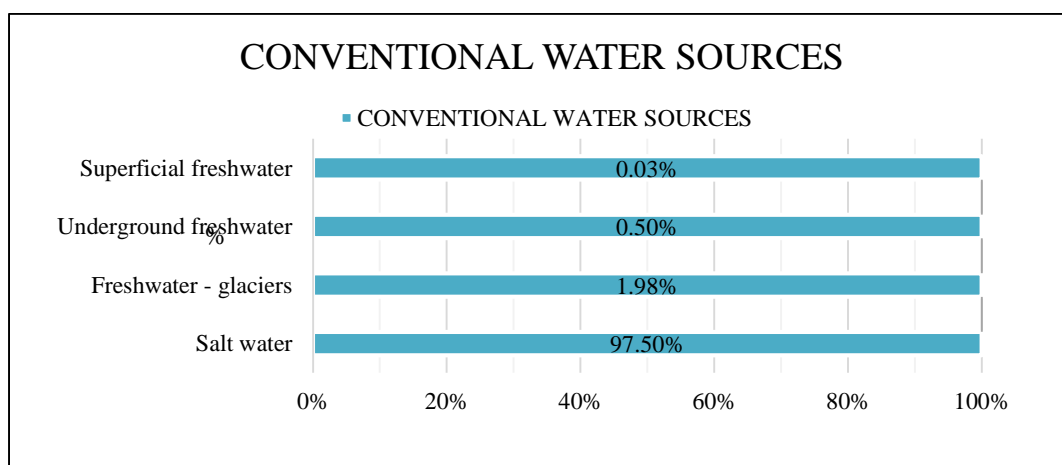


Figure 2.39 - Percentage of conventional water resources

Source: GREENPEACE, (2010) - adapted

The analysis of the figures in this figure shows that barely 2.505% of the total volume of water in the world can be suitable for consumption. However, only 0.525% represents a conventional alternative of usable water. Aquifers can be classified according to their texture, their hydraulic behavior or their hydrodynamic behavior. One of the main disadvantages of these natural water resources is their recharging take place in greater periods than those of the surface resources, which is why they are more prone to extinction without a control in the extraction of water.

2.4.2.2. Alternative water resources

There are more treatment processes that are required to improve the quality of waste water; however, these waters are not used for human consumption. Its function is focused on non-consumptive use, which is very positive considering that natural water resources can be affected by the pollution of waste water. The level necessary to maintain the safety of the treated waste water is adequate based on the current quality standards requires a high cost of regeneration. This is the main disadvantage of using this type of alternative water resource.

The development of these alternative systems is also related to economic and financial factors that tend to resort to new alternative resources to have additional resources that can supply the activities that the human being develop without ceasing.

On the contrary, unconventional water resources fall exclusively on the intelligence and ingenuity of the human being to obtain water from different resources other than natural ones. Non-conventional resources of water for consumption purposes are characterized because they do not increase the burden on primary freshwater renewable resources.

The way to analyze which are the alternatives or unconventional resources of water in development is based on the study of the method of water supply for countries with shortage of fresh water resources, with extensive desert areas or with wild climates. Their need to find resources of water that can supply their populations, has developed different methods, techniques, technology and systems to obtain drinking water from unusual resources.

These measures not only provide water for consumption, irrigation and industries, but also offer an opportunity to discharge the existing pressure by extracting water from small resources of fresh water that they still have. One of the advantages of the few conventional freshwater resources is the probability of recharging while using other methods of obtaining water.

- 1. **RAINWATER HARVESTING SYSTEM:** Rainwater feeds the natural resources of fresh water. However, its direct use for urban uses is an old and unconventional practice. This system goes back to ancient times; however, with the design of modern supply systems and urban growth this type of alternative resources has experienced a notable reduction in its use as shows the Figure 2.40.

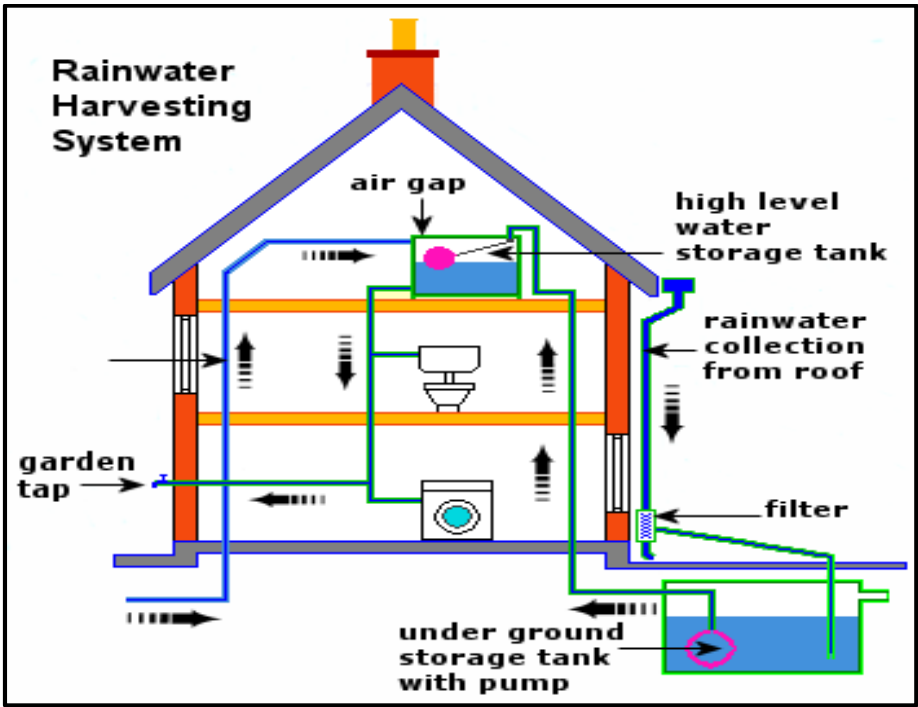


Figure 2.40 - Rainwater Harvesting System
Source: LowEnergyHouse.com, (2018)

This type of systems allows the reuse of rainwater for non-potable consumption, that is, for use in sanitary devices, the irrigation of gardens, agriculture, etc. Its collection is possible through the flow of rainwater on surfaces such as roofs, terraces, parking, canalization systems, among others. The importance of rainwater harvesting systems stands out because it contributes to the reduction of floods and to the reduction of drinking water consumption in activities that do not require this type of water.

2. DESALINATION OF WATER: Seawater becomes one of the unconventional resources for obtaining drinking water. According with the Figure 2.41, the process that converts salt water into fresh water is known as desalination and consists of separating salt from water.

This process involves high costs, which represents a clear disadvantage with respect to obtaining fresh water from natural resources. However, it is a valid alternative to cover the demands of consumption, irrigation and industry.

According with TEDAGUA - Técnicas de Desalinización de Aguas, S.A. (2017), different techniques are applied to be able to separate the salt from the water, among them, the distillation, the freezing, the instantaneous evaporation or the formation of hydrates, nevertheless the method that at the moment is the most used is the one of reverse osmosis.

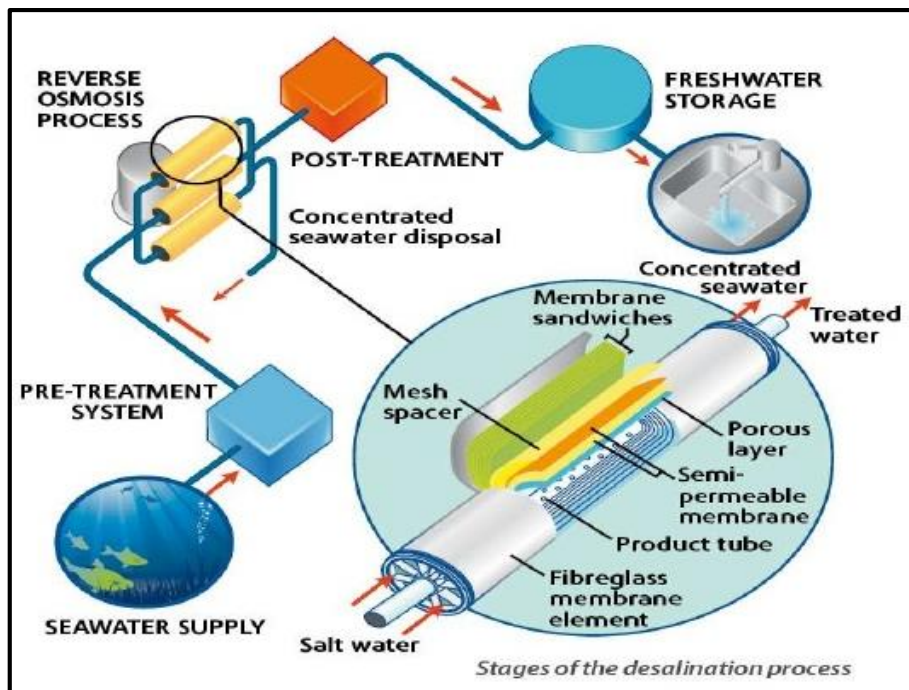


Figure 2.41 - Seawater Desalination Process

Source: SlideShare, (2011)

Desalination by reverse osmosis separates salt from water, both for seawater and for groundwater. The process is conceptually simple: The water receives a pre-treatment where the thickest particles and the objects that can be contained in the volume of water entering the process are separated. After, the water pumped at high pressures is passed through a

membrane to decrease the amount of salt in the original water. The next stage corresponds to post-treatment where remineralization techniques are applied to obtain drinking water reducing the salt concentration. Finally, the water is stored in reservoirs where the characteristics of drinking water are maintained and where it is stored to be distributed through the different supply systems.

- 3. REUSE OF DOMESTIC OR INDUSTRIAL WASTE WATER:** One of the most important reasons about the water stress existing around the world is the drinking water use in buildings, which arises the need to plan a sustainable system that reduces the consumption of water for consumption.

The treatment technologies are different and applied for each case in common:

- **Microfiltration:** removes suspended solids that are contained in waste water. It also has great effectiveness for the elimination of pathogenic organisms.
- **Membrane technologies:** they are used exclusively for those cases in which the production of regenerated water justifies the expenses that are required for their treatment.
- **Ultrafiltration:** process of total elimination of colloidal particles and pollutants that are contained in waste water. They are pre-treatment systems for the elimination of bacteria, viruses and pathogenic microorganisms.

2.4.3. Water losses, consumption and energy reduction

Water services and the improvement of water efficiency in buildings can be controlled through water audits applied annually and can be implemented to identify weaknesses in the system. These audits carried out to the managing entities allow to reduce water losses, water consumption and excess of energy that is spent due to the inefficiency of water distribution facilities in buildings.

Therefore, the amount of water consumed by a building will be calculated as the sum of daily use, water losses and the waste water generated.

2.4.3.1. Water losses reduction

In this case, it is important to differentiate two completely distant concepts. Water losses are not the same as waste water. It is necessary to find their difference in order to reduce them through the improvement of practices that increase the water efficiency in a building.

- Water losses are volumes consumed, but are not incorporated into the total measure of water that enters the water supply system. These consumptions are due to failures or inefficiency in the components that are part of the water distribution facilities in buildings.
- Waste water is an unnecessary consumption of this resource. In other words, is an excessive water consumption that are directly dependent on the users of the system, their bad practices or consumption reduction.

The reduction of water losses in buildings can be carried out through the following procedures:

- 1. Level of hydraulic and sanitary design:** Many of the disadvantages with respect to the management of pressures have to do with the distribution of the pipes and sanitary devices in each floor. A homogenous and symmetrical design of the sanitary facilities in the building reduces water losses because the distribution of the pipes is the same for each floor of the building, allowing for a reduction of pressures. The management of pipe lengths and the smaller amount of accessories of derivation or changes of direction will increase the efficiency of the system with respect to water pressures.
- 2. Installation of control/regulating valves:** The installation of control valves on the water distribution network will allow to maintain the permanent control of the pressures in the network and therefore to reduce water losses. There is a wide variety of devices (including automatic) that can be used to reduce water losses.
- 3. Replacement of defective elements:** It is essential to permanently maintain the elements that make up the water distribution facilities in buildings, through permanent monitoring of the characteristics of the network. Water losses in buildings are usually caused by

damage to the pipes and fittings that allow these elements to be connected. The control of water faucets is important (4000 to 1000 liters of waste water every day)¹⁷, because it is very common that water losses occur through these elements by a constant drip when its hermetic or closing mechanism is damaged due to the use and the useful life of the accessory.

- 4. Maintenance of elements and accessories:** The timely review of water distribution facilities in buildings will undoubtedly reduce water losses and increase the water efficiency of the building.

2.4.3.2. Consumption reduction

The reduction of water consumption in buildings has to do in large part with the social awareness of users.

- 1. Facilities and accessories:** In addition, the use of high efficiency hydraulic devices allows to reduce the consumption of water in buildings and to fulfill the same functions as conventional sanitary devices. The shower, the toilets, the water faucets and other elements can significantly reduce the consumption of a building. In this group are the low flow faucets that regulate the volume of water per minute. High efficiency toilets that consume less liters than conventional sanitary devices can also be installed.
- 2. Motion sensors:** As in electrical and electronic systems, motion sensors become a very efficient technological tool to automate the flow of water at times strictly necessary. Only when the user activates the device with the movement of their hands, for example, the water faucets are activated, allowing the reduction of water consumption and avoiding waste.
- 3. Waste water (gray):** Another strategy to reduce water consumption in buildings is through the reuse of waste water from showers and hand basins or the installation of rainwater collection systems for uses that require water not potable. This strategy can

¹⁷ ARAB FORUM FOR ENVIRONMENT AND DEVELOPMENT - AFED, (2015)

reduce drinking water consumption in buildings by 20% to 30%. However, it is necessary to consider a treatment system that allows reducing levels of contamination in this type of water for reuse.

4. **Water meters:** allow control of water consumption through the creation of records that analyze the pattern of consumption in the building.

2.4.3.3. Energy reduction

The consumption of energy in buildings are closely related to water consumption. Generally, pumps are installed to be able to supply the water to all the floors of the buildings and to be able to generate the necessary pressure for all the users to have water in their homes. However, these water drive systems require large amounts of energy. On the other hand, the permanent interaction of the building with the external environment produces a permanent thermal exchange that often reduces the comfort inside the structure. This thermal deficiency inside the building produces the need to resort to systems that increase the temperature of the spaces of the building, increasing the energy consumption.

Among the most efficient measures to reduce the energy consumption of a building are:

1. **Efficient pumping valves:** allow control of water consumption through the creation of records that analyze the pattern of consumption in the building. Currently hydraulic accessories are designed and built with the aim of improving the water and energy efficiency of the systems in which they are installed. This type of pumps have systems that require less energy or that are connected to renewable energy systems (biomass, solar energy, thermal energy or solar-photovoltaic).
2. **Heating and thermal insulation installations:** due to the implementation of hot water systems in the building, it is important to guarantee that these systems supply the water according to the adequate temperatures and with a minimum energy consumption. Currently, centralized gas units reduce the building's energy consumption and water consumption since they require controlled volumes of water to activate the water heaters.

The thermal insulation of the building will avoid the change of temperature in the hot and cold water systems with respect to the outside temperature of the building. This significantly reduces the energy consumption that would be required to reach the desired temperatures again.

3. **Passive measures:** are designed to reduce energy demand based on the orientation and ventilation of the buildings.
4. **Active measures:** act on the systems and facilities of the building to produce an adequate level of comfort with a lower energy consumption.

All these measures are essential to increase the energy and water efficiency of a building. The costs of these devices represent an investment in the short and medium term, since the expenses for water losses; water consumption and energy are higher due to the interruptions generated in the supply of the service and the repair of its elements. Devices that require electrical power to operate water distribution systems must be qualified as energy efficient.

2.4.3.4. Audit of water efficiency in buildings

The purpose of water audits is to evaluate the efficiency of buildings and reach levels of savings in water, energy, economy and environment. As the name implies, are evaluation processes that are responsible for rating the degree of efficiency at the water or energy level in buildings in relation to their performance, operation and facilities. Generally, the audits can be applied at macro-measurement levels (Public Water Company) to evaluate their management in water supply systems or micro-measurement levels (buildings) to determine their water efficiency.

The reduction of water consumption, the improvement in the efficiency of water distribution facilities, the implementation of systems that are nourished by unconventional resources and energy reduction make it possible to increase the levels of sustainability in buildings. The audit must comply with the stages detailed in Figure 2.42 to check the water efficiency of a building.

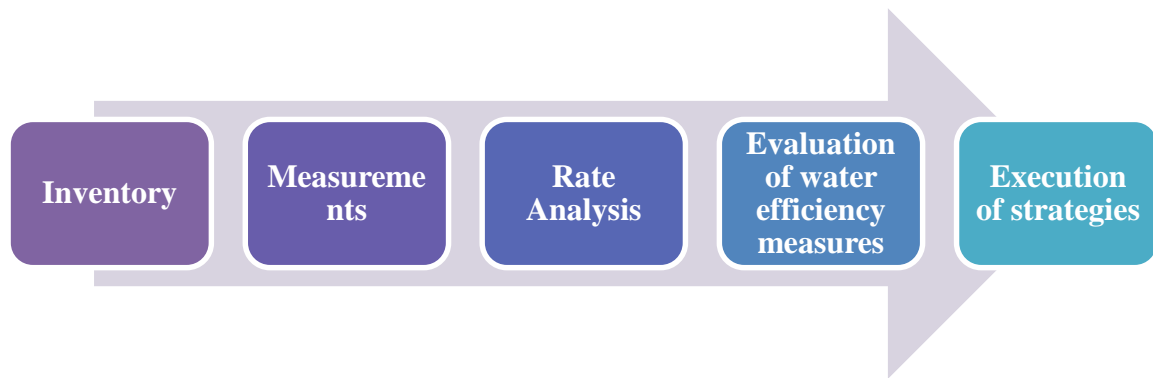


Figure 2.42 - Audit stages

Source: Author's own drawings

Each of these stages is fundamental to determine the degree of water efficiency that a building has reached. The inventory or building diagnosis, for example, corresponds to the count of the goods that are part of the sanitary facilities of the building, in addition to the cold and hot water systems, the heating or air conditioned systems, the energy system used for the operation of equipment and devices, the water resources used, the frequency of maintenance, the strategic plan for emergencies and the training of users.

The measurement of consumption, water losses, energy consumption, equipment calibration and devices is essential to know the current status of the water network in the building. Within these measurements, a record must be maintained with technical specifications of the state of each element, as well as the detail of the hydraulic and material characteristics that constitute them. This information will be very useful to make up the inventory.

The rate analysis is an economic comparison between the tariffs of the public water service and the consumptions of the building to promote the saving of money by obtaining high levels of water efficiency in the building, the reduction of water losses and the reduction of waste water to minimum values.

The analysis of the efficiency measures can be applied through hydraulic and energy modeling to buildings already built or to be built. In this stage, the characteristics of the elements and accessories used in the water distribution facilities of the building will be taken into account in the mathematical modeling to analyze the behavior of the network in comparison with the existing consumption demands and the characteristics of the building. Its development allows to choose within the range of options, the best alternatives of water

efficiency in buildings to implement or to reform in the case that they have already been considered. The results offered by the hydraulic simulation, allow to configure the economic and financial evaluation necessary to evaluate the feasibility of implementing measures that contribute to the improvement of the hydric and energetic efficiency of the building, without affecting the resources of which it has.

Finally, and based on the results of the entire audit, the measures to improve the water and energy efficiency of the building can be executed. The cost/benefit analysis will determine which measures can be applied to each case and which measures should be discarded. The inventory and the measurement will allow to grant to the elements that constitute the water installations in buildings, their respective label in accordance with the requirements listed in the data banks about water efficiency.

There are worldwide references for the execution of methodologies designed to reduce the water consumption in existing buildings and for the execution of water audits, such as the case of “Associação Nacional para a Qualidade nas Instalações Prediais” – (ANQIP, 2011) with its AUDITAQUA program. This Portuguese technical-scientific association promotes and guarantees the quality and efficiency in building services as shows the Figure 2.43.



Figure 2.43 - Interventions made through the AUDITAQUA Program

Source: Associação Nacional para a Qualidade nas Instalações Prediais” – (ANQIP, 2011)

- Adapted

This program offers an integral solution with respect to the execution of audits, certification and voluntary labeling of water efficiency and the development of Technical Specifications for the design of rainwater harvesting and waste water systems. The effect of this Program on water efficiency in buildings is important because it provides the creation of social awareness, in addition to a maintenance plan that allows the resources that make up the water distribution facilities of buildings to be conserved in optimum conditions.

This is a key step to guarantee that not only the installation of high efficiency water devices is the solution to be considered in all buildings evaluated. Without a permanent policy of maintenance and monitoring, no measures adopted can achieve the total optimization of resources, consumptions, energy and money.

Water efficiency audits for buildings have a wide range of application. Although it is true that the suggested configurations are applied differently for each building, audits can be executed in the structures detailed in Figure 2.44 according to their function.



Its applicability in these buildings is justified by the necessary implementation of water and energy distribution systems.

1. Residential Buildings
2. Commercial Buildings
3. Teaching Buildings
4. Public Buildings
5. Hotel Buildings
6. Buildings for health care
7. Industrial Buildings
8. Sports/Recreation Buildings

Figure 2.44 - Buildings where water audits can be applied

Source: Author's compilation – Adapted

The age and typology of the buildings is another factor that must be considered at the time of executing the advisories to evaluate levels of water efficiency in buildings. It is important to include the literal citation of the configurations suggested by the AUDITAQUA program.

BUILDINGS IN PROJECT (OR IN CONSTRUCTION):

- Building diagnosis (based on the project).
- Proposal of efficient devices, solutions, and management plan.
- Maintenance plan (for buildings for collective use, also recommended for residential buildings).
- Proposal for efficient water management in the building envelope (when justified).
- Support for the development of a water safety plan (when necessary)

NEW BUILDINGS (UP TO 5 YEARS):

- Diagnosis of the building and quantification of consumption.
- Inspection of the facilities.
- Proposed of devices, efficient solutions, and management plan.
- Sensitization and training actions (recommended level two, in buildings for collective use).
- Maintenance plan (for buildings for collective use, but also recommended for residential buildings).
- Proposal for efficient water management in the building envelope (when justified).
- Study of reduction of energetic consumption and CO₂ emissions (recommended)
- Support for the development of a water safety plan (when necessary).

EXISTING BUILDINGS (UP TO 30 YEARS):

- Building diagnosis and consumption quantification
- Inspection of facilities and leak detection.
- Propose efficient devices, solutions, and management plan.
- Awareness and training actions (recommended level two in some buildings for collective use).
- Maintenance plan.
- Proposal for efficient water management in the building envelope (when justified).

- Study of reduction of energy consumption and CO₂ emissions (recommended for buildings for collective use).
- Support for the development of a water safety plan (when necessary).

ANTIQUÉ BUILDINGS (WITH MORE THAN 30 YEARS OLD):

- Diagnosis of the building and quantification of consumption.
- Detailed inspection of the facilities and leak detection (level two, if necessary).
- Proposal of efficient devices, solutions, and management plan.
- Awareness and training actions (recommended level two in some buildings for collective use).
- Maintenance plan (and rehabilitation, when warranted).
- Proposal for efficient water management in the building envelope (when justified).
- Study of reduction of energy consumption and CO₂ emissions (recommended for buildings for collective use).
- Support for the development of a water safety plan (when necessary).

All this information available on practices related to the development of technical specifications on measures of water efficiency in buildings, allows to conclude the need to execute them in countries where these policies are scarce. The development of the present thesis is a valuable opportunity to apply the configurations suggested by audit entities to the building that is part of the chosen case study.

The execution of these measures to improve water efficiency in buildings of Ecuador is a fundamental tool to initiate activities that improve the quality of water supply service in buildings in the country, through strategies that are friendly to the environment and that generate in the reduction of water and energy consumption.

2.4.3.5. Technology for water losses reduction

The development of technologies to save water through the reduction of water losses is a reality; its innovation unquestionably increases the operational efficiency of any water system. The improvement of the levels of efficiency in a building cannot be reached

completely if there is no change in the habits and current practices of users. The awareness and training in these issues is essential for technology to fulfill its design purpose.

According to the Arab Forum for Environment and Development (2015), the figures establish that approximately 10 to 30% corresponds to the water losses that occur in sanitary devices such as toilets, showers, faucets or plumbing in general. The technology focuses on improving the hydraulic performance of these devices to increase their efficiency and behavior.

TECHNOLOGY FOR TOILETS AND URINALS: These devices are a perfect target for the intervention of technology due to the high level of water they use in buildings. From the “simplest” to the “most complex”, technological innovations in these sanitary devices are:

- **Composting toilets:** This type of systems does not consider the use of water. The organic content can be used to create fertilizer or humus through an appropriate treatment process. Its application is related to the technological innovations proposed by the field of agronomy.
- **Objects for water volume displacement:** It is probably not a state-of-the-art innovation, because this measure can be applied with simple objects that are placed over the toilets tanks, can occupy a volume inside these elements making the volume required to fill this unit considerably less. While it is true and you can find products of this type developed exclusively for this purpose, you can place simple items such as bottles filled with water, to reduce approximately 30% of the water that would be used for each discharge.
- **Dual-mode flush systems:** Technology has developed this type of rinsing systems to reduce the volume of water required in each discharge, be it total or partial. In this way, the devices effectively perform their function with a minimum amount of water. The percentage of reduction of water with each discharge fluctuates between 65 to 68% for a complete discharge and a partial discharge respectively. In volume, this type of devices can require from just 3.5 to 4 liters, which in conventional systems translates to an expenditure of 9 to 12 liters undifferentiated (only total discharges).

- **Vacuum-toilets:** As shows the Figure 2.45, this type of toilets have a system of pumps that create a vacuum and that with a minimum amount of water, flush the contents of these devices. Depending on the system, 0.5 - 1.0 liters of water may be required.



Figure 2.45 - Efficient Toilets

Source: Author's compilation – Adapted

The Figure 2.46 shows the following devices:

- **Waterless urinals:** In this case, the urine flows by gravity through the drain trap installed in the device to the sewer system directly by the existing connection with the plumbing. This type of systems does not require water to flush the contents of the urinal. Its principle is the same as that of the composting toilets.
- **Waste water in flushing:** These devices operate under the action of non-conventional water resource systems used in water distribution facilities for buildings (as discussed in section 2.4.2.2). Its principle is based on the installation of pipes, pumps, storage units and treatment, which allow to reuse the water coming from washbasins, showers and laundry. This type of water receives a simple treatment that allows this non-conventional water resource to be used in non-potable uses, such as the filling of toilets.
- **On-demand sensors:** In the same way that sensors are used for hand washing, these elements can be installed based on movements, so that they activate the discharge of water when the user moves away from the device. The optimal functioning of these devices depends exclusively on the sensor, for this reason it is important that they are in good condition. Working in water efficiency conditions, 1 to 1.5 liters of water are required.



Figure 2.46 - Efficient Urinals

Source: Author's compilation – Adapted

TECHNOLOGY FOR SHOWERS: The showers are the hydraulic devices in buildings that consume more water due to hygiene activities that users perform daily. They consume from 30 to 40% of the water use that each house requires in average values. However, with the installation of devices that have been developed thanks to technological innovations, these consumptions can be reduced to half the usual ranges.

The main problem experienced by the user to accept these technological measures to reduce water consumption, is their feeling to not reach comfort levels with the amount of water to which they are accustomed. However, this feeling is badly unfounded. Although the volume of water is reduced when using the shower, the user can fulfill its purpose without diminishing the efficiency of the hygiene process. Some examples are given in the Figure 2.47.

- **Water flow and time control:** Simple timers can reduce huge volumes of water per year by the use of the shower. In general, users spend too much time in bathing; however, this bad practice produces large amounts of waste water, not water loss. It is important to clarify this because undoubtedly the misuse of water by users does not imply a loss in water volumes but an increase in "waste" due to lack of awareness and misuse of the resource. This is how these water resistant devices alert the user that their time to bathe has reached the reasonable average for this activity. It is important that users become aware that the shower cannot be activated during the entire process; it is important to turn it off during shampooing or soaping.

- **Automatic shut-off systems:** The use of sensors and electronic devices installed in the showers, controls the volume of water that on average the user should use to bathe. When this amount is reached, the shower is turned off automatically avoiding excessive consumption of water translated as waste. These devices are related to time controllers.
- **Shower heads:** These efficient devices are connected to the heads of the showers to modify the conditions of the flow that flows through it. Precisely this type of devices makes the user practically not perceive the reduction of the volume of water that is required with conventional facilities. The "magic" lies in the jet of air that mixes with the flow of water. These devices are designed to reduce the passage of water and cause an airflow through the paper that meets the pressure in the distribution system. They reduce approximately 65% of the volume of water that would be required in a shower without this system.
- **Mixers:** These devices allow immediate adjustment of the temperature levels required by the user, preventing water from being wasted by manually regulating the cold water system and the hot water system. In this "small" fraction of time, the user does not perceive the volume of water that is wasting and worse that, this bad practice occurs daily.



Figure 2.47 - Efficient Devices for Showers

Source: Author's compilation – Adapted

WASH BASINS, FAUCETS AND TAPS: The permanent dripping due to deficiencies in these devices or the poor regulation of the water flow causes the increase of water consumption due to faults in the installed accessories. In this case, the water deficiency is

related to water losses and not to waste, since they depend exclusively on the performance and operation of the accessories that are part of the water distribution facilities.

- **Faucet and tap adaptors:** These accessories have the same function as efficient shower heads. They are simple and inexpensive elements that are installed in the nozzles of water faucets and taps to produce an air jet that mixed with the outgoing water flow. These accessories reduce the flow of water per year and allow the saving of considerable volumes taking into account that almost every day users wash dishes.
- **Faucet with on-demand sensors:** In the same way that sensors are used for hand washing, these elements can be installed based on movements, so that they activate the flow of water when users approach their hands to the sensor installed in the lower area of the faucet. The optimal functioning of these devices depends exclusively on the sensor, for this reason it is important that they are in good condition.
- **Automatic shut-off systems:** The use of sensors and electronic devices installed in the faucets controls the volume of water that on average the user should use to wash the dishes or the food. When this amount is reached, the shower is turned off automatically avoiding excessive consumption of water translated as waste. These devices are related to time controllers.

LAUNDRIES AND KITCHENS: In this type of spaces inside the buildings, water consumption is usually high due to the large amount of water that is required for the different activities of laundry and cooking food respectively. The technology applied to the devices that handle water in these places is the same as that already detailed above, depending on the accessory required for each installation. However, the following innovations and strategies can be included to reduce water losses and waste.

- **Napkin or Brush:** these mechanical devices allow to scrub and remove food residues in the dishes, in such a way that the user uses less water to wash them. These elements are used when the washing of dishes must definitely be manual.
- **Dishwasher:** are mechanisms that allow washing dishes and utensils automatically. These mechanisms have a washing capacity according to the number of plates or utensils that are considered. For this reason, the use of water they use is regulated unlike what happens when the user washes their dishes manually. These machines

save water in large quantities per year. However, one of its main disadvantages is the energy consumption that require.

- **Triggered spray nozzles:** this type of nozzles regulates the flow of water that is used to wash dishes and utensils. Are essential in large kitchens, industrial or commercial kitchens, where the quantities of utensils and dishes to be washed are high.
- **Air-cooled machines:** this type of machines require only 2 liters to produce a kilogram of ice. Conventional systems require approximately 12 - 14 liters to produce the same amount of ice, in addition to high-energy consumption.

Technology is a very powerful tool for the innovation and improvement of accessories, systems and devices that reduce water losses and waste in buildings. As well as for the creation of new materials and properties for the improvement of the water efficiency of buildings.

The investment by application of technology for the improvement of water efficiency in buildings generates costs that can undoubtedly be lower than those corresponding to water losses or waste. Therefore, the efficient use of water in buildings should consider the development of technology as a positive tool to achieve water efficiency levels.

When technology (technical option) cannot be applied in order to reduce consumptions, water losses and waste, there are only two options to be used: the analysis in the rates for the consumption of water by the management companies (increase of tariffs) or rely on the awareness of society to adopt good practices of efficient water use.

2.4.3.6. Certification and water efficiency labeling of devices

In the same way that in many countries food products are certificated and labeled (through nutrition semaphores) to make the consumer aware of what they intend to buy and eat, the certification and labeling of water products is made based on their performance and efficiency in buildings, as shows the Figure 2.48.

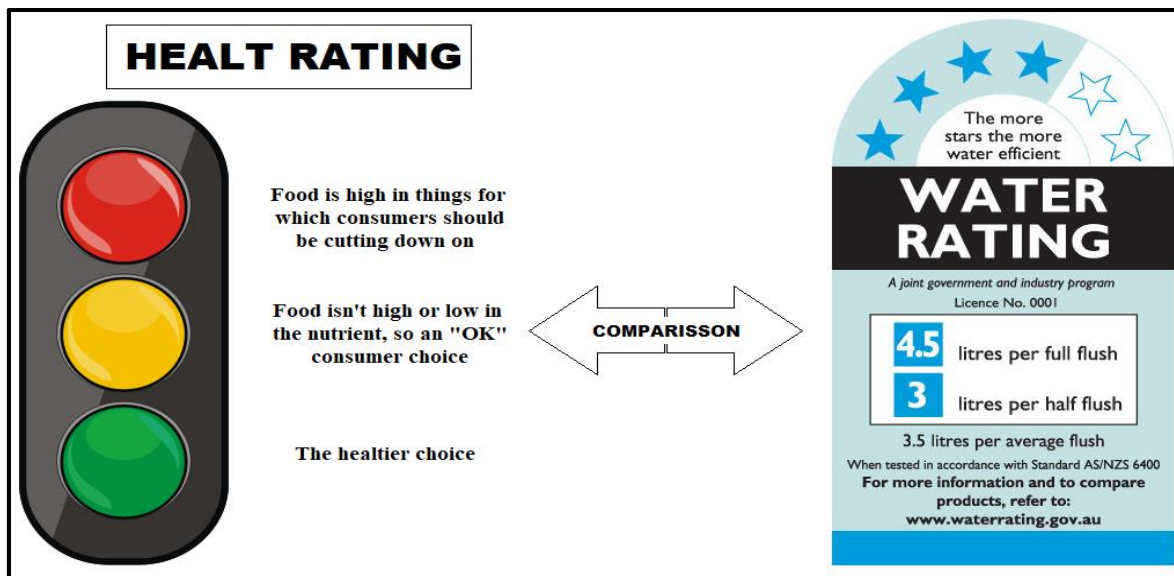


Figure 2.48 - Efficient Devices for Showers

Source: Australian Government Department of Health and Ageing, (2004) - Adapted

With this graphic explanation, it is easy to understand the main purpose of the certification and labeling activities in the assessment of water efficiency. Entities develop technical specifications to evaluate the water efficiency of water systems; both at the level of supply systems and distribution facilities in buildings, establish specific parameters that allow to "qualify" or characterize the devices, accessories, hydraulic installations that are part of a building.

Again, there are no systems or organizations that certify or label the water efficiency of products that are part of buildings in Ecuador. In spite of this, countries such as Colombia and Peru (neighbors of Ecuador) have their first evaluation tools to grant the certification and labeling of water efficiency in buildings. Thus, Colombia uses the technical standard NTC-6048 (Colombia Patent No. NTC-6048, 2013) and Peru has its own program called "Water Footprint Program" conferring the Blue Certificate (Autoridad Nacional del Agua - ANA, 2017).

For this reason, it is necessary to resort to international sources, which allow to analyze the importance of certification and labeling in the evaluation of water efficiency for buildings. The European Union, Australia, Singapore are once again pioneer states in the development of these evaluation tools that emerge from water audits. Portugal continues to be an example

to follow in the implementation of this type of models at the level of research and at the level of water management.

For its extension, only the technical specifications on certification and water efficiency labeling of products that should be considered in the design and evaluation of buildings are mentioned in the present thesis as shows Table 2.2. These referents should be consulted and used to contemplate the minimum requirements on water volumes and allowable tolerances to qualify the degree of efficiency of each element analyzed. This is a function of the standards that each country establishes for the evaluation of the hydric efficiency of products.

Table 2.2. Certification and Labeling Systems

CERTIFICATION AND LABELING SYSTEMS		
Country / Region	Technical Specification	Source
Europe	European Water Label	European Water Label, (2017)
Portugal	Technical Committee 0802	Associação Nacional para a Qualidade nas Instalações Prediais - ANQIP, (2011)
Australia	Water Rating Label	Water Rating - Australian Government, (2018)
Singapore	Mandatory WELS	Singapore's National Water Agency, (2018)
New Zealand	Water Efficiency Labelling	Ministry for the Environment Manatú Mo Te Taiao, (2018)


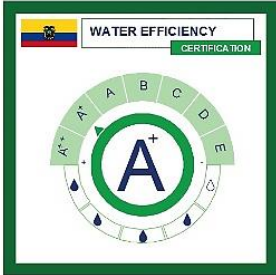
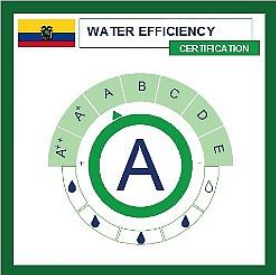




Source: Author's own analysis

2.4.4. Proposal of Water Efficiency Labeling for Ecuador

The suggested labeling to certify the water efficiency of a building and its sanitary devices is based on the total volume of drinking water that they consume monthly where A⁺⁺ is considered the highest degree of efficiency and E, the lowest. The basic colors of these labels are the green that represents the sustainability, the efficiency or the preservation of the environment and the blue that together with the designed drops attempts to qualify the degree of efficiency of the evaluated building.

Table 4.3 details the labeling system designed to certificate the water efficiency of a building. The Ecuadorian flag is also included, as a representation of the initiative that promotes the efficient use of water in the countries of the region. The labeling system is proposed according to the categories established in Table 4.9 for the water efficiency analysis developed for non-residential buildings in Quito – Ecuador. Also, this system is used to evaluate the water efficiency of devices. The ANQIP labeling is tanking as a reference.

Table 2.3. Water Efficiency Labeling for Non Residential Buildings in Ecuador

WATER EFFICIENCY LABELING	
Labeling according to the certification	
	
A⁺⁺	A⁺
	
A	B
	
C	D
	
E	

Source: Author’s own analysis

3. Rainwater harvesting systems

3.1. Introduction

It is essential to resort to alternative resources for water supply in buildings, especially for non-potable uses. In the previous chapters, it was possible to identify that water is one of the main natural resources for the development of life on the planet and for the execution of activities related to residential, commercial, agricultural and industrial demand.

In Ecuador, the climate change, environmental contamination of natural water resources, population increase, the accelerated urbanization process (waterproofing of soils), the increase in water rates in recent decades and the fluctuating topography of the country, generates the need to use alternative resources such as rainwater harvesting systems. In addition, the reality of the region allows observing the increase in rainfall intensities and the high risk of flooding that cities have. For this reason, it is important to mitigate this effect with the implementation of this type of systems that reduces the burden of urban drainage systems. It is also important to consider that the implementation of this type of systems contributes to the natural recharge of the water resources that provide the public water supply systems.

Currently, the use of rainwater harvesting systems, to meet domestic needs, are well received in different countries of the world. It is one of the most widely used alternative water resources and that requires low investments to be applicable. Its potential is exploited in areas with high rainfall intensities and with high possibilities of flooding.

The (United Nations Environment Programme Division of Technology, Industry and Economics, 2018) provides some real examples of the use around the world of rainwater harvesting systems as shows the Figure 3.1.

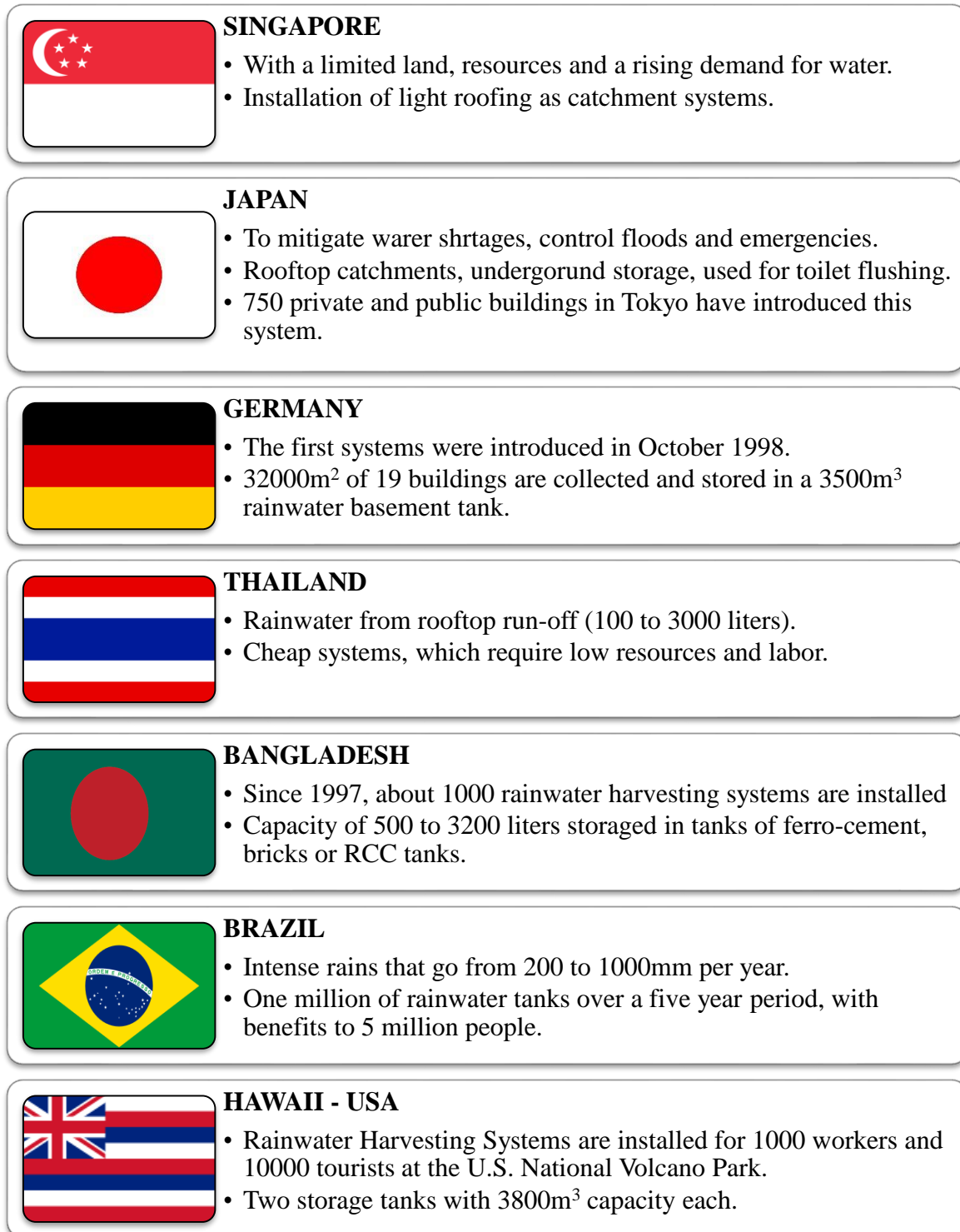


Figure 3.1 - Examples of use around the world of Rainwater Harvesting Systems

Source: United Nations Environment Programme, (2018) - adapted

However, what do these countries have in common? An accelerated population growth, high population densities and a limitation of its natural water resources due to its geographic location, demand for consumption, pollution, habits.

To use the rainwater, it is necessary to design a design that allows draining the water that falls on the roofs of the buildings towards deposits or reserves that can be underground. These storage structures are known as cisterns and it is very important that their walls are waterproofed to avoid contamination of the water inside the tank and also to avoid leaks due to damage to the structure.

Among its main objectives, the systems of rainwater use allow to provide water for non-potable consumption to buildings through a storage system that allows to conserve the water captured. Among the non-potable consumption are: the supply of water for toilets and urinals, irrigation of gardens or similar and car washing.

3.1.1. Advantages of Rainwater Harvesting Systems

The most important advantages in the technical and water aspects of using this type of systems in conventional buildings facilities and that are considered as a starting point for this thesis are:

- 1. Reduction of drinking water consumption in buildings:** when installing a system that provides rainwater to the building's sanitary facilities (non-potable consumption) the consumption of drinking water from the public supply system is reduced. In addition to the reduction of volumes of drinking water, there is a reduction in the expenses that correspond to the user.
- 2. Reduction in the water volume that urban drainage systems receive** by capturing a certain volume of water through the roofs or tanks installed in buildings. There is a reduction in the volume of water that enters the urban drainage systems, improving their performance and preventing them from collapsing when there is heavy rain. To avoid intervention increasing diameters in the drainage pipes, systems for the use of rainwater can be installed, regulating these volumes.
- 3. Increased water efficiency of buildings:** by becoming an alternative resource of water supply for non-potable consumption, thus ensuring the improvement of the building's water efficiency and its friendly behavior with the environment.

The specific advantages of the use of rainwater harvesting systems are analyzed below:

- By reducing the consumption of drinking water, the energy consumption of the building is also reduced, especially when the water distribution facilities in buildings work through pumping systems.
- The use of a rainwater harvesting systems speaks very well of eco-sustainable policies that must be applied to buildings in order to mitigate the effects that the same human being produces due to their lack of awareness.
- Rainwater Harvesting Systems reduce the risk of flooding due to surface runoff, especially in paved areas or with deficiencies in the urban water drainage system.
- Reserves for these systems can be built, which allow the building to be equipped with water even in times of low rainfall, since water can be stored when the rains are intense.
- Rainwater does not require complex treatments, considering that its consumption is intended for non-potable uses. However, treatment systems can be installed based on filters that turn out to be very low in costs.
- Reduce the dependence on conventional water resources. The massive use of these rainwater-harvesting systems allows recharging conventional water resources.
- Avoid the use of drinking water in activities where such a high quality of the resource is not required: irrigation of gardens, discharges of toilets and urinals or car washing.
- In comparison to other systems of alternative water resources such as: the reuse of waste water, the desalination of water, or reverse osmosis, the rainwater harvesting system requires lower costs to be installed in buildings.
- The maintenance that must be done to this type of systems is not complex: cleaning in the roofs, in the collection system and drainage to remove the presence of leaves, cleaning in the reserve tank and periodic inspections in the rainwater distribution pipes.

3.1.1.1. Compatible uses

The use of water from rainwater harvesting systems has different uses apart from those already exposed. At the level of residential or public buildings, water comes from non-

potable uses, however, for industrial or commercial buildings, the uses of this alternative resource of water increase.

- Irrigation for greenhouse buildings.
- Source to fight fires or emergencies.
- Irrigation of gardens, green walls, green roofs.
- Replacement of water for swimming pools.
- Vehicle washing.
- Cleaning services.
- Water for air conditioning systems.
- Washing clothes.

3.1.2. Disadvantages of Rainwater Harvesting Systems

Like any system, there are disadvantages that can be associated with the use of this type of alternative water resources as shows the Figure 3.2. Among the most common are:

- Depending on the region and geographic location of a project, costs can vary significantly, especially in rural areas where economic resources are very limited.
- The efficiency of these systems is conditioned exclusively to the frequency of rainfall. In times of intense drought, water utilization systems may stop functioning due to the absence of rain.
- The use of pumps to distribute the water from the tanks to the sanitary devices of the building can increase the energy consumption and the associated costs.
- In the case, that rainwater is considered for drinking, it is essential to carry out filtration and disinfection treatments to avoid risks to the health of consumers. This represents an increase in the investment that is required in the system because new components and more treatment processes are considered.

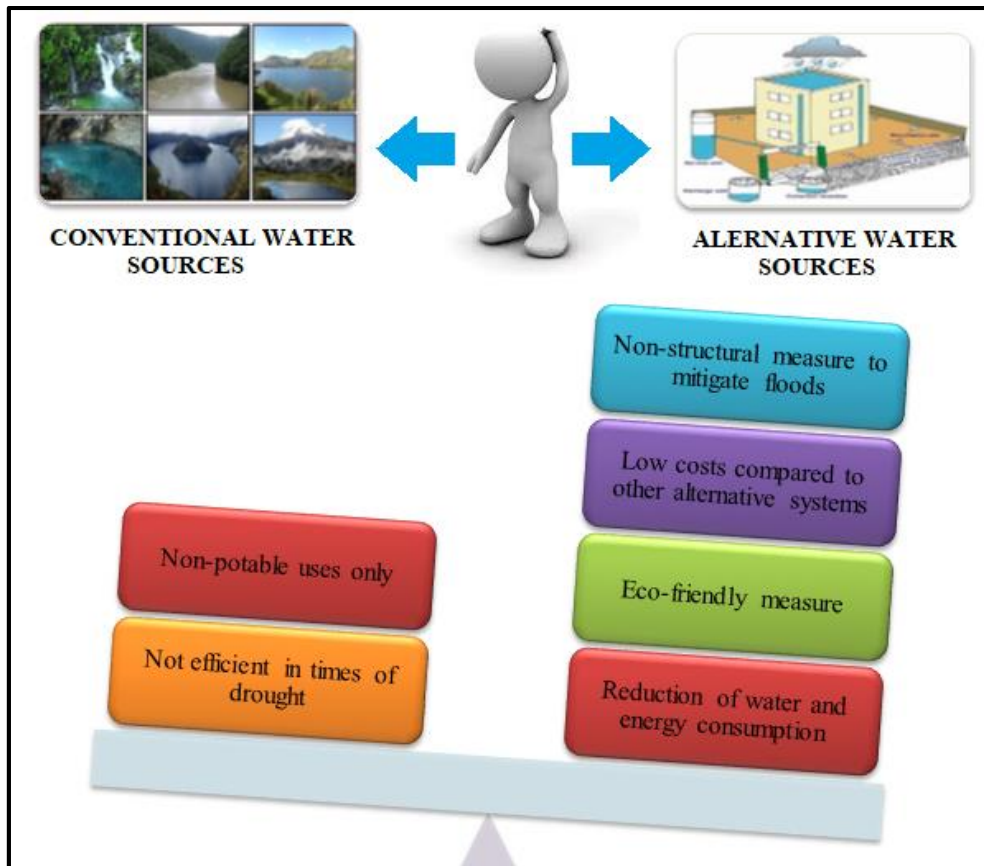


Figure 3.2 - Summary of comparison between conventional and alternative water systems

Source: Author’s own drawings

It is logical that natural water resources cannot be completely replaced; however, it is important to reduce the dependence on this resource to sensitize people and understand that these resources are affected with the lack of control over their extraction and management.

3.1.3. International Rainwater Catchment Systems Associations

It is important to take into account some references on associations that promote the development of rainwater harvesting systems and their technical specifications. Nowadays, it is necessary to gather all the resources to prevent water as a natural resource from being exhausted due to the uncontrolled consumption that exists and also to prevent it from starting to restrict access to this service as a drastic measure. At the global level, different rules can be cited that govern the design and construction of this type of systems.

- Rainwater Catchment Design and Installation Standards 2009 – (American Rainwater catchment Systems Association).
- The Texas Manual on Rainwater Harvesting (Texas Water Development Board).
- Guidelines for Residential Rainwater Harvesting Systems Handbook – (Canada).
- Addis Abba: RAIN, SearNet, WAC, AgWA, IFAD, waterhealth, 2015 – (Paris).

At present, different associations and companies that develop rainwater-harvesting systems are promoting new tools, technology and devices that make it possible to use this alternative. In Ecuador, there are laws, rules and regulations in force to control water resources and water use. According to **Article 63** of the Law of Water Resources II Supplement RO 305 6-08-204, *"any person may store rainwater in cisterns, or in small reservoirs, for domestic and irrigation purposes for food sovereignty, provided that it does not harm third parties and affects the quantity and quality circulating through public waterways, the Single Water Authority shall establish the technical parameters to define the volume of water that can be stored without authorization"*.

- Law of Water Resources II Supplement RO 305 6-08-204.
- Secondary Regulations.
- Regulation: Law of Water Resources Uses and Water Harvesting.

3.2. Components of the rainwater harvesting system

Before analyzing the components of a rainwater harvesting system, it is important to define the stages that constitute it. This consideration allows to understand better, what elements should be part of this type of system.

Figure 3.3 details the stages that a rainwater harvesting system must comply with. For the optimally work of the system it is important to consider the general elements or components that constitute the rainwater harvesting systems according to their functions.

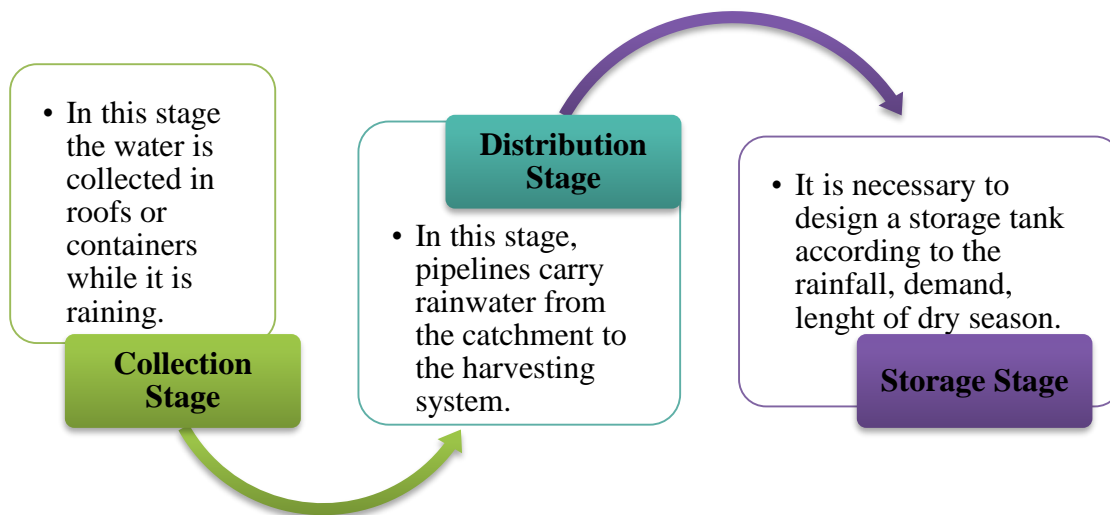


Figure 3.3 - Stages in Rainwater Harvesting System

Source: Das, O., Bera, P., & Moulick, S. (2015) - adapted

- **Catchment system:** It is formed by the rainwater collection surface. The area to be considered within the design as well as the rainfall intensity must be determined with precision.
- **Filtration:** In this group are the components that separate any type of contaminating object to avoid its deposit in the reserve. Generally, devices are installed for leaf retention, primary flow diverters and filtration devices.
- **Pipelines from catchment to cistern:** In this group are all the pipes that transport water collected from the surface to the reserve where the water is stored.
- **Flow separator:** Separates the first rainwater that is collected from the collector surfaces, eliminating possible contaminants. In this way, the cleanest water is stored in the reserve.
- **Cistern / Reservoir:** It is composed of all the structures that are installed (reinforced concrete or polyethylene) that function as water storage tanks. Its physical characteristics must prevent the contamination of stored rainwater.
- **Turbulence reducer:** Sometimes these components are installed to prevent rainwater entering the tank with too much turbulence and remove sediments deposited at the bottom of the cistern.
- **Floating valve:** It allows to suck the water that is in the upper part of the cistern and not the one in the bottom. This ensures that the pump sucks only the cleanest water.

- **Pumping system:** The pumps are used to drive water from the tank to a reserve located at the top of the building. During this process, the water enters through a filtration system.
- **Treatment (two filters):** It is important to understand that for non-drinking purposes, the treatment processes for rainwater are less demanding. However, precautions should be taken especially for animals that can haunt the collection areas and whose waste can contaminate this alternative resource of water.
- **Elevated tank:** It stores the filtered rainwater in the upper part of the building, so that through gravity the water can be distributed to the toilets, urinals, gardens, etc.
- **Distribution Pipes:** They conduct the rainwater stored in the reserve to all the sanitary devices installed in the building. The distribution can be by gravity or through pumping equipment, when the reserve is located at a lower level than the base of the building.

The components of rainwater harvesting systems can vary significantly as shows the Figure 3.4, however this general analysis of the basic elements of these systems allows to establish which materials, design parameters and criteria should be adopted to select the individual components in each case.

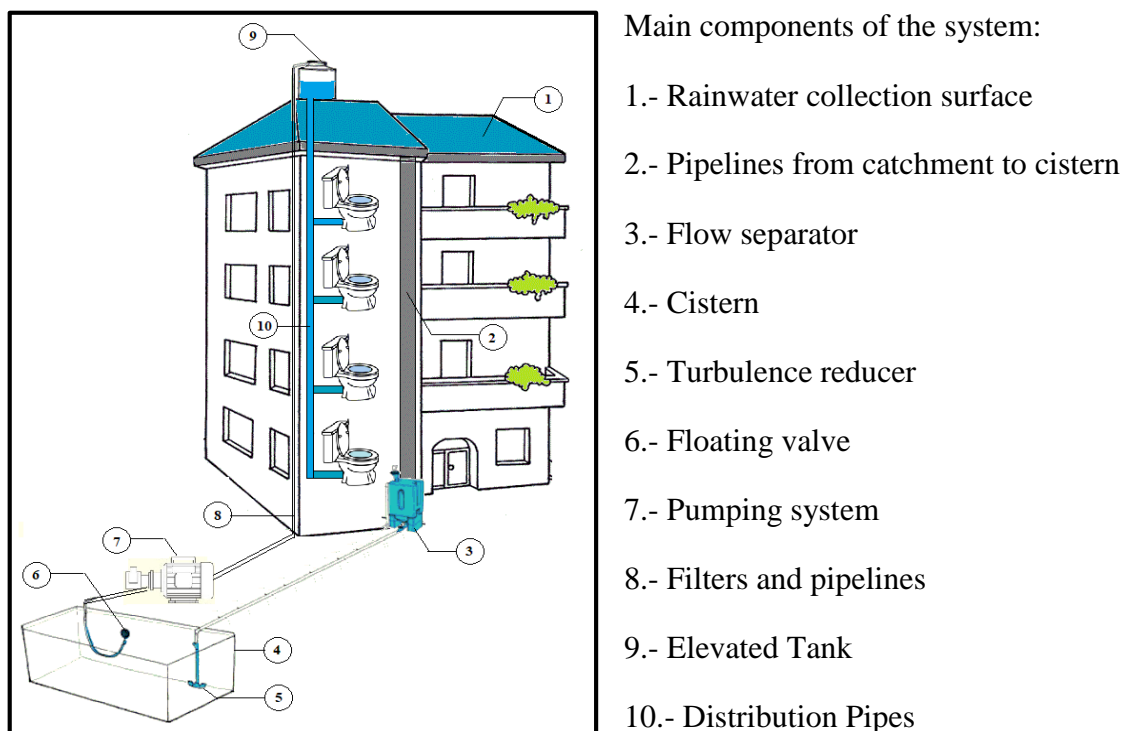


Figure 3.4 - Components of rainwater harvesting system

Source: Author's own drawings - adapted

3.2.1. Catchment systems

In the case of buildings, the water catchment surfaces are the roofs. The quality of rainwater that is captured depends mainly on the material that constitutes the roof (concrete, steel, aluminum, wood, clay, polycarbonate or fiberglass). In this way, the amount of rainwater that is captured depends on the dimensions of the roof and the surface that can be considered as contributing to the design. In addition, the texture of the roof plays a fundamental role in the runoff of the water towards the installed collection systems according to the typical values of the roughness coefficients as shows Table 3.1.

Table 3.1 - Typical values of the Roughness Coefficient

TYPICAL VALUES OF THE ROUGHNESS COEFFICIENT			
Material	Manning Coefficient (n)	Hazen-Williams Coefficient (C_H)	Absolute Roughness e(mm)
Asbestos cement	0.011	140	0.0015
Asphalt	0.016	-	-
Brass	0.011	135	0.0015
Tabique	0.015	100	0.6
Cast iron (new)	0.012	130	0.26
Concrete (metal formwork)	0.011	140	0.18
Concrete (wood formwork)	0.015	120	0.6
Simple concrete	0.013	135	0.36
Copper	0.011	135	0.0015
Corrugated steel	0.022	-	45
Galvanized steel	0.016	120	0.15
Enameled steel	0.010	148	0.0048
New steel	0.011	145	0.045
Riveted steel	0.019	110	0.9
Lead	0.011	135	0.0015
Plastic (PVC)	0.009	150	0.0015
Wood	0.012	120	0.18
Glass	0.011	140	0.0015

Source: The Engineering Tool Box, (2018)

Geometrically, the roofs whose surfaces are horizontal, become the most efficient to collect rainwater because they can catch greater amounts of this natural resource. It is very important that periodic cleanings be made on the roofs to avoid contamination of rainwater by animal feces such as birds, cats and rodents. In roofs with clay tiles, the percentage of rainwater collection is considerably lower due to the capacity of these materials to retain water inside.

3.2.2. Pipes

These components allow water to be transported from the collection surface to the storage cistern or reservoir. Its function is aimed at conducting water from one point to other avoiding losses of the resource during its journey. They can be PVC, galvanized steel, or aluminum. Generally PVC pipes are the most common and least expensive. The pipes that transport water from the cistern to the reserve tanks located at the top of the buildings through the pumping of water should also be considered within this group.

As for the design of these elements, the physical characteristics of the building, the pipe lengths, the maximum rainwater flow rate, the roughness of the material used, among others, should be taken into account. The specified diameters of pipes for rainwater utilization systems are indicated in Table 3.2.

Table 3.2 - Pipe diameter required according to average precipitation and area of the roof

PIPE DIAMETER REQUIRED						
Ø of Pipe (mm)	Average rainfall (mm)					
	50	75	100	125	150	200
	Roof Area (m ²)					
50	13.4	8.9	6.6	5.3	4.4	3.3
35	24.1	16	1	9.5	8	6
75	40.8	27	20.4	16.3	13.6	10.2
100	85.4	57	42.7	34.2	28.5	21.3
125	-	-	80.5	64.3	53.5	40
150	-	-	-	-	83.6	62.7

Source: Das, O., Bera, P., & Moulick, S., (2015)

The gutters installed in the roofs or rainwater collection pipes must have the necessary inclination to lead the water towards the fall tubes. For this, it is important to consider slopes of 1% to 5% in such a way that the concentration of water in certain areas of the collection surface, the accumulation of polluting particles, the growth of algae and the breeding sites of insects and flies are avoided. These components should be subject to the collection surface in such a way that they do not move, especially with the movement of water inside or in the presence of heavy rains.

3.2.3. Filters

The filtration system of a rainwater harvesting system must provide for the separation of leaves, seeds, flowers, insects, animal feces, or any other type of residue that may remain on the collection surfaces. The main function of these filters is to prevent these residues from reaching the cisterns. According to their function, these filters can be classified as follows:

1. **Sieves:** They allow to separate and restrict the passage of leaves and other large debris towards the rainwater pipes. They can be installed in the gutters as shows the Figure 3.5.



Figure 3.5 - Components of rainwater harvesting system

Source: The Water Development Board, (1997)

2. **First flush diverters:** This type of system allows diverting the first flow of rainwater to avoid storing this volume of water in the cistern (Figure 3.6). These systems have a storage device, which once full, allows the passage of rainwater that goes to the

cistern. The importance of restricting the passage of the first rain flow is that there is a greater possibility that more pollutant particles are found in this first flush

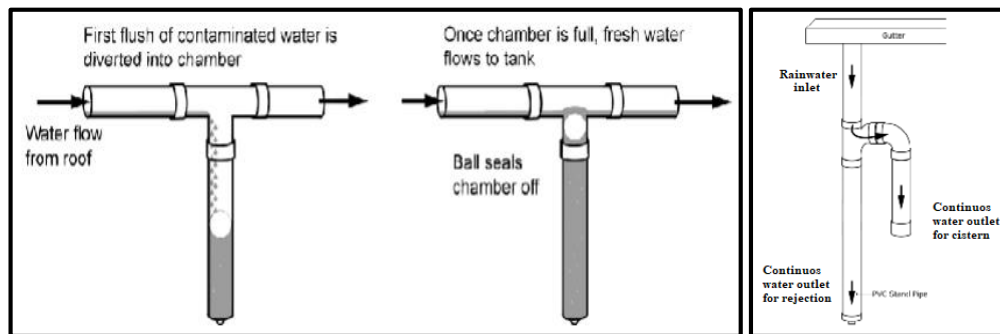


Figure 3.6 - First flush diverter

Source: Boulware, B. (2009) – adapted

3. **Filtration Device:** This type of filters are located before the storage tanks that allow rainwater to be distributed later to the sanitary installations of the building. Its function is to remove the smallest particles that are in the water. It is important that these filters receive constant cleaning and that they be replaced when they no longer fulfill their main function to prevent the distribution of rainwater with unacceptable contamination levels. Figure 3.7 shows a commercial filtration device.



Figure 3.7 - Filtration Device

Source: Bricolaris, (2018)

3.2.4. Self-cleaning Reserve

This component is directly related to the flow deviators. It is the reserve that allows to store the first flow of rainwater from the collection surface. The operation of this system is simple, when the rain starts; the first flow is transported through the pipe to reach this reservoir, later when this reservoir is full the water rises to the diverter, allowing the remaining flow of rainwater can enter the cistern. These reservoirs must have a discharge pipe for cleaning after the rain has stopped. The general scheme is showed in the Figure 3.8.

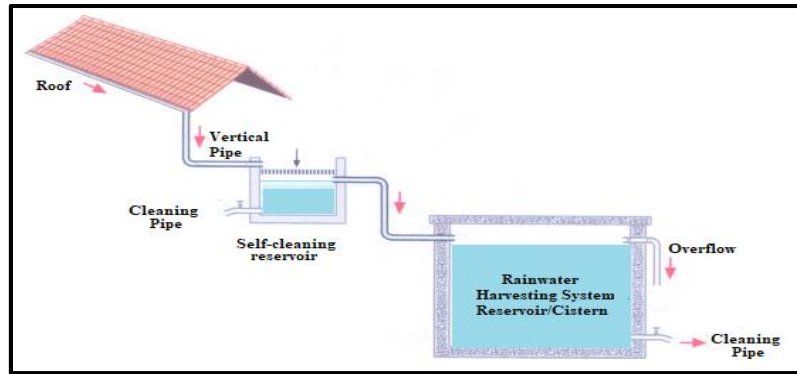


Figure 3.8 - Self-cleaning reserve operation scheme

Source: Tomaz, (2007) – adapted

As can be seen in Figure 3.9, any type of reservoir can be used for self-cleaning rainwater. In this case, the use of a tank with a cleaning pipe for the first flush of rainwater is detailed.

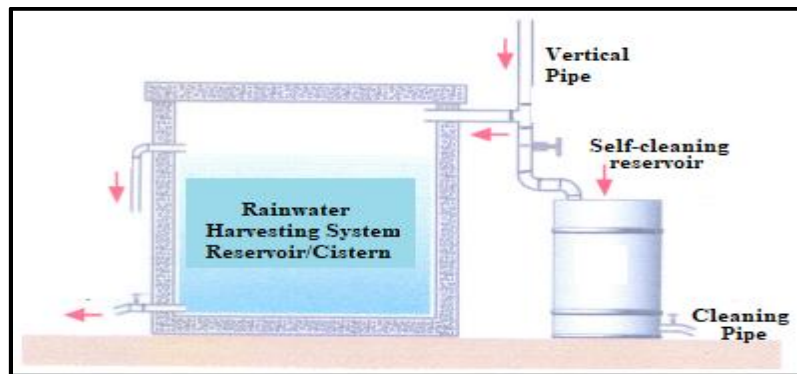


Figure 3.9 - Reservoir of first flush of rainwater with tank

Source: Dacach, N. (1990) - adapted

These self-cleaning tanks can be provided with a float valve that allows the immediate closure of the rainwater flow to this reservoir, when its maximum capacity has been reached.

3.2.5. Reservoir / cistern for rainwater storage

This is one of the most important components that are part of the rainwater harvesting system. Its design and sizing is a function of the intensity of rainfall, the collection surface and the demand. In general, these tanks are located below the ground and their walls, in the case of concrete structures, must be waterproofed. They can also be installed at the level of

the ground surface, but in this case it is necessary to guarantee that the sun does not penetrate the structure of these tanks and that they have a totally hermetic closure.

The materials of these structures that are commonly used: reinforced concrete or high-density polyethylene. As shown in Figure 3.10, the image on the left shows a high-density polyethylene tank, cemented on the surface of the ground; while the image on the right shows an underground cistern whose internal walls are waterproofed. Both types of tanks work properly, however it is important to ensure that there are no leaks or the possibility that the stored water will be contaminated by external agents.



Figure 3.10 - Different type of cisterns

Source: INSTALACIONES, (2015)¹ ; PAQSA, (2018)²

These cisterns can also be built with stones, which keep the temperature of the stored rainwater, however it is necessary to waterproof the walls to avoid contamination of the water by the filtration of toxic substances through the stones. When there is not enough stone, other materials can be used, such as galvanized steel, which is very resistant to hydrostatic loads, but whose problem can undoubtedly be corrosion. Currently, materials such as fiberglass are also used, but their costs can be considerably higher.

3.2.6. Treatment

It is important to consider that for non-potable consumption, the rainwater harvesting system must take into account filtration devices that separate the leaves of trees or particles contained in the rain. With respect to the waste produced by animals, it is important to consider measures on roofs to prevent their access. However, if this type of alternative water system were used for potable consumption, a more rigorous treatment should be carried out, including disinfection phases.

3.2.7. Distribution pipelines

These pipes lead the rainwater that has already been treated within the system, to the different sanitary devices (consumption of non-potable water). The distribution can be done through a gravity system (by means of a raised tank) or by pumping systems that carry water directly from the tank. For buildings, it is necessary to use pumping systems that allow the rainwater to be transported from the cistern to the elevated tanks so that from this point, the distribution is by gravity to all floors of the structure. The power and the number of pumps must depend on the flow to be transported and the height of the building.

3.2.8. Strengths, Weaknesses, Opportunities, Threats

Through all the factors analyzed for rainwater harvesting systems, it is important to establish a SWOT analysis as shows the Figure 3.11, which allows identifying the positive and negative effects caused by the application of this alternative water resource.

STRENGTHS	WEAKNESSES	OPPORTUNITIES	THREATS
<ul style="list-style-type: none">•Reduction of drinking water consumption and associated costs.•Reduction of rainwater in urban drainage systems.•Applicable to urban and rural areas, elements that represent a relatively low investment compared to other systems.•Components of this system are available in the market and their installation is simple.	<ul style="list-style-type: none">•Alternative water source limited to rainfall and a good water collection system.•There is a possibility that the water is contaminated with the waste of birds, cats and rodents.•In Ecuador, as the host country of the case study, there are no standards or technical specifications of these systems.	<ul style="list-style-type: none">•There is an opportunity to apply the design criteria for these systems, based on international codes such as those established in the United States, Europe and Australia through their guides and manuals.•Apply this type of systems in rural areas, where economic resources are low.	<ul style="list-style-type: none">•Climate change, long periods of drought in certain regions of the world.•Ignorance about the advantages and disadvantages of this system.•Excessive dependence on conventional water sources and traditional water supply systems.

Figure 3.11 - Different type of cisterns

Source: Author's own drawings

3.3. Water losses and energy consumption

In practice, the water that is collected from the roofs is lower than the average values established in the theory.

According to the Texas Water Development Board (2005), “*most installers assume an efficiency of rainwater utilization systems between 75% to 90%*”. This Institution also establishes the intensity of precipitation: 0.62 gallons per square foot, equivalent to 25.26 liters per square meter of area.

However, this data is altered in reality by the water losses that occur due to different circumstances such as:

- The first flush of water at the beginning of each rain.
- The evaporation of water on the collection surfaces.
- The splashing of the water through the collection components as gutters.
- Excess water in heavy rains (much of the rainwater is lost by its overflow through).
- The material of the roof collection surface (high roughness).
- Pre-storage treatment devices (reduce the collection of rainwater).
- In the overflow of rainwater when cisterns or storage tanks are full.
- When there are technical deficiencies in the system components such as pipes, filters, or tanks (leaks).
- Lack of periodic maintenance to the system.

In a common way, rainwater-harvesting systems suffer an initial loss of rainwater when the primary flow is separated. This loss depends on the sizing of the self-cleaning reserve. However, it is essential that in this type of systems the flow separation be carried out, in order to consider only rainwater flows with better chemical and microbiological characteristics. Then, rainwater losses can be high in treatment systems such as filters, where the volume of rainwater lost will depend fundamentally on the operation of the device. Likewise, the pumping system can generate rainwater losses within the system due to the variation of pressures produced during its operation.

The energy consumption in the systems of use of rainwater is related to the use of pumps, therefore it is important to comply with all the energy requirements required for optimal operation of the equipment. Although the energy consumption of a rainwater harvesting system is relatively small compared to the energy consumption of a building, this amount cannot be underestimated. This is how new methods emerge to estimate the energy consumption of rainwater, as suggested by the European Commission.

Currently, different methods and models are developed to identify the real energy consumption of rainwater systems and equations are established to define the energy consumption of pumps. These equations are based on the mechanical parameters of the pumps such as pumping capacity, power, efficiency, volume of water pumped, among others.

Non-gravity rainwater harvesting systems require electricity so that the pumps can be operated or also for more demanding treatment processes for this type of water such as UV rays. According to Ward *et al.*, (2011), life cycle analyses, show that the main energy consumption in rainwater harvesting systems comes from the use of pumps and disinfection systems based on UV rays.

It is important to cite this paper within the present research work because its authors establish a method for the calculation not only of the energy consumption of the pump but also of the CO₂ emissions that arise from rainwater harvesting systems. This calculation method summarizes the following steps:

1. Starting from the expression that establishes (Dixon, A. 2000), about pumps energy consumption, the calculations are made to determine operating costs of the system. However, [Equation 2] does not consider CO₂ emissions.

$$E(kWh) = P_R \times O_D$$

[Equation 2]. Energy use (E) of a pump; (The Simple Method)

$$O_D = \frac{V}{P_C}$$

[Equation 3]. Operating duration [h]

Where:

P_R: Pump rating [kW]

V: Volume of rainwater pumped [m³]

P_c: Pump capacity [m³/h]

However, in the Simple Method, three important criteria were omitted:

- a) The efficiency of the pump (no water pump is 100% efficient)
- b) The energy consumption is not the same during the start-up and during the operation of the pump. According with Yago (2008), more than 60% of energy can be consumed on start-up.
- c) CO₂ pumping system emissions.

As can be analysed, these two parameters of the pump used in each system significantly influence the energy behaviour of these components. Omitting these important factors of the pumps referred to their energy efficiency; provide values of energy consumption far from reality.

The method proposed by Ward *et al.*, (2011), is based on an empirical process of measurements to the pumping system. As energy consumption cannot be obtained directly in rainwater systems by applying Equation 2, it is therefore important to consider the two parameters omitted, in order to have a more precise idea of the energy consumption produced by the pumping system.

2. The readjustment of [Equation 2], considering the omitted factors, produces a new expression:

$$E_2 = E_{PST} + E_{POT}$$

[Equation 4]. Energy use (E_2) of a pump; (Empirical Method)

Where:

E_{PST}: Total Energy Consumed on pump start-up [kW]

E_{POT}: Total Energy Consumed during operation [kW]

Therefore:

$$E_{PST} = E_{PS} + (E_{PS} \times S_F)$$

[Equation 5]. Total Energy Consumed on pump start-up [kW]

$$E_{PS} = P_R \times O_{DS}$$

[Equation 6]. Energy Consumed on pump start-up [kW]

Where:

S_F: Start-up energy factor [%]

O_{DS}: Start-up operating duration [h]

$$E_{POT} = P_R \times O_{DO}$$

[Equation 7]. Total Energy Consumed during operation [kW]

Where:

$$O_{DO} = \frac{V_1}{P_C}$$

[Equation 8]. Operating duration

$$V_1 = V \times O_V$$

[Equation 9]

Where: Volume of water pumped during operation

V₁: Volume of water pumped during operation

V₂: Volume pumped during start-up

O_v: percentage of water consumed that is pumped during operation (1-S_v) (manufacturer)

$$O_{DS} = \frac{V_2}{P_C}$$

[Equation 10]. Start-up operating duration [h]

$$V_2 = V \times P_S \times S_V$$

[Equation 11]. Volume pumped during start-up

$$P_S = \frac{V}{((H_C \times H_2) - (H_C \times H_1))}$$

[Equation 12]. Number of pump start-ups

Where:

Sv: percentage of water consumed pumped on start-up

Ps: number of pump start-ups

Hc: header tank capacity [m³]

H1: float switch on level [%]; Obtained from RWH system manual or specifications

H2: float switch off level [%]; Obtained from RWH system manual or specifications

Considering that, there are no 100% efficient pumps:

$$P_E = \frac{P_R}{P_1}$$

[Equation 13]. Pump efficiency

Where:

P1: pump input power [kW]; Obtained from RWH system manual or specifications

Therefore, the final equation for estimating the total energy consumption (E_{TOT}) in rainwater harvesting systems is:

$$E_{TOT} = E_2 + [E_2 \times (1 - P_E)]$$

[Equation 14]. Estimating the total energy consumption

And the carbon dioxide emission (E_{CO_2}) can be estimated from:

$$E_{CO_2} = E_{TOT} \times E_C$$

[Equation 15]. Carbon dioxide emission

Where:

Ec: CO₂ emitted in [kg] from electricity derived from the combustion of coal, that being 1.04kg/kWh (CDIAC, 2010)

Analyzing these equations, it can be concluded that the calculation of the energy consumption of a rainwater harvesting system is very simple. It requires exclusive information about the pumps to be installed (available in the manufacturer's catalogs) and the volume of water to be pumped. The result allows understanding the energy expenditure of the pumping system and comparing it with the benefit - cost relation that has to implement the whole rainwater harvesting system.

3.4. Rainwater quality and treatment

Rainwater harvesting systems are characterized by representing alternative resources of water with low risks to health. However, it is important to consider the application of measures that minimize the hazards related to the storage of rainwater and the conservation of its quality.

One of the most common strategies to guarantee the quality of rainwater is precisely the application of a sensitization policy that requires periodic maintenance activities in the system. Timely management through maintenance of system components will ensure efficient levels of operation, safety and water quality.

To identify some treatment processes, it is important to define the risks and hazards that may arise in a rainwater harvesting system, as shown in Figure 3.12. Generally, the weak point of these issues with respect to the quality of rainwater has to do with the pollutants that have cities with high CO₂ emissions. However, in the rainwater collection and storage phase, there is a potential risk of physical, chemical and microbiological contamination. Especially storage tanks or cisterns can become an environment of proliferation of bacteria, insects and mosquitoes. In the same way as roofs, which is why it is important to include certain measures in the design of rainwater harvesting systems to reduce health risks.

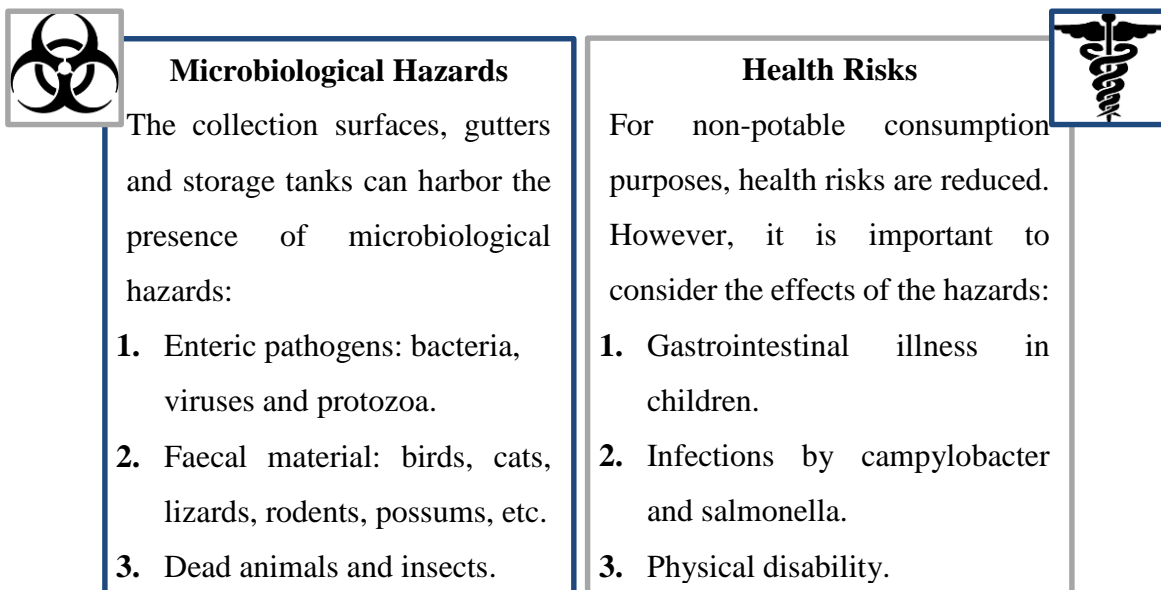


Figure 3.12 - Potential Microbiological Hazards and Health Risks of RWH systems

Source: Author's own drawings

Chemical and physical hazards are directly related to the possibility of contamination of stored water due to the filtration of toxic substances such as oil, sulfur, fuels, etc. These hazards depend on the area where the reserve tanks are installed and to check that the walls of these structures are adequately waterproofed.

According to this type of risk, there are pollution factors that influence the quality of rainwater harvesting systems:

- **Component materials:** in some cases, deficient materials in tanks or cisterns can contribute to the contamination of rainwater due to the use of toxic substances in the paint or waterproofing of these elements.
- **Pesticides:** the chemicals used in agricultural activity can be transported by the wind and mixed with rainwater, becoming a potential poisonous source for consumer purposes.
- **CO₂ emissions:** the increase in the automotive fleet generates, especially in urban areas, an accelerated degradation of the available air. The CO₂, retained in the air, can be combined with water particles generating acid rain and altering the quality of this alternative resource.
- **Forest Fires:** the combustion generated by fires also alters the chemical quality of rainwater. In these cases, it is important to consider the area and the ambient temperature of the place where these systems are installed.

To prevent risks and hazards from becoming a reality, it is important to apply preventive measures to avoid water contamination due to the presence of pathogenic microorganisms.

- Perform periodic cleaning on crop surfaces to prevent the growth of vegetation and the proliferation of insects, mosquitoes, rodents, etc.
- Isolate the components of the system through screens or traps, which prevent the access of animals to both the rainwater drainage system and the tanks or cisterns. It is very important that these elements can be hermetically closed.
- Perform periodic analyzes of the quality of the collected rainwater, to keep a record of the chemical and microbiological behavior of this resource.
- Make use of diverter systems for the first flush of rainwater and apply treatment processes based on disinfection (chlorination).

In the present case study, the objective of consumption is not potable. For this reason, emphasis is placed on mitigation and treatment measures that can be considered for this specific case, in order to improve the quality of rainwater in a harvesting system.

- Perform the cleaning of the collection surface, every three months at least.
- Cleaning branches and leaves from surfaces every three months minimum and six maximum.
- Clean the gutters every month to avoid contamination of rainwater and its waste by obstructions caused by the accumulation of tree leaves.
- It is necessary, in spite of the fact that the use is not potable, to disinfect the whole system at the beginning of its operation and every two years at least.
- Cover the gutters with metal profiles to prevent access to birds, rodents, mosquitoes or insects.
- Check and maintain the walls of underground tanks to avoid contamination of stored rainwater.
- In storage tanks, certain chemicals can be applied that keep insects, mosquitoes away, and that do not represent any risk for users.
- Clean the storage tanks every two years and perform inspections every six months to verify their status.
- If a component is defective or defective, it is necessary to repair it or replace it to guarantee the efficient operation of the system.
- Remove the sediments that are deposited in the gutters, in the filtration systems and inside the storage tanks.
- Perform inspections every year of the roofs and repair possible vanishing points to avoid the loss of rainwater.

Disinfection through chlorine should be done exclusively to avoid the proliferation of bacteria. Its effectiveness depends fundamentally on the time of the dosage and the flow of water that it treats. However, it may not be effective for certain types of chemical attacks where chlorine reacts with organic substances and loses its effectiveness. Due to these reasons it is important to dose in such a way that the chlorine provides a residual action of at least 0.5mg / L after 30 minutes of its initial contact, as it is established by the (Australian Government Department of Health and Ageing, 2004).

3.5. Cost/benefits analysis

Like any Civil Engineering project, the installation of a Rainwater Harvesting System requires the economic and financial evaluation to establish the feasibility of its application. This evaluation must be carried out through a benefit-cost analysis and the consideration of financial performance indicators.

In order to obtain the best technical and economic option, it is important that several design alternatives must be considered and evaluated, to identify the one that meets all the required technical parameters and at the same time, the most economical. The reduction of water and energy consumption is not enough if to achieve this objective, an expensive system is installed. The use of this type of alternative water resource systems must ensure that the investment made can be recovered over time.

In general, the economic and financial evaluation of this type of system depends on the existence or not of financing, the economic conditions of the city or country where they are installed and the availability of components that constitute these systems. Based on these criteria, the feasibility of the benefit-cost can be established, expecting that the mathematical result of this relationship is always greater than one (>1). For the case study, the economic and financial indicators updated for Ecuador will be considered.

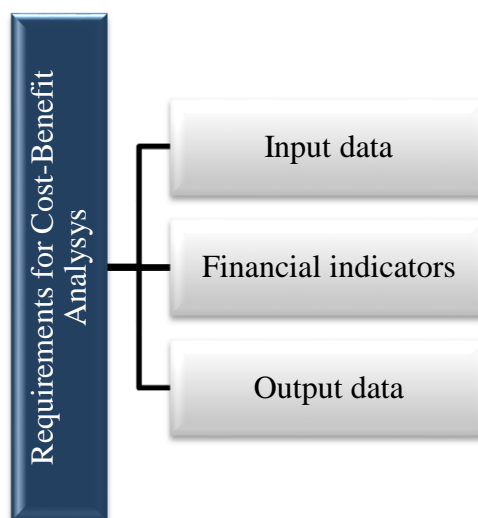


Figure 3.13 - Methodology for the economic analysis of a RWH system

Source: Author's own drawings

As shown in Figure 3.13, the economic analysis of a rainwater harvesting system should be carried out based on data about the implementation, operation and financial indicators to establish the benefit-cost relationship. This methodology is based on the proposed thesis of May (2004).

3.5.1. Input Data (Time and financial indicators)

Data referring to the years of installation and start of operation of the rainwater harvesting system.

- **Implementation period (year):** In this period, there is no financial return because this is when investments are made to implement the system.
- **Design period (year):** In this period, the system is able to fulfill the functions for which it is designed and generating the income that was allocated to its installation (recovery of investment and profits). In Ecuador, the systems related to drinking water, irrigation and sanitation systems consider a design period of 20 to 25 years. This design period can be applied to the rainwater harvesting system.
- **Start of implementation (year):** Is the year in which the system is installed, (first year).
- **Start of operation (year):** This is the year in which the rainwater harvesting system begins to operate. (first or second year).

The costs required to evaluate the economic feasibility of the system are related to the cost of the first investment and the operation and maintenance costs.

- **Cost of the first investment (\$ USD):** Is the cost required to carry out the information gathering, the studies and the construction of the system.
- **Cost of operation and maintenance (\$USD):** Is the cost related to the devices, materials, components, energy and labor that are required to maintain the system during its operation.
- **Income generated by water savings (\$ USD):** It is the direct economic benefit that the Rainwater Harvesting System produces, by reducing the consumption of potable water.

3.5.2. Financial Indicators

They are based on the economic and financial indicators of the country or region where the rainwater harvesting system is implemented.

- **General inflation index (%)**: reflects the variation in the internal prices of the system over the years.
- **Sectoral index (%)**: this index readjusts the operation and maintenance expenses after the start of system operation. It will depend exclusively on the market and the region where the system is installed.

3.5.3. Output Data

Corresponds to all costs incurred during the operation and maintenance of the system.

- **Detachment of costs with operation and maintenance (%)**: corresponds to the relationship between the variation of the sectorial index and the general inflation index. This percentage allows adjusting the costs in the operation and maintenance stage.

$$DC\% = \left[\left(\frac{1 + IS\%}{1 + IG\%} \right) - 1 \right] \times 100$$

[Equation 16]

Where:

DC: Detachment of costs Factor

IS: Sectorial index

IG: General inflation index

- **Financial Movement (\$USD)**: monthly financial movement considering all expenses and income.
- **Accumulated cash flow: (\$ USD)**: cumulative month-to-month result of financial movements.

- **Investment:** referred to all the investments made in the first disbursement (first month of the first year).
- **Accumulated cash flow after the investment (\$USD):** once the investment is considered, it is the cumulative result month by month of the financial movements.
- **Return (\$USD):** it is a financial indicator that measures the profitability of an investment, that is, it establishes the net profit or the profit obtained.
- **Investment / Return flow (\$ USD):** relationship between investment and return. It allows identifying the internal rate of return.
- **Internal rate of return (%):** is the geometric average of the expected future returns of the investment.

$$I = \sum_{K=q+1}^n \frac{r_K}{(1 + TIR)^{K-1}}$$

[Equation 17]

Where:

I: Investment applied at the beginning

ik: return parcel (k: years)

TIR: Internal rate of return (%)

n: Total period of financial flow (years)

q+1: Year of the start of the return flow

- **Payback (year):** is the term of recovery of investment capacity.

In this case, the necessary variables for the economic and financial evaluation of a rainwater harvesting system without financing were considered. Taking into account, that this research tries to establish a measure to reduce drinking water consumption in *public buildings*, it may be possible that financing is more difficult to obtain. However, when there is external financing (bank) it is important to include other financial indicators such as the percentage of the implementation to be financed and the interest corresponding to the financing.

The detail of the calculation will be carried out in the respective study cases in order to have a clear idea of the benefit-cost relationship of the alternatives proposed.

3.6. Certification and technical specifications

Different organizations and associations certify the efficiency of rainwater harvesting systems through the allocation of points that are based on the water efficiency of these systems. Thus, these points are added to the total points a building can obtain to qualify its water efficiency and its classification as a green building. The certification of a rainwater harvesting system results in an advantage for the overall rating given to a building based on the efforts made to reduce consumption of drinking water, energy and to maintain a strict respect for the environment.

In the same way, the Leadership in Energy and Environmental Design (LEED) method evaluates the water efficiency of a building as was described in the section 2.4 (Efficient use of water in buildings), it certifies the efficiency of rainwater use systems. This method becomes one of the international references for the certification of this type of alternative water resources.

The importance of rainwater harvesting systems is directly related to the principles sought in buildings to qualify them as hydraulically efficient, as shown in Figure 3.14.



Figure 3.14 - Principles of LEED certification

Source: WATER HARVESTING SOLUTIONS, (2018)

The summary of the LEED points for water conservation is detailed in the Table. This is the maximum score that rainwater-harvesting systems can receive.

Table 3.3 - LEED certification according water conservation points

LEED CERTIFICATION POINTS		
Credit	Criteria	Points
Water Efficiency Credits		
Credit 1	Outdoor Water Reduction	2
Credit 2	Indoor Water Use Reduction	6
Credit 3	Cooling Tower Water Use	3
Credit 4	Water Metering	1
Sustainable Sites Credits		
Credit 4	Rainwater Management	3

Source: WATER HARVESTING SOLUTIONS, (2018)

Associations such as the American Society of Sanitary Engineering establish programs (ASSE Series 21000)¹⁸ to certify personnel as a designer and installer of rainwater harvesting systems through the application of tests requiring a passing grade of 75%. These certifications can be classified as follows:

1. Designer Standard #21110
2. Installer Standard #21120
3. Inspector Standard #21130

These specifications are very important, because they allow to train the personnel so that they execute tasks of design, installation and inspection of systems of rainwater use. The requirement required to be certified in any of these three specialties undoubtedly motivates to improve the performance of alternative water systems and the workforce that becomes qualified and meets the quality standards in force.

In Ecuador, there are no certification mechanisms or technical specifications available to evaluate the performance of rainwater harvesting systems. It is for this reason that international standards and criteria are required to study and apply them to the reality of the country.

¹⁸ American Rainwater Catchment Systems Association , (2018)

Some applicable codes, standards and guidelines can provide technical specifications for the design of rainwater harvesting systems.

- **CSA Standard B128.1 (2006):** Specifications for the installation of drainage piping.
- **NSF Protocol P151 (1995):** Selection of roofing materials, coating, paints and gutters.
- **NSF/ANSI Standard 14:** Plastic Piping System Components and Related Materials.
- **NSF/ANSI Standard 42:** Drinking Water Treatment Units-Aesthetic Effects.
- **NSF/ANSI Standard 53:** Drinking Water Treatment Units-Health Effects.
- **NSF/ANSI Standard 55:** Ultraviolet Microbiological Water Treatment Systems.
- **NSF/ANSI Standard 58:** Reverse Osmosis Drinking Water Treatment Systems.
- **NSF/ANSI Standard 60:** Drinking Water System Chemicals Health Effects.
- **NSF/ANSI Standard 61:** Drinking Water System Components Health Effects.

With these references, the development of this thesis can motivate the creation of a model that qualifies the water efficiency of a building and alternative water systems such as rainwater harvesting systems. In this way, certification techniques can be included not only -in Ecuador, but also in the different countries of the region.

4. Case Study

4.1. Introduction

The need to create awareness policies on the saving of drinking water and responsible consumption of water, motivate the development of this thesis to apply techniques and procedures established in Europe to case studies located in Quito, the capital of Ecuador. “Universidad Central del Ecuador” is the oldest university in the country, founded on May 19, 1651. Its campus is one of the most majestic in the universities of Ecuador and its infrastructure is endowed with a great diversity of modern buildings and old remodeling. However, there is no control or regulation mechanism for the consumption of potable water in their facilities, because the municipal water supply system supplies the water demand throughout the university.

In this case, two public buildings that are part of the infrastructure of this university and that host a large number of users (students) in their facilities have been chosen. The reason why these two buildings were chosen in particular, has to do with the need to certify water efficiency in public buildings where knowledge is generated, in order to propose the best technical alternatives that allow future replication of this type of projects at the residential level, industrial and why not commercially and other buildings from the service sector, like hospitals, stadiums, etc..

The main idea of this project is to identify the technical solution at the local level that allows to reduce the consumption of drinking water in both buildings. The first, a classroom building that welcomes around 1200 students from the careers of Civil Engineering, Physics, Mathematics and Systems Engineering that has remodeled its sanitary facilities. The second building is the Hydraulics Laboratory, where academic practices are carried out for student learning, construction of hydraulic models, commercial tests, among others and where the use of large amounts of water is frequent due to the need to recreate hydraulic models. In these buildings are also installed pumping systems that allow the flow of water to the different sanitary facilities.

Being a University of the Ecuadorian State, it is important to generate awareness from this place about the importance of saving water users consume, because the economic resources are lower compared to private education centers. In general, water efficiency analyzes in buildings are carried out for residential structures, sports complexes or private buildings, however, it is important to identify the hydraulic behavior of a public building as well as to quantify and qualify its levels of water efficiency.

How important it would be to be able to certify this type of buildings that are part of the social interest of thousands of students and that should be the example of green buildings, sustainable buildings, water and energy efficient buildings.

Part of the reasons that justify this study were described in Chapter I, section 1.3.1 (Justification of the project), however it is important to emphasize that in Ecuador, there are no entities that certify the water efficiency of buildings. This factor generates that the majority of public constructions do not plan a strategy that contributes to the conservation of natural resources such as water and the reduction of environmental impacts. There is also no certification of the personnel and labor that build the sanitary facilities and even worse of technicians with knowledge of systems with alternative water resources. The responsibility falls directly on the Engineers and Architects who build each building, without considering the new sustainability trends worldwide.

Knowledge is not the problem. In Latin countries there is still a certain lack of sensitivity to the environmental problems suffered by the planet and it is precisely here that there is greater population growth and the use of natural resources. Therefore, it is important to modify this social and cultural component based on projects that support technical and economical ideas that can be applied, to improve the living conditions of the inhabitants and to take care of the natural resources that people use without any control.

This is precisely where it is possible to see an opportunity to suggest techniques or design alternatives that can reduce the consumption of drinking water and, in turn, generate new knowledge by applying procedures that have given excellent results in countries such as Portugal, Australia and the United States through the installation of rainwater harvesting systems. For both buildings, the best technical alternatives for the implementation of rainwater harvesting systems as well as their benefit-cost ratio are evaluated.

4.2. Current situation of the buildings selected

The current situation of both buildings is not positive. There is a deterioration in the structure of the Classroom Building and the Hydraulics Laboratory that can be identified by the naked eye due to the lack of intervention and structural maintenance. The occupation of these buildings, especially in the Classroom Building is very high since it is in this place where the classes of the different specializations are taught from Monday to Friday in periods of 12 hours.

An audit has never been carried out to identify the levels of water efficiency in any of these buildings, which is equivalent to a scarcity of information on this subject. However, this apparent disadvantage represents a very valuable opportunity to know the hydraulic behavior of buildings, the variation of consumption, the fluctuation of users, water losses and other key criteria to assess the water efficiency of these structures.

Due to the antiquity of the structures, especially the Hydraulics Laboratory and its high heritage value for the University and the country, the access to the architectural information of these structures is quite difficult, since the existing historical records are protected as part of the cultural legacy that rests in the museum of the Institution.

Other factors that are added to the current conflicts of these buildings related to the antiquity of the urban drainage systems that exist in their surroundings must also be considered. The antiquity and capacity of these systems is not enough during the winter, which causes flooding in this sector causing inconvenience to teachers, students and visitors. This reality must be considered in the design of the rainwater harvesting system to minimize the effects of the inefficiency of the drainage systems.

In spite of this situation, an integral survey of all the buildings that are part of the case study and of its sanitary installations is carried out in order to characterize the real conditions of both structures. It is important to have as much information as possible to propose different design alternatives to improve the water efficiency of these buildings and to certify them as hydraulically sustainable.

4.3. Description of Case Study

The Classroom Building and the Hydraulics Laboratory of the Civil Engineering Faculty are part of the infrastructure of the “Universidad Central del Ecuador”. This University receives around 40,000 students and its campus is known as "University Citadel" (according to the Figure 4.1). The University area covers approximately 50 hectares and on this campus 14 Faculties of the 16 existing in Quito are presents. The proximity of these buildings to each other will allow to consider the collection areas necessary for the rainwater harvesting system.

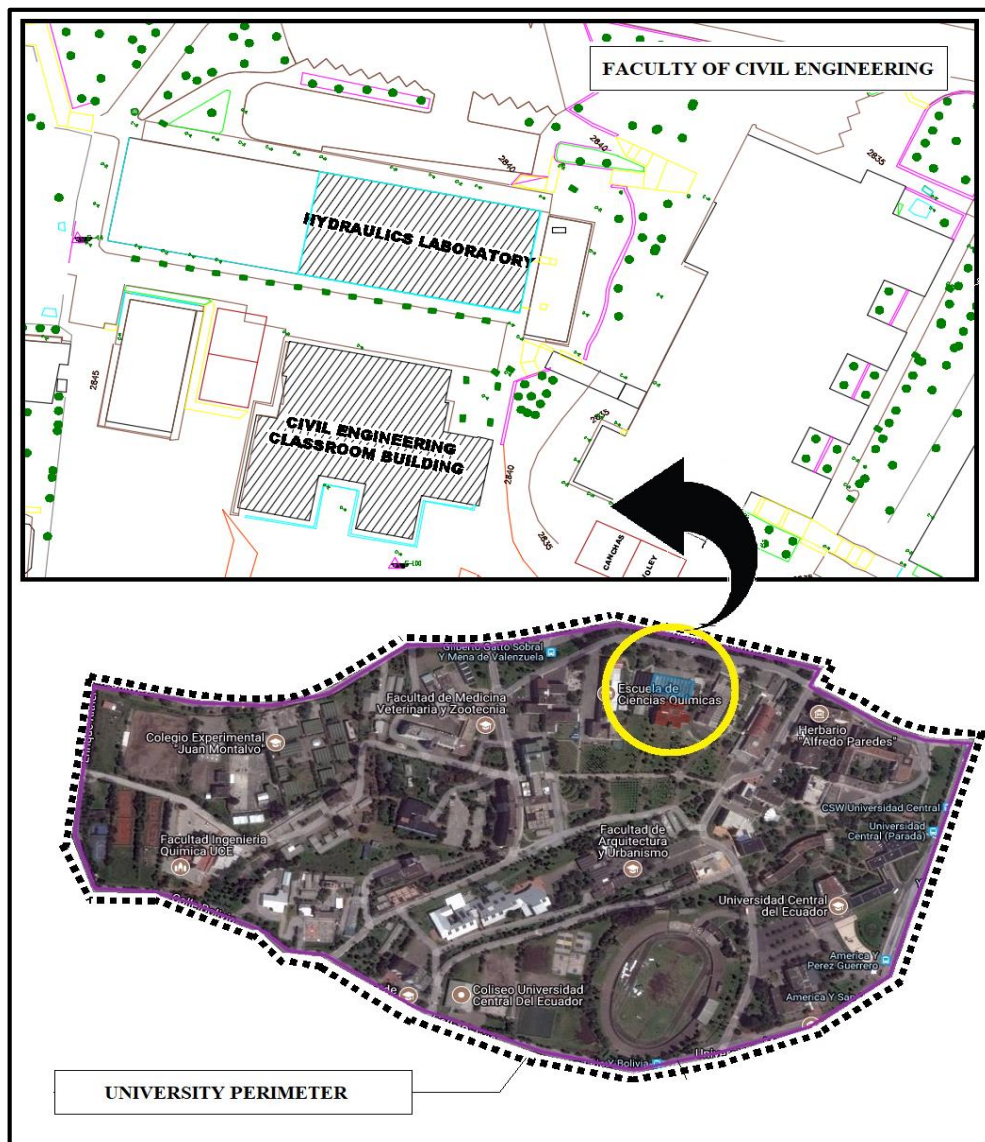


Figure 4.1 - Faculty of Civil Engineering and University Citadel

Source: Author’s own drawings - Google Maps, (2018)

- **CLASSROOM BUILDING:**

This building is located in Benjamín Chávez and Carvajal Avenues. According to historical records and existing original plans of the structure, its age ascends to 22 years since this building was built in the year of 1996. Based on the available information, it can be established that its design was prepared in 1989 by the Architects Freddy Cevallos, Marcelo López and the Engineer José Segovia. Its construction was completed in 1996 with four architectural stories.

This reinforced concrete structure has four floors: three floors for classes and the last one corresponds to the postgraduate department. The slabs of the building are made up of lightened elements and their inaccessible roof is also made of reinforced concrete. This building is formed by three structural blocks as shows the Figure 4.2, separated by their respective structural joints.

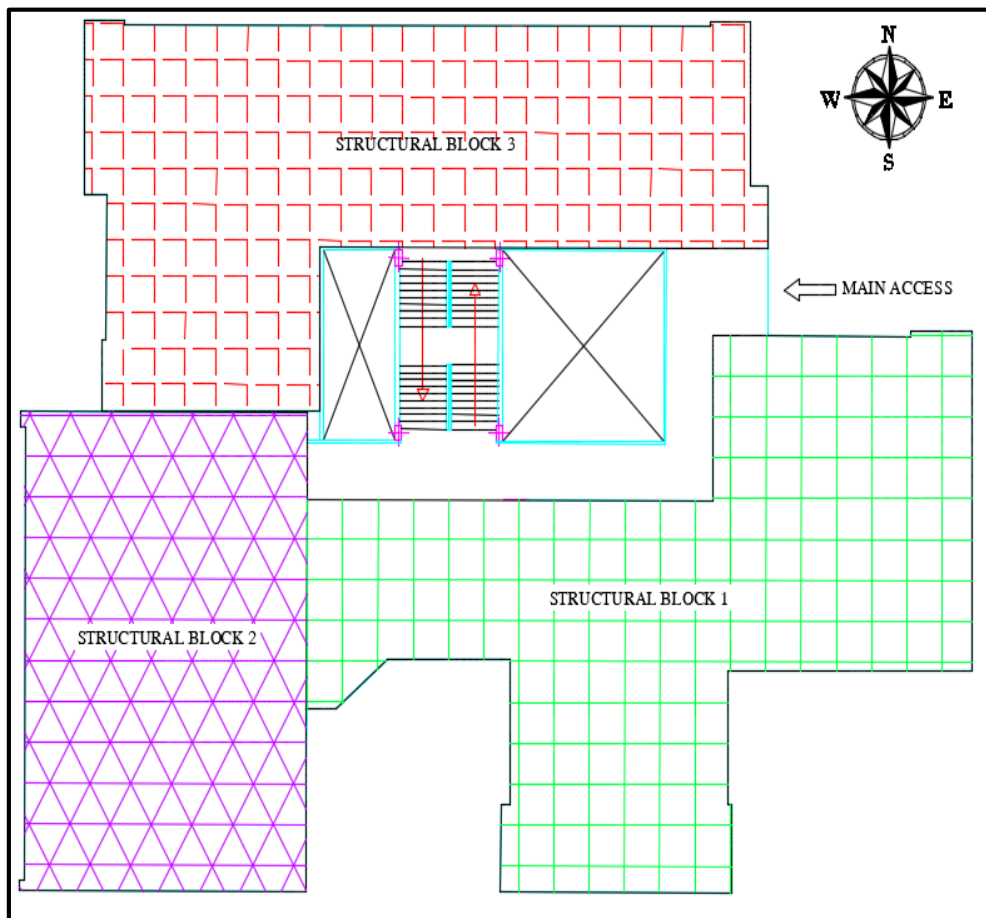


Figure 4.2 - Structural configuration of the Classroom Building

Source: Author's own drawings

The Building has 15 classrooms available on its first three floors, there is also the Topography Department, the small warehouse, the cistern for drinking water with its respective pumping system, the Library, the Graduate Institute on the fourth floor, the Teachers' Office, Projection room, the Research Institute, the Auditorium, the inaccessible terrace and the bathrooms.

Figure 4.3 shows the facades of the building and its aesthetic current state. These image allow to understand the architectural configuration of the structure and its interaction with the natural contour of the terrain.



Figure 4.3 - Classroom Building Facades

Source: Author's own figures

As can be seen in the south facade, there are green areas whose groundwater levels are high. This condition could provide another alternative source of water (underground) usable for the non-potable consumption of the classroom building. After the first visual inspection in the building, it can be noticed that there are rainwater pipes that take water from the roofs and transport it directly to the drainage system, wasting this valuable natural resource.

- **HYDRAULICS LABORATORY:**

This Hydraulics Laboratory is located in Benjamín Chávez and Carvajal Avenues. This building is much older, there is no record that details the exact age of this building. However, its importance is essential for the development of knowledge in the area of hydraulics. In this place, hydraulic models are developed and tested to simulate real scale conditions.

This building has its own water recirculation system to use the same volume in all the developed practices. However, when it is required to maintain the tank, this volume is emptied. It is very interesting to apply the rainwater collection system for this building considering the form of waves on the roof that can be used to catch rainwater easily. Figure 4.4 details the architectural configuration of this building and allows the identification of existing tank water and sanitary facilities.

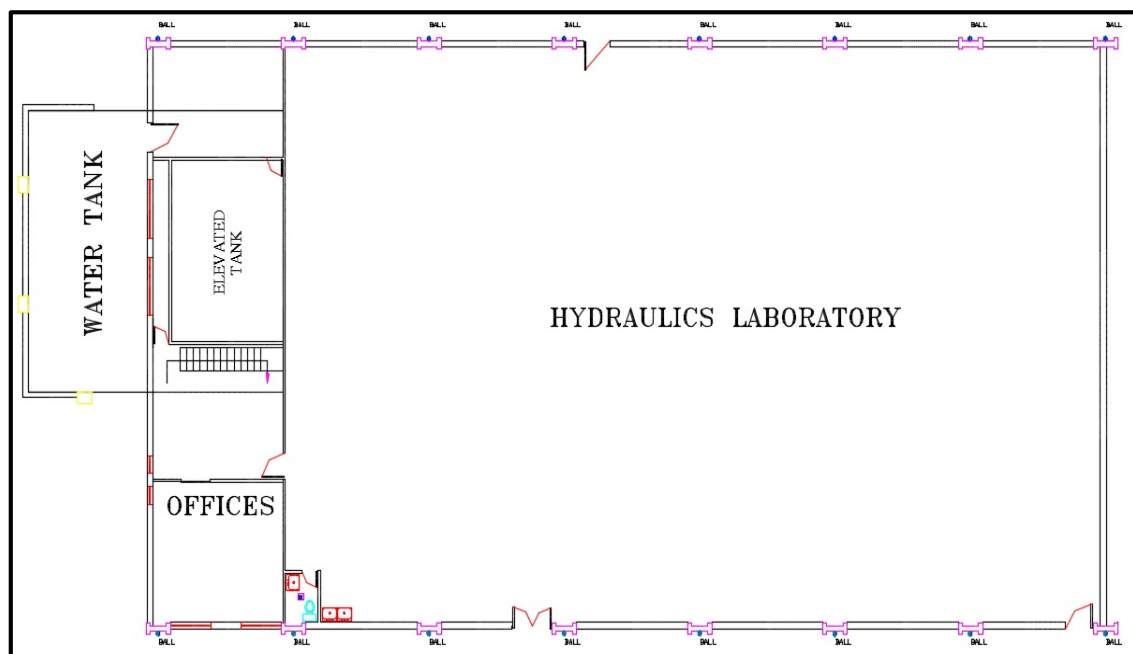


Figure 4.4 - Structural configuration of the Hydraulics Laboratory

Source: Author's own drawings

In this building five people remain daily performing functions in the office. Its concurrence admits up to 50 students when the Lab practices are developed. However, there are no sanitary batteries that are intended for student use. The main use of water in this structure has to do with the water that is required for the tanks providing the different hydraulic models.

4.3.1. Location, topography and areas considered

The exact location of the buildings that are part of the case study is summarized in table 4.1. The coordinate system is considered in units UTM WGS 84 (Universal Transverse Mercator) and zone 17M, corresponding to the location of Quito.

Table 4.1 - Coordinates of Study Case

COORDINATES OF STUDY CASE		
Coordinate	Angular Coordinate	Data
Classroom Building:		
North	Latitude	9978041 S
East	Longitude	777834 E
Hydraulics Laboratory:		
North	Latitude	9978111 S
East	Longitude	777848 E

Source: Author's own analysis

Next to the Classroom Building there is a large green area (as shows the Figure 4.5) that is used as an area for the development of topographical practices in certain occasions. The total of this area available to locate the possible storage system (cistern or artificial lake) is 0.524 hectares.



Figure 4.5 - Green areas close to the Classroom Building

Source: Author's own drawings – Google Earth, (2018)

The analysis of the areas considered focuses on the water collection surfaces that will be part of the rainwater harvesting system. It is essential to identify these surfaces that will serve as a means of collecting rainwater. In the case of the Classroom Building, the roof is inaccessible, which guarantees that there is no student or unauthorized personnel circulating through this roof. This condition is an advantage over the quality of the rainwater expected, since there is also no possibility of access to animals such as cats or rodents due to the height at which this level is found (L + 15.38m).

The use of technology such as drones and aero photography allows to clearly identify the geometrical configuration and the state of this roof. Figure 4.6 shows that in general terms the cover is in good condition but requires maintenance. In the internal part of the building no problems of structural type as fissures are identified, reason for which it is considered that this surface is apt to collect rainwater.



Figure 4.6 - Rainwater collection surface on the top of the Classroom Building

Source: Author – DJI Drone

For the specific case of the Hydraulics Laboratory, the surface of the roof has the shape of waves. According to testimonies of the Director of this Laboratory, rainwater collection systems have been designed through the collection of water that falls on this cover but simply to drain this type of water directly into the drainage system. Figure 4.7 shows the shape of

the roof surface based on the inspection performed for this building. Also, there are areas where the water stagnates, due to the rains that fall on this surface.



Figure 4.7 - Rainwater collection surface on the top of the Hydraulics Laboratory

Source: Author – Drone Parrot 2.0

To solve the problem of accumulation of rainwater on the roof it's required a cover reformulation and use it as an alternative source for non-potable consumption in the buildings analyzed. The level of this roof corresponds to (L + 3.75m). The level of the classroom building corresponds to L+15.38 as shows the Figure 4.8.



Figure 4.8 - Rainwater collection surface on the top of both buildings

Source: Author – DJI Drone

The proximity of these buildings is clear and represents an opportunity to collect rainwater by means of the two roofs to supply them with water for non-potable consumption and to mitigate the floods during the winter that takes place precisely between the streets that connect both buildings as shows the Figure 4.9.



Figure 4.9 – Hydraulics Laboratory and Classroom Building Roofs
Source: Author – DJI Drone

Figure 4.10 shows the eastern facade of both buildings. The street that separates the Class Building and the Hydraulic Laboratory is often flooded by heavy rains from January to May.



Figure 4.10 – Hydraulics Laboratory and Classroom Building Roofs
Source: Author – DJI Drone

4.3.2. Architectural characterization

1.- CLASSROOM BUILDING: The architectural conception of the Classroom Building is developed on four clearly defined floors. The spaces or defined areas of each plant are detailed below in Table 4.2.

Table 4.2 - Distribution and use of the Classroom Building by areas

DISTRIBUTION AND USE OF THE CLASSROOM BUILDING			
Floor	Level	Use/Spaces	Area (m²)
1	Ground Floor (L+0.18)	Auditorium	232.39
		Department of Topography	141.25
		Teacher's office	122.16
		Small warehouse	12.36
		Cistern – Pumping System	12.30
		Copy center	12.90
		Projection Room	13.53
		Classroom A1-1	78.20
		Classroom A1-2	58.55
		Classroom A1-4	145.96
		Bathroom / Sanitary Facilities	35.08
2	1 st Floor (L+3.98)	Library	470.45
		Classroom A2-5	59.90
		Classroom A2-6	59.07
		Classroom A2-7	78.55
		Classroom A2-8	81.14
		Classroom A2-9	121.90
		Bathroom / Sanitary Facilities	5.30
3	2 nd Floor (L+7.78)	Classroom A3-14	59.52
		Classroom A3-15	59.31
		Classroom A3-16	78.78
		Classroom A3-17	81.83
		Classroom A3-18	128.39
		Classroom A3-19	114.38
		Classroom A3-20	135.44
		Classroom A3-21	71.08
		Classroom A3-22	77.87
		Bathroom / Sanitary Facilities	39.82

		Postgraduate Institute	560.81
4	3 rd Floor (L+11.58)	Postgraduate Classrooms	136.38
		Research Institute	143.60
		Bathroom / Sanitary Facilities	37.19
5	4 th Floor (L+15.38)	Inaccessible cover	1092.18

Source: Author's own analysis

The levels corresponding to each floor can be analyzed in a better way with the elevation view of the classroom building according to the Figure 4.11.

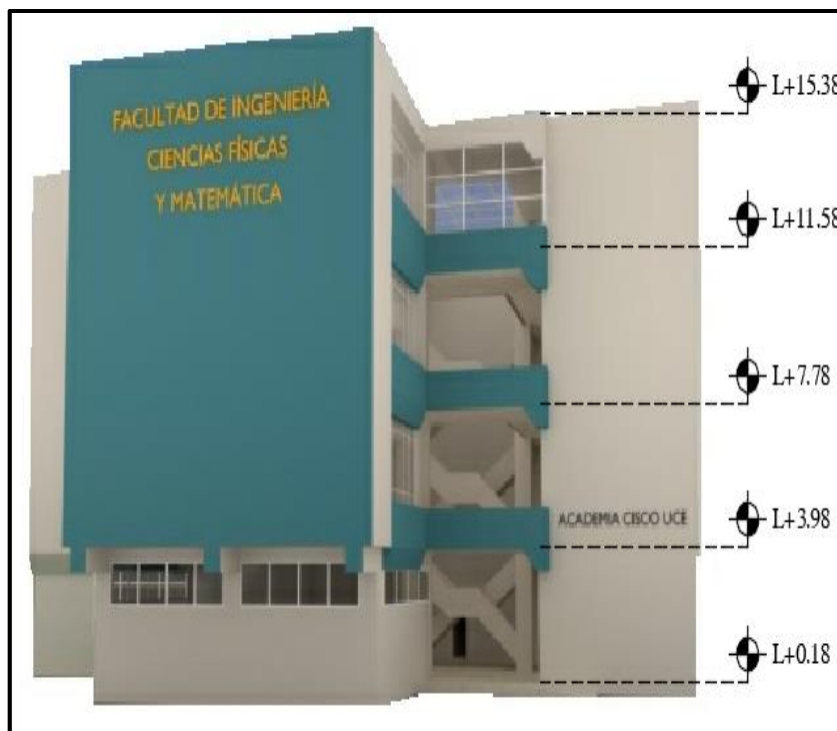


Figure 4.11 - Levels of Classroom Building

Source: Caiza, J. & Tapia, S. (2017) - adapted

To carry out the architectural characterization of the project, inspections are developed on the structure to verify the existing information in the original plans. The methodology consists of carrying out the architectural survey of each floor evaluated, as well as the determination of the areas that are part of the structure. For this, the original plans of the classroom building that are supplied by the Department of Physical Planning of the University are verified. It should be noted that for their age, the original plans were drawn completely by hand, which is why it is important to check if there are modifications made to the structure in recent years through the architectural survey.

- **GROUND FLOOR (L+0.18m)**

To calculate the total area of this architectural floor (as shows the Figure 4.12), it is necessary to add the area corresponding to the corridor that gives access to the different detailed places and that is equal to 107.12m².

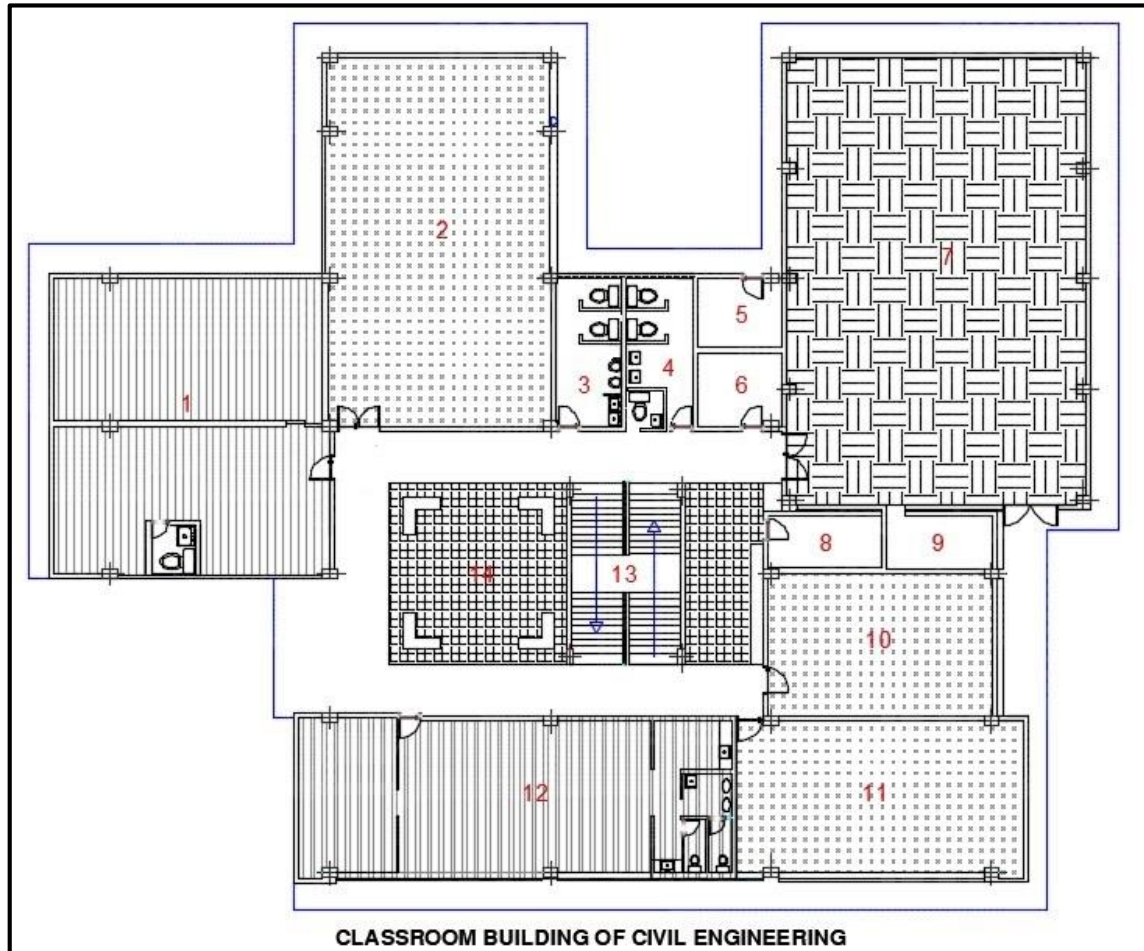


Figure 4.12 - Ground Floor of Classroom Building

Source: Author's own drawings

- | | |
|--|---|
| 1. Department of Topography A=141.25m ² | 8. Projection room A=13.53 m ² |
| 2. Classroom A1-4 A=145.96m ² | 9. Copy center A=12.90 m ² |
| 3. Bathroom (Men) A=18.34m ² | 10. Classroom A1-2 A=58.55 m ² |
| 4. Bathroom (Women) A=16.74m ² | 11. Classroom A1-1 A=78.20 m ² |
| 5. Small warehouse A=12.36m ² | 12. Teacher's Office A=122.16 m ² |
| 6. Cistern – pumping system A=12.30 m ² | 13. Concrete staircase A=35.89 m ² |
| 7. Auditorium A=232.39 m ² | 14. Lobby A=77.33 m ² |

GROUND FLOOR – TOTAL AREA = 1085.02 m²

- **FIRST FLOOR (L+3.98m)**

To calculate the total area of this architectural floor (as shows the Figure 4.13), it is necessary to add the area corresponding to the corridor that gives access to the different detailed places and that is equal to 109.83m².

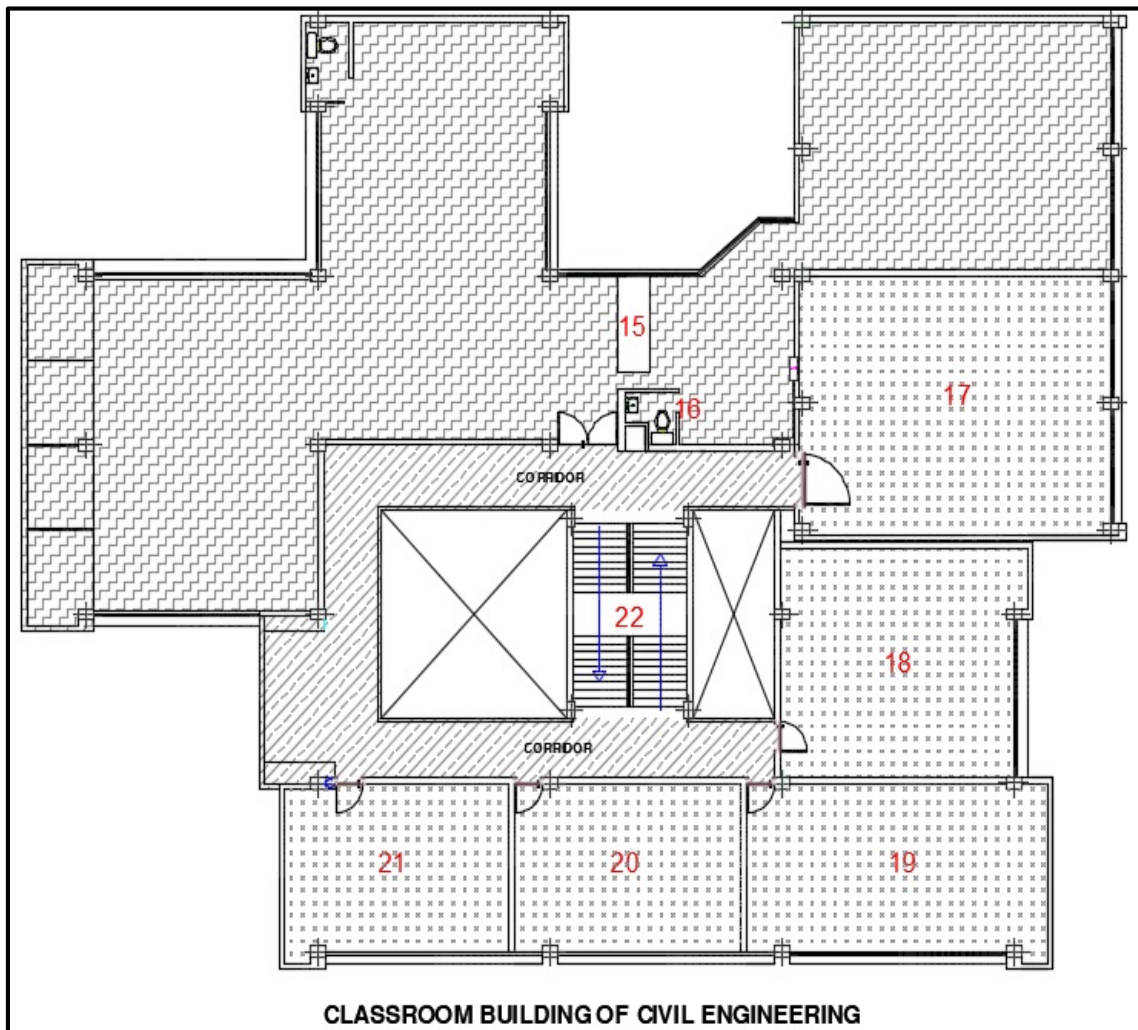


Figure 4.13 - First Floor of Classroom Building

Source: Author's own drawings

- | | |
|--|--|
| 15. Library A=470.45m ² | 19. Classroom A2-7 A=78.55m ² |
| 16. Bathroom A=5.30m ² | 20. Classroom A2-6 A=59.07 m ² |
| 17. Classroom A2-9 A=121.90m ² | 21. Classroom A2-5 A=59.90 m ² |
| 18. Classroom A2-8 A=81.14m ² | 22. Concrete staircase A=35.89 m ² |

FIRST FLOOR – TOTAL AREA = 1022.03 m²

- **SECOND FLOOR (L+7.78m)**

To calculate the total area of this architectural floor (as shows the Figure 4.14), it is necessary to add the area corresponding to the corridor that gives access to the different detailed places and that is equal to 139.72m².

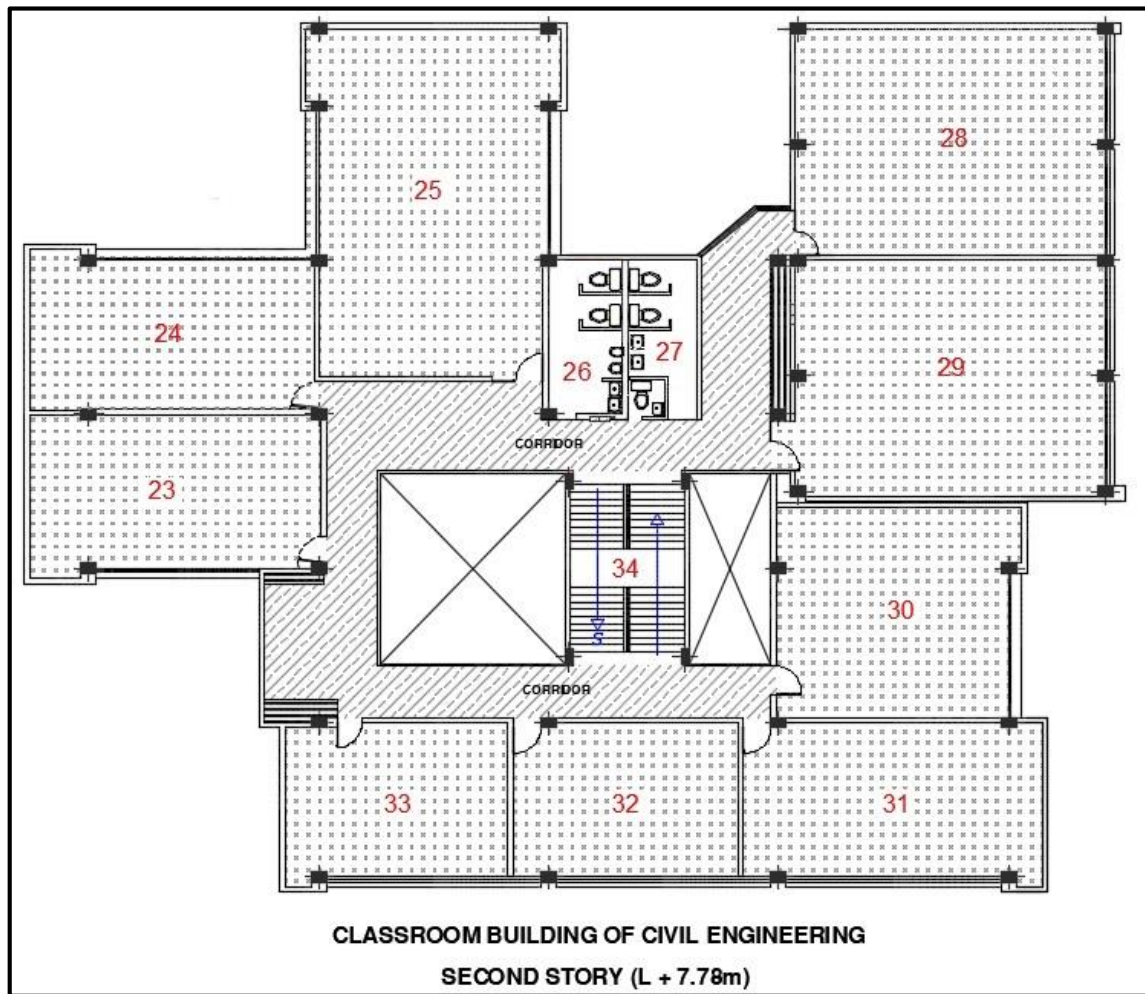


Figure 4.14 - Second Floor of Classroom Building

Source: Author's own drawings

- | | |
|---|---|
| 23. Classroom A3-22 A=77.87m ² | 29. Classroom A3-18 A=128.39m ² |
| 24. Classroom A3-21 A=71.08m ² | 30. Classroom A3-17 A=81.83m ² |
| 25. Classroom A3-20 A=135.44m ² | 31. Classroom A3-16 A=78.78m ² |
| 26. Bathroom (Men) A=21.27m ² | 32. Classroom A3-15 A=59.31m ² |
| 27. Bathroom (Women) A=18.55m ² | 33. Classroom A3-14 A=59.52m ² |
| 28. Classroom A3-19 A=114.38m ² | 34. Concrete staircase A=35.89m ² |

SECOND FLOOR – TOTAL AREA = 1022.03m²

- **THIRD FLOOR (L+11.58m)**

To calculate the total area of this architectural story (as shows the Figure 4.15), it is necessary to add the area corresponding to the corridor that gives access to the different detailed places and that is equal to 108.16m².

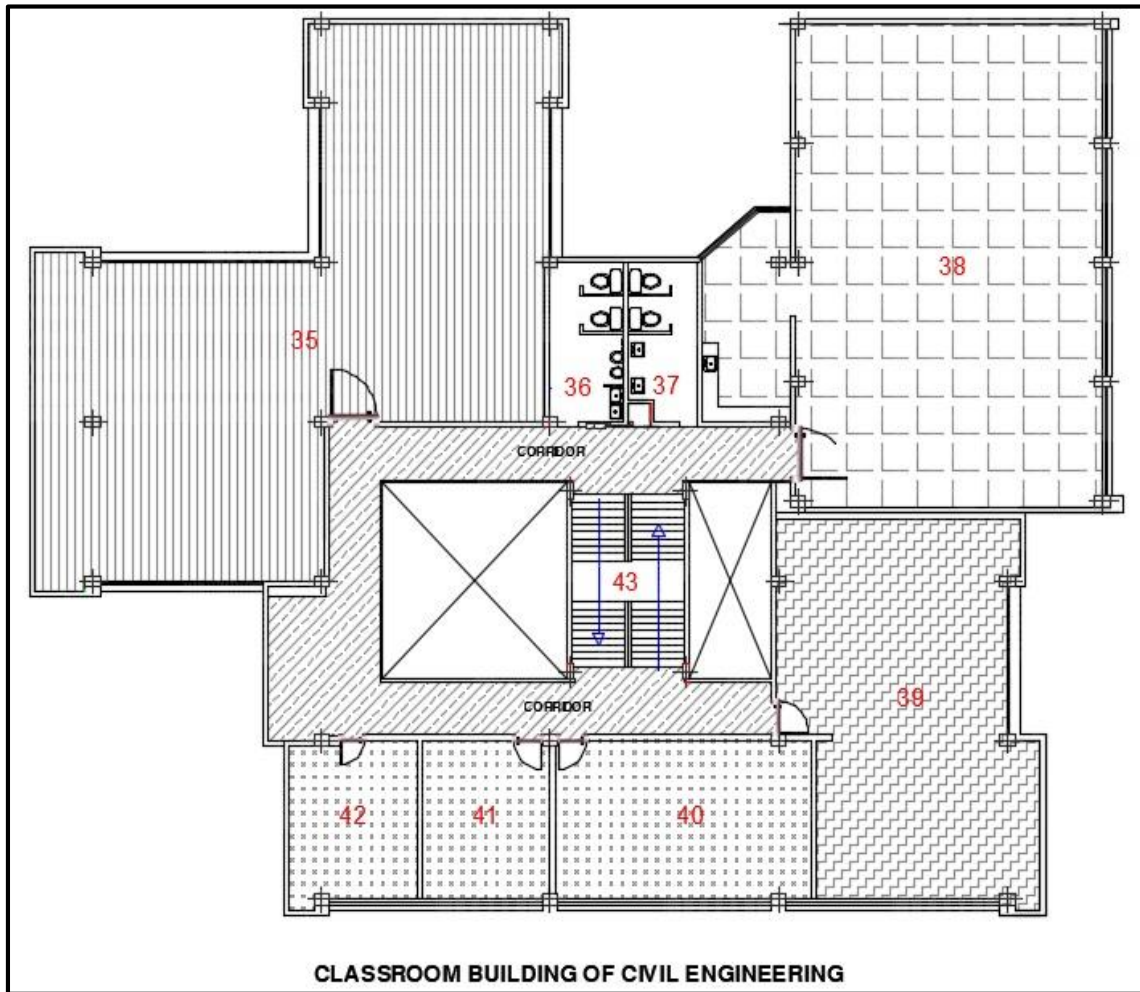


Figure 4.15 - Third Floor of Classroom Building

Source: Author's own drawings

- | | |
|--|---|
| 35. Postgraduate Institute A=297.64m ² | 40. Post. Classroom A=67.41m ² |
| 36. Bathroom (Men) A=19.91m ² | 41. Post. Classroom A=32.75m ² |
| 37. Bathroom (Women) A=17.28m ² | 42. Post. Classroom A=36.22m ² |
| 38. Graduate Management A=263.17m ² | 43. Concrete staircase A=35.89m ² |
| 39. Research Institute A=143.60m ² | |

THIRD FLOOR – TOTAL AREA = 1022.03 m²

- **FOURTH FLOOR – INACCESSIBLE COVER (L+15.38m)**

Therefore, the architectural characterization of the Classroom Building allows concluding that the total construction area is 5243.29m². The most important data of this characterization is undoubtedly the one belonging to the surface considered for rainwater harvesting as can be analyzed in the Figure 4.16, as well as the location of sanitary facilities (water demand points).

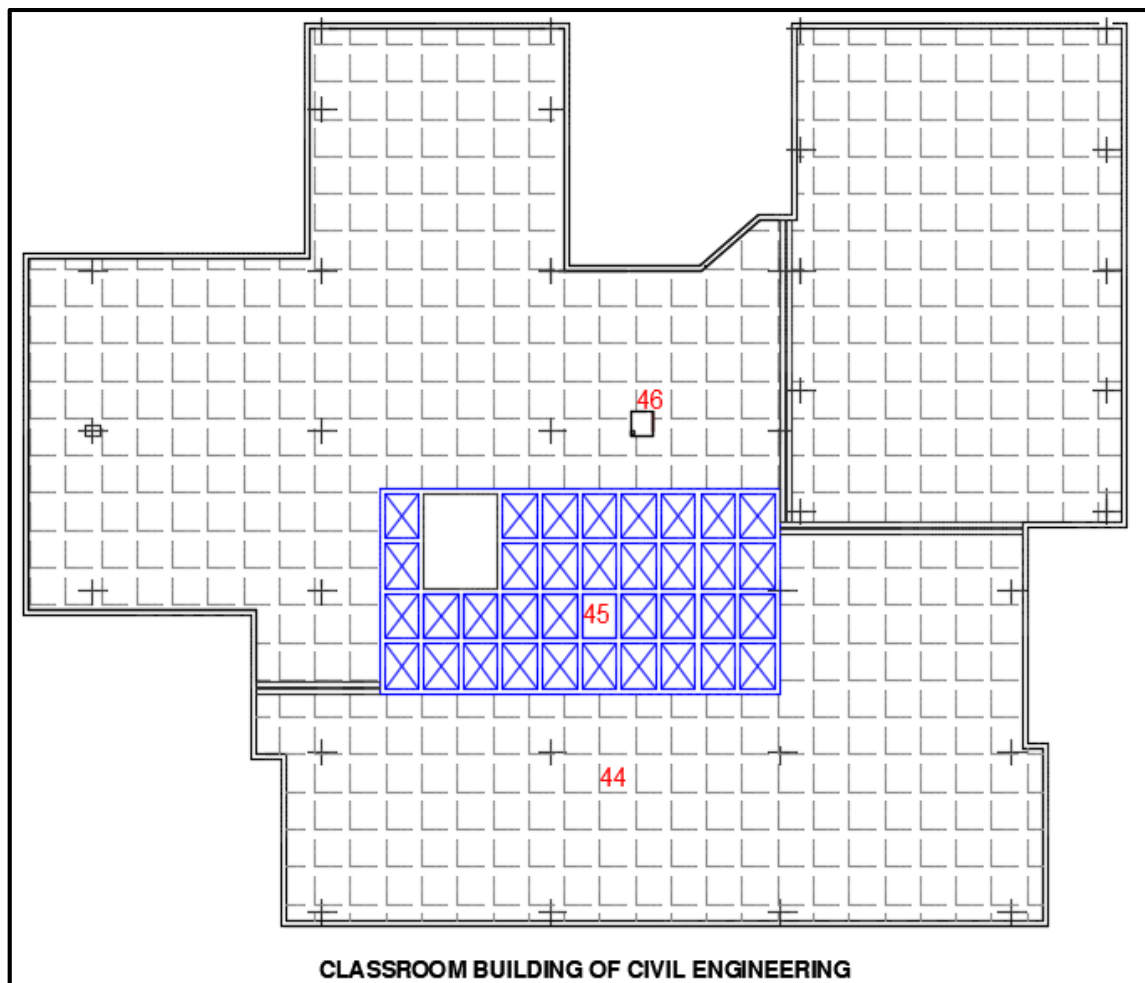


Figure 4.16 - Fourth Floor of Classroom Building (Roof)

Source: Author's own drawings

44. Surface Collection A=970.10m²

45. Skylight A=121.30m²

46. Duct A=0.78m²

FOURTH FLOOR – ROOF'S TOTAL AREA = 1092.18 m²

2.- HYDRAULICS LABORATORY: The architectural configuration of this building is simpler as shows the Table 4.3. Most of the area analyzed is intended for the exclusive use of the laboratory during classroom practices or the creation of hydraulic models. There is a small office area for teachers and students that is located inside the laboratory.

Table 4.3 - Distribution and use of the Hydraulics Laboratory by areas

DISTRIBUTION AND USE OF THE HYDRAULICS LABORATORY			
Floor	Level	Use/Spaces	Area (m ²)
1	Ground Floor (L+0.15)	Academic practices	545.22
		Teacher's Office	23.06
		Library	13.83
		Cistern	42.87
		Warehouse	17.80
		Equipment warehouse	40.15
		Bathroom	1.37
2	1 st Floor (L+3.15)	Director's Office	23.22
		Offices	14.50
		Elevated Tank	29.50
3	Roof (L+3.75)	Inaccessible Cover	1038.66

Source: Author's own analysis

The levels corresponding to each floor can be analyzed in a better way with the elevation view of the Hydraulics Laboratory according to the Figure 4.17.



Figure 4.17 - Levels of Hydraulics Laboratory

Source: Author – Drone Parrot 2.0

- **GROUND FLOOR (L+0.15m)**

The total area is obtained by adding also the corresponding area of the elevated tank (29.50m²) that was not numbered on the ground floor. The area number 1 is the most representative of the Hydraulics Laboratory and it is in this space where hydraulic models are created to simulate real conditions.

The sanitary facilities in this building are scarce, there is only one bathroom that is used by teachers who use the offices of this building as shows the Figure 4.18.

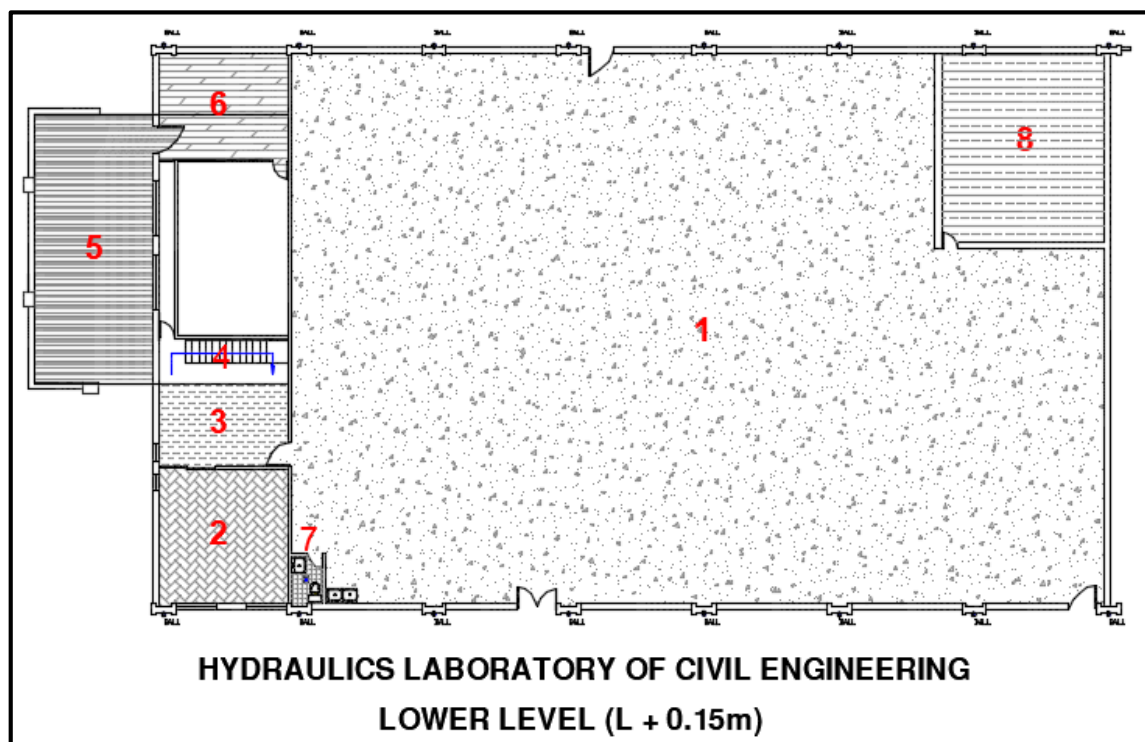


Figure 4.18 - Lower Level Characterization

Source: Author's own drawings

- | | |
|---|--|
| 1. Area of academic practices A=545.22m ² | 5. Cistern – water tank A=42.87m ² |
| 2. Teacher's office A=23.06m ² | 6. Warehouse A=17.80m ² |
| 3. Library A=13.83m ² | 7. Teacher's Bathroom. A=1.37m ² |
| 4. Wood staircase A=8.00m ² | 8. Equipment warehouse A=40.15m ² |

GROUND FLOOR – TOTAL AREA = 721.80 m²

- **FIRST STORY (L+3.15m)**

The top floor of this building corresponds to a small area that is used by the Laboratory Management, Professors of the Academic Area, Assistants and personnel that works in this Laboratory (according to the Figure 4.19). These offices allow the development of calculations and reports for commercial jobs that contract external companies as a Laboratory service.

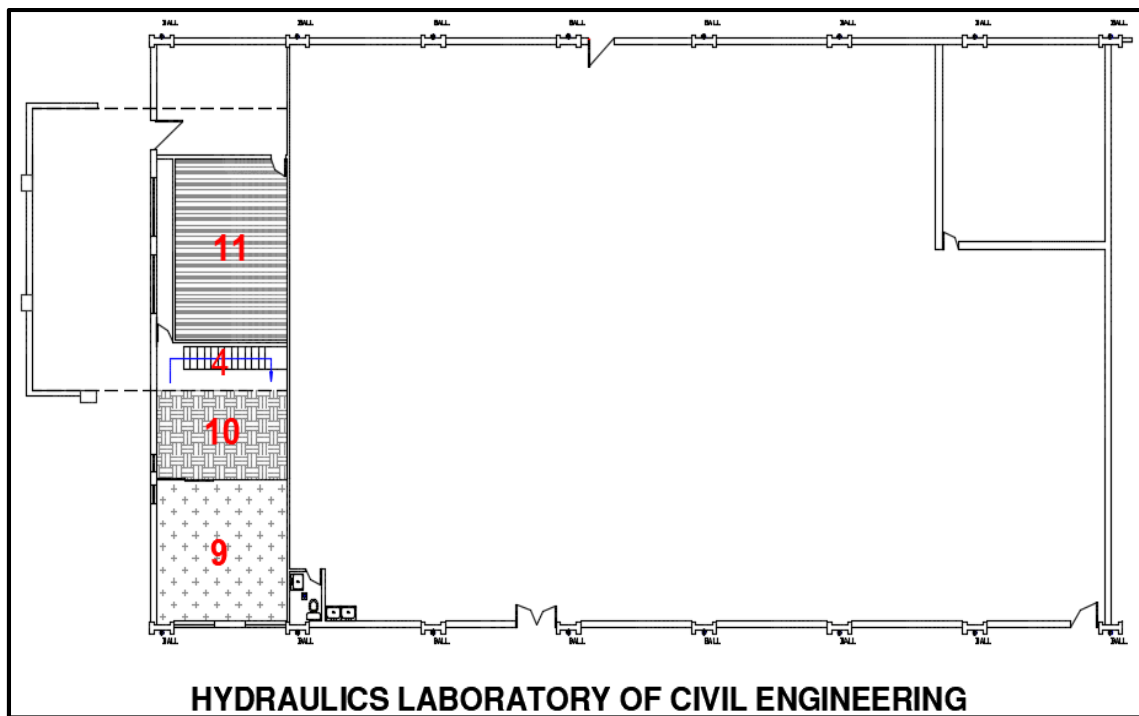


Figure 4.19 - First Floor of Hydraulics Laboratory

Source: Author's own drawings

- | | |
|---|--|
| 4. Wood staircase $A=8.00\text{m}^2$ | 10. Office $A=14.50\text{m}^2$ |
| 9. Director's office $A=23.22\text{m}^2$ | 11. Elevated Tank $A=29.50\text{m}^2$ |

FIRST FLOOR – TOTAL AREA = 75.22 m²

The elevated tank provides water to the hydraulic models built in the laboratory by gravity. The water recirculates through the components installed in the Laboratory and with the help of pumping systems; the water used is stored again in this tank. The cistern (5) is a structure that is not operational today. This system provided the water to supply the hydraulic models in the past.

- **INACCESSIBLE COVER (L+3.75m)**

However, for the calculation of the collection surface in this cover only flat roofs are considered since rainwater drains through the inclined roofs and is deposited in the bottom as shown in Figure 4.20 on the facade north of the building. The rainwater collection area in this building is **137.60m²**.

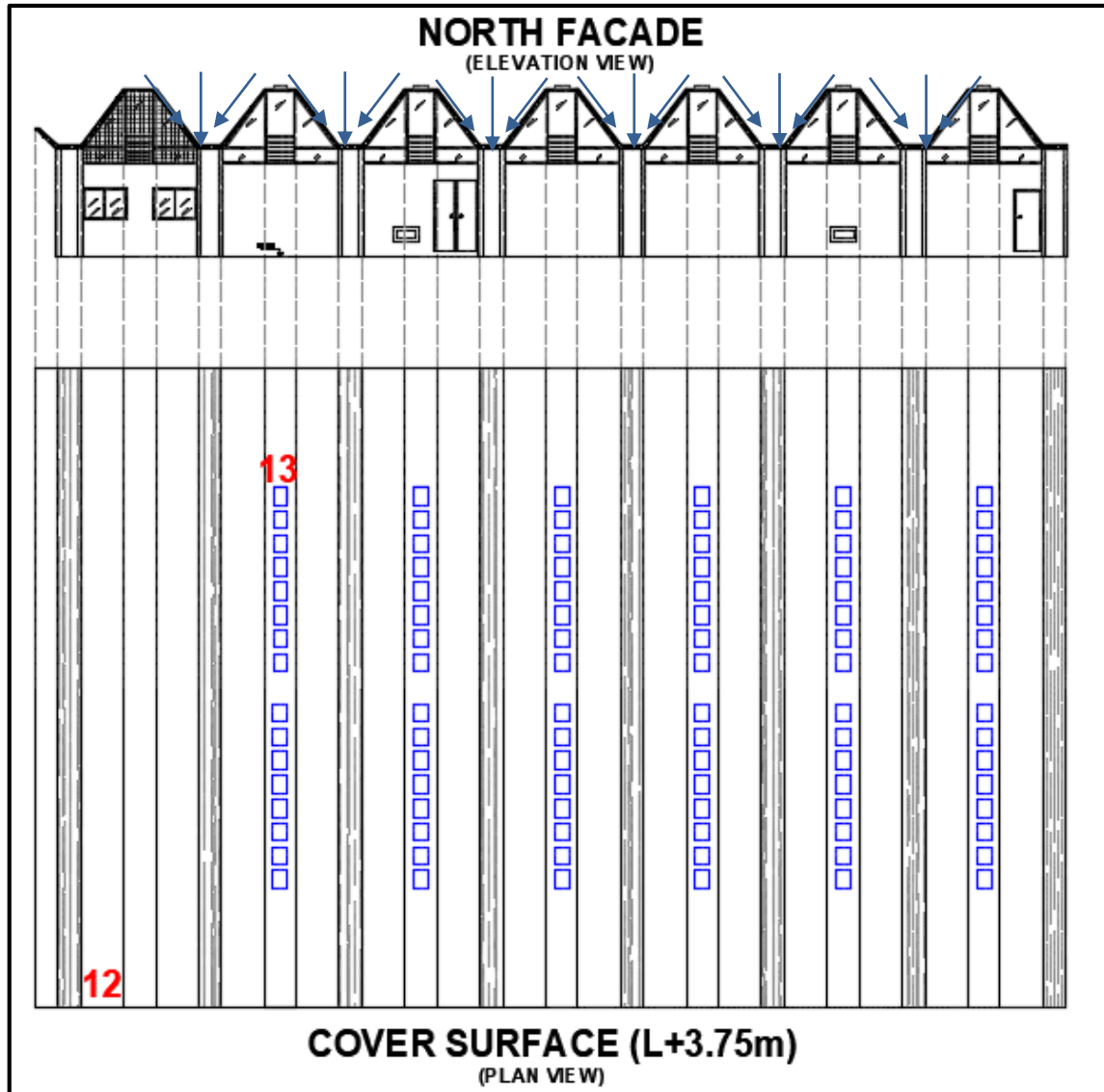


Figure 4.20 - Inaccessible Cover of the Hydraulics Laboratory

Source: Author's own drawings

12. Inaccessible Cover $A=1009.86\text{m}^2$

13. Skylight $A=28.80\text{m}^2$

COVER TOTAL AREA = 1038.66 m²

4.3.3. Hydro-sanitary system of the building

Hydro sanitary characterization is carried out based on the inspection developed in the Classroom Building and the Hydraulics Laboratory with the photographic survey of the sanitary devices found in these facilities.

4.3.3.1. Classroom Building

- **GROUND FLOOR (L+0.18)**

The ground floor of this building is constituted by four bathrooms that are operational and that are differentiated by the users that have access to them. Table 4.4 shows the distribution of the sanitary devices in this floor.

Table 4.4 - Hydro sanitary characterization in the ground floor

HYDRO SANITARY CHARACTERIZATION IN THE GROUND FLOOR				
Area	Place	Users	Sanitary Devices	Quantity
3	Bathroom (Men) A=18.34m ²	Students	Toilets	2
			Faucets	2
			Urinals	2
4	Bathroom (Women) A=16.74m ²	Students	Toilets	2
			Faucets	2
		Concierge	Toilet	1
			Faucet	1
12	Teacher's Bathroom A=122.16m ²	Teachers	Toilets	2
			Urinals	2
			Faucets	3

Source: Author's own analysis

In this floor there are three different sanitary facilities. The bathrooms for students (men and women) are of a collective nature, while in the case of the Teacher's bathroom and the concierge bathroom are private facilities. The devices comply with Ecuadorian Standard NTE INEN 1571 called "Plumbing Fixtures. Classification and Requirements".¹⁹

¹⁹ (Servicio Ecuatoriano de Normalización - INEN, 2016)

Figures 4.21, 4.22, 4.23 and 4.24 show the sanitary facilities that are part of the ground floor and their main characteristics. Some devices have quality seals, which proves that their production processes, materials and tests used to prove their resistance, are developed with the highest standards. These kind of bathroom faucets have an aerator.



Figure 4.21 - Bathroom's devices (Women) – Ground Floor

Source: Author's own inspection



Figure 4.22 - Bathroom's devices (Men) – Ground Floor

Source: Author's own inspection



Figure 4.23 - Bathroom's devices (Concierge) – Ground Floor

Source: Author's own inspection

The Teacher's Office has a bathroom for men and another for women. Both are constituted by a toilet and a faucet, with the only difference of two urinals in the men's bathroom. The first faucet shown in the Figure 4.24 corresponds to a device installed in the cafeteria of the Teacher's Office and the second one is a bathroom aerator faucet. It is appreciated that the toilets in these bathrooms correspond to green line devices with a flush of 6 liters for solids and one of 4.1 liters for liquids.



Figure 4.24 - Bathroom's devices (Teacher's bathroom) – Ground Floor

Source: Author's own inspection

- **FIRST FLOOR (L+3.98)**

On this floor, the sanitary facilities are composed only of a small bathroom located in the Library. With a private nature and for the exclusive use of staff working in the library, the sanitary facilities also have a small cafeteria equipped with a washbasin. This bathroom has not received the remodeling of its facilities. Table 4.5 shows the distribution of the sanitary devices in this floor and the Figure 4.25 provides the devices currently installed.

Table 4.5 - Hydro sanitary characterization in the first floor

HYDRO SANITARY CHARACTERIZATION IN THE FIRST FLOOR				
Area	Place	Users	Sanitary Devices	Quantity
16	Water Center A=5.30m ²	Library Personnel	Toilets	1
			Faucets	2

Source: Author's own analysis



Figure 4.25 - Bathroom's devices (Library Personnel) – First Floor

Source: Author's own inspection

- **SECOND FLOOR (L+7.78m)**

The bathrooms for men and women located on this floor are of a private nature and its architectural configuration is the same as the sanitary facilities of the second floor. Table 4.6 shows the distribution of the sanitary devices in this floor.

Table 4.6 - Hydro sanitary characterization in the second floor

HYDRO SANITARY CHARACTERIZATION IN THE SECOND FLOOR				
Area	Place	Users	Sanitary Devices	Quantity
26	Bathroom (Men) A=21.27m ²	Students	Toilets	2
			Faucets	2
			Urinals	2
27	Bathroom (Women) A=18.55m ²	Students	Toilets	2
			Faucets	2
		Concierge	Toilet	1
			Faucet	2

Source: Author's own analysis

Only access to personnel of the School Management is allowed. That is, 10 people have access to these facilities and the concierge has one bathroom for his personal use. There is also a water tap located in the cafeteria of the School Management. Figures 4.26, 4.27 and 4.28 show the sanitary facilities that are part of the ground floor and their main characteristics.



Figure 4.26 - Bathroom's devices (Women) – Second Floor
Source: Author's own inspection



Figure 4.27 - Bathroom's devices (Men) – Second Floor
Source: Author's own inspection



Figure 4.28 - Bathroom's devices (Concierge) – Second Floor
Source: Author's own inspection

- **THIRD FLOOR (L+11.58m)**

On this floor is the Postgraduate Department. It is estimated that approximately 15 people have access to the bathrooms that are at this level during the day. In general, when there are graduations or events in this area, the small cafeteria is used, which is also furnished with all the kitchen equipment and the corresponding washbasin. Table 4.7 shows the distribution of the sanitary devices on this floor.

Table 4.7 - Hydro sanitary characterization in the third floor

HYDRO SANITARY CHARACTERIZATION IN THE THIRD FLOOR				
Area	Place	Users	Sanitary Devices	Quantity
36	Bathroom (Men) A=19.91m ²	Students	Toilets	2
			Faucets	2
			Urinals	2
37	Bathroom (Women) A=17.28m ²	Students	Toilets	2
			Faucets	2

Source: Author's own analysis

The water tap shown in Figure 4.29 is part of the small kitchen that exists on this floor and is generally used when there are events or meetings in the Postgraduate Department. The bathrooms on this floor have a private character, however when there are graduation events it is allowed to enter these facilities to students and assistants.



Figure 4.29 - Bathroom's devices (Women) – Third Floor

Source: Author's own inspection

The toilets in these bathrooms have a side button on the tank for the discharge of water as shows the Figure 4.30.



Figure 4.30 - Bathroom's devices (Men) – Third Floor

Source: Author's own inspection

4.3.3.2. Hydraulics Laboratory

The hydro-sanitary characterization of this building contemplates few installations as shows the Figure 4.31. Due to its use and functionality, the highest water consumption is for the hydraulic models and tests that are carried out in this laboratory. The water in this Laboratory recirculates to be stored in the existing tanks, after its use in hydraulic models. There is a pumping system that allows to raise the water from the cistern to the elevated tank; these pumps exceed 25HP each. The distribution of the sanitary devices is given by the Table 4.8.

Table 4.8 - Hydro sanitary characterization in the Hydraulics Laboratory

HYDRO SANITARY CHARACTERIZATION IN THE LABORATORY				
Area	Place	Users	Sanitary Devices	Quantity
7	Teacher's bathroom A=1.37m ²	Teachers	Toilets	1
			Faucets	2

Source: Author's own analysis

The elevated water tank allows an approximate volume of 60 cubic meters to be stored. The water pumps raise the water from the channels that exist on the surface of the hydraulics laboratory and that lead the flow back to the elevated tank. The pumping system detailed in the Figure 4.32 is completely new and is part of the remodeling of equipment that was installed at the beginning of 2018 for this laboratory.



Figure 4.31 - Teacher’s Bathroom – Hydraulics Laboratory

Source: Author’s own inspection



Figure 4.32 - Elevated Water Tank and Pumping System - Hydraulics Laboratory

Source: Author’s own inspection

The inspection made allows to conclude that the diversity of devices in both buildings is quite broad. Only in the Teachers' Office of the Class Building there are green line toilets, with low volumes in their water discharges. The use of devices certified with Ecuadorian Standards, is a guarantee of the quality, dimensions, material and manufacture of these products. However, this standard does not refer to the water efficiency of these devices.

4.4. Water consumption in the buildings

The “ANQIP” calculation methodology according to Silva & Pimentel (2017) is applied. The method consists of adding up the flows of each device that is part of the sanitary facilities of the buildings under study and multiplying them by the number of users that use them to determine the total water consumption. This is a very efficient method for calculating water consumption in buildings because it considers each sanitary installation of the building and

its respective flow. However, the ANQIP methodology requires certain basic parameters that are necessary for the determination of water consumption in buildings. In this case, the characteristic parameters for Quito are taken into account, considering the case study location and the function of the building (public – university). In addition, certain international indicators that are referential for the countries of the region are considered.

4.4.1. Average water endowments

For indoor household use by fixture: It is important to consider that, worldwide, a World Health Organization reference value of 100 liters/(inhabitant.day) is established as the minimum vital consumption, however the consumption of drinking water from watersheds in South America exceeds this value in most of the countries of the region. The average consumption of drinking water for Latin America is 169 liters/(inhabitant.day). Ecuador leads the list as the country that consumes more drinking water 237 liters/(inhabitant.day) as shows the Figure 4.33.



Figure 4.33 - Average consumption of drinking water in Latin America

Source: El Comercio, (2015)

Paradoxically, Quito is one of the capital cities of South America with the highest consumption of drinking water per day. This data has been maintained in recent years and can be confirmed in 2018 by the EPMAPS (Empresa Pública Metropolitana de Agua Potable y Saneamiento) and the Standard named “Normas para Estudio y Diseño de Sistemas de Agua Potable y Disposición de Aguas Residuales para Poblaciones Mayores a 1000 habitantes” (Study and Design of Drinking Water Systems and Disposal of Waste water for

Populations over 1000 inhabitants CO 10.07 - 601) in chapter IV, section 4.1.4.2, Table V.3. According to the (Standard CO 10.07 – 601), the average water endowment of drinking water for each inhabitant per day in Quito is 220 liters/(inhabitant.day).

Use of water in Educational Centers (Universities): This is the case study for the present thesis. There are no studies on water efficiency in non-residential buildings that facilitate the construction of consumption diagrams. However, if there is the current Ecuadorian Standard for hydro-sanitary installations in buildings (Norma Ecuatoriana de la Construcción , 2011). This standard indicates that for buildings where education centers such as universities operate, the average water endowments of drinking water per student is 40 to 60 liters per day, which is why the Table 4.9 is adjusted to the reference value.

This value includes the percentages related to other uses (2.12%). Therefore, in the calculation methodology of water consumption for the buildings, it will be necessary to discount the corresponding percentages that are detailed in Figure 4.36.

4.4.2. Average of useful reference consumption

Thereby, and considering that the aforementioned consumptions must be withdrawn to apply the methodology of calculation according to the ANQIP, a value of 50 liters/(student.day) is established. This consumption is called "average of useful reference consumption".

This reference value becomes a measure of average category that characterizes the consumption of drinking water per university students in Quito; therefore, the suggested categorization for labeling of water efficiency of devices will depend on this referential data.

4.4.3. Classification of buildings according to the non-residential consumption pattern

Based on the average of useful reference consumption, sanitary devices in the Ecuadorian market and considered an analogous proportion to the certification and labeling model

adopted for Quito in section 2.4.4 of the present thesis, the proposed methodology establishes the consumption categories detailed in the Table 4.9.

The ANQIP methodology considers an extra category (A⁺⁺⁺) for systems that produce drinking water from alternative sources such as rainwater harvesting systems. This qualification may be granted to buildings that, in addition to demonstrating water efficiency in their devices and facilities, contemplate a system for the regeneration of drinking water with unconventional water resources.

Table 4.9 - Classification of university buildings according to the consumption pattern

CLASSIFICATION OF UNIVERSITY BUILDINGS ACCORDING TO THE CONSUMPTION PATTERN IN QUITO	
Category	Public network drinking water consumption liters/(student.day)
A⁺⁺	0 < c ≤ 20
A⁺	20 < c ≤ 25
A	25 < c ≤ 30
B	30 < c ≤ 35
C	40 < c ≤ 60
D	60 < c ≤ 70
E	c > 70

Source: Author's own analysis

World Health Organization establishes that between 50 and 100 liters of water per person per day are required to cover most of the basic needs and to avoid most health problems when drinking water.

4.4.4. Internal use of water by fixture

In Ecuador, there are no official figures about the uses of drinking water for the non-residential sector (universities). For this reason, the application of a student survey is considered in both the Class Building and the Hydraulics Laboratory to obtain the real consumption diagrams in these buildings. The results obtained were processed during two continuous weeks (March 5 to 16, 2018) from Monday to Friday. The Hydraulics laboratory only foresees the consumption of water for its employees (10 people).

4.4.4.1. Classroom Building

The average number of students and teachers entering the bathrooms in the Classroom Building is 228 per day, according to the Figure 4.343. As can be seen, users who make the most use of the sanitary facilities in this building are men, more than twice as many as women.

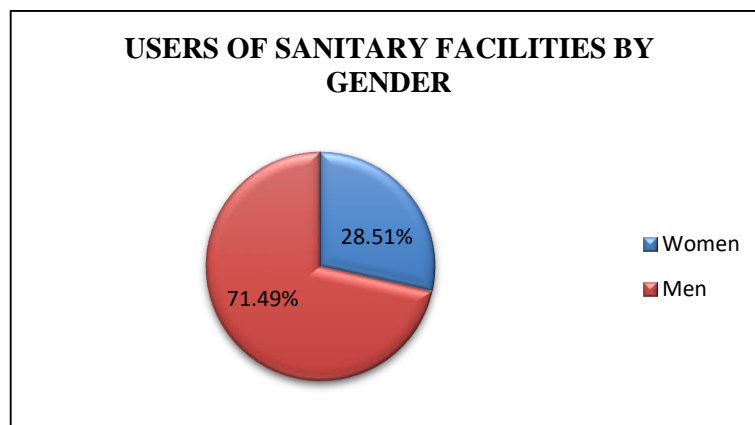


Figure 4.34 - Users of sanitary facilities by gender in the Classroom Building

Source: Author's own survey and analysis

According to the ANQIP methodology, the consumption diagram by type of building (percentage of consumption per use or device), considers the determination of the use percentage of water faucets, urinals, showers and others. The survey applied in the bathrooms that are part of this building, allow obtaining the results shown in Figure 4.35.

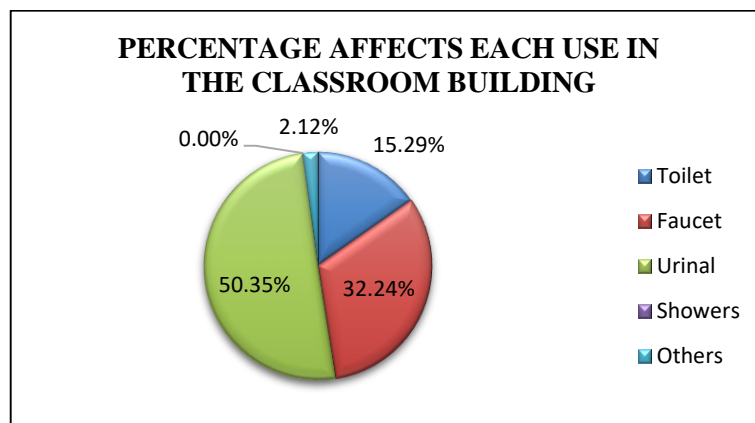


Figure 4.35 - Percentage affects each use in the Classroom Building

Source: Author's own survey and analysis

As shows the Figure 4.36, the maximum non-residential consumption of drinking water belongs to sanitary devices such as urinals. After, the consumption of drinking water in the Classroom Building is distributed for the faucets, toilets and other uses (irrigation purposes). The use of showers in this building has a percentage of 0% because these devices do not exist. Therefore, this value in conjunction with that of other uses, should be discounted from the water uses for this building in such a way that these values are corrected.

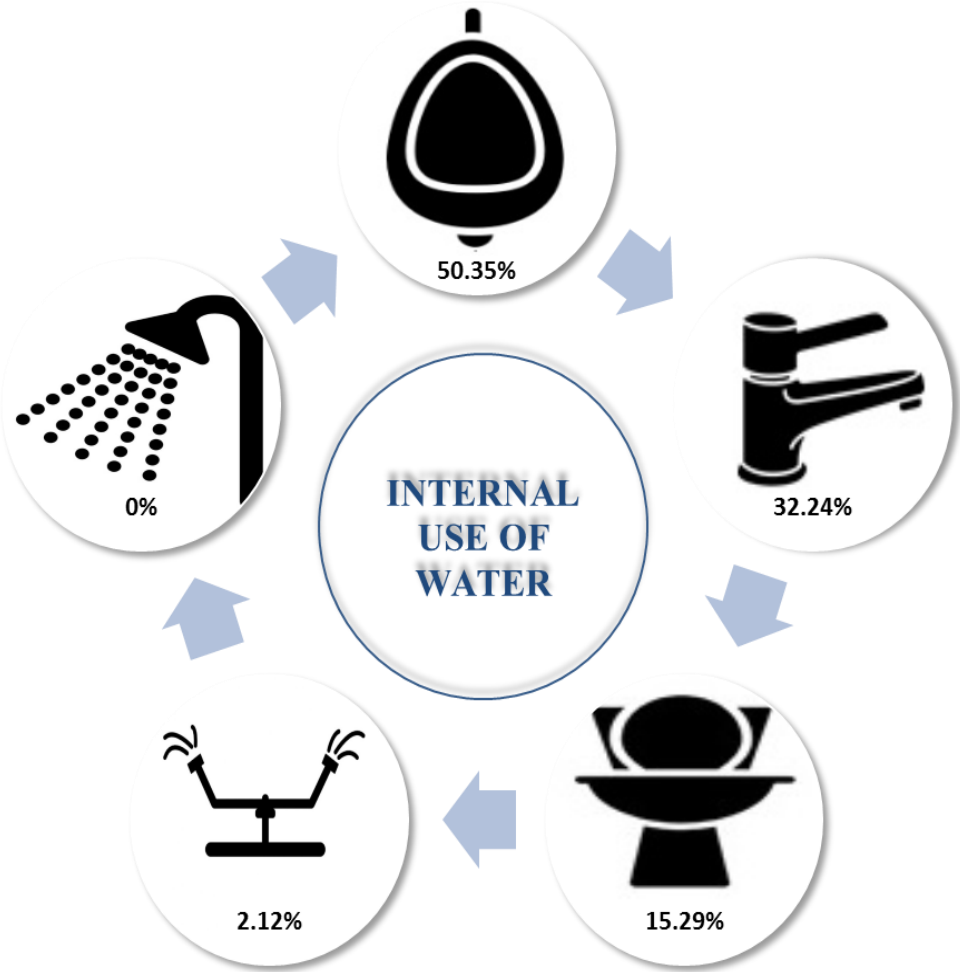


Figure 4.36 - Internal use of water by fixture for the Classroom Building

Source: Author’s own drawings

As can be seen, "other uses" and "showers" are not considered as a normal water use, so it is appropriate to redistribute these percentages in such a way that they are included within the most representative uses for this building. It is important to mention that within “other uses” are grouped two specific cases: the rare irrigation of green areas and water losses in the building.

4.4.4.2. Hydraulics Laboratory

The average number of students and teachers entering the bathroom in the Hydraulics Laboratory is 10 per day, according to the Figure 4.37. As can be seen, users who make the most use of the sanitary facilities in this building are men, more than twice as many as women.

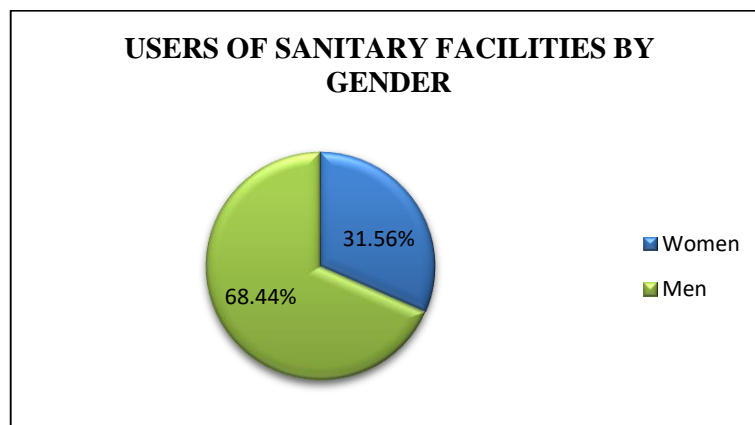


Figure 4.37 - Users of sanitary facilities by gender in the Hydraulics Laboratory

Source: Author's own survey and analysis

According to the ANQIP methodology, the consumption diagram by type of building (percentage of consumption per use or device), considers the determination of the use percentage of water faucets, toilets and in in this case, the use of water to the develop of hydraulics models. The survey applied allow to obtain the results shown in Figure 4.38.

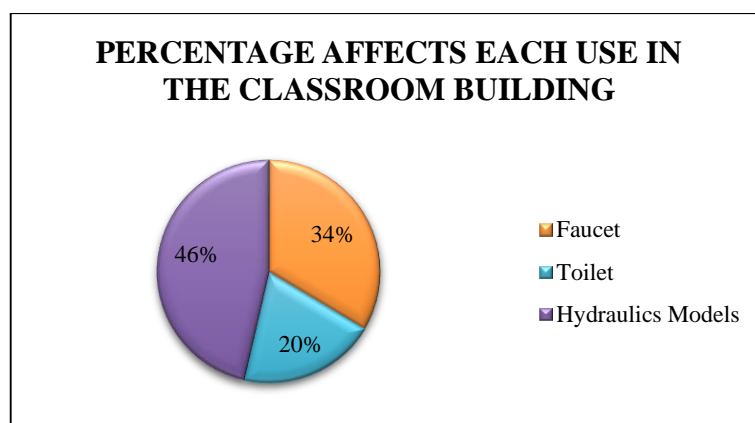


Figure 4.38 - Percentage affects each use in the Hydraulics Laboratory

Source: Author's own survey and analysis

As can be seen in Figure 4.39, "water for hydraulics models" is not considered as a normal water use, so it is appropriate to redistribute these percentages in such a way that they are included within the most representative uses for this building.

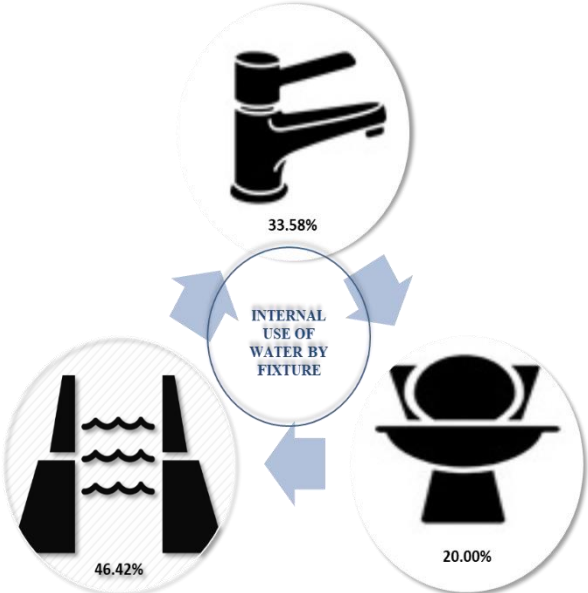


Figure 4.39 - Internal use of water by fixture for the Hydraulics Laboratory

Source: Author’s own drawings

4.4.5. Correction for internal use of water

Both the Class Building and the Hydraulics Laboratory do not have showers, washing machines, baths or washing machines for dishes. Therefore, it is important to correct the percentages of water use according to the devices and sanitary facilities that actually exist in these buildings. Table 4.10 and 4.11 shows the water uses that are not part of the Class Building and the Hydraulics Laboratory:

Table 4.10 - Water uses not included in the Classroom Building

WATER USES NOT INCLUDED IN THE CASE STUDY	
Use	Percentage
Others (external uses)	2.12%
Showers	0%
TOTAL	2.12%

Source: Author’s own analysis

Table 4.11 - Water uses not included in the Hydraulics Laboratory

WATER USES NOT INCLUDED IN THE CASE STUDY	
Use	Percentage
Hydraulics Models	46.42%
TOTAL	46.42%

Source: Author's own analysis

In relation to the different types of water faucets in the Classroom Building, whose percentages are not discriminated in Figure 4.27, the audit carried out on the buildings indicates an approximate proportion of 4/5 for bathroom faucets and 1/5 for kitchen faucets.

4.4.5.1. Classroom Building

Knowing that the “other uses” and “showers” represent according to Table 4.10 about 2.12% of water uses in the building, the corrected percentages considered in the model for the remaining uses will be:

- *Urinals*: $50.35 \times \frac{100}{97.88} \approx 51\%$
- *Bathroom Faucets*: $\frac{4}{5} \times 32.24 \times \frac{100}{97.88} \approx 26\%$
- *Kitchen Faucets*: $\frac{1}{5} \times 32.24 \times \frac{100}{97.88} \approx 7\%$
- *Toilets*: $15.29 \times \frac{100}{97.88} \approx 16\%$

4.4.5.2. Hydraulics Laboratory

Knowing that the uses for “hydraulics models” represent according to Table 4.11 about 46.42% of water uses in the building, the corrected percentages considered in the model for the remaining uses will be:

- *Bathroom Faucets*: $33.58 \times \frac{100}{53.58} \approx 63\%$
- *Toilets*: $20.00 \times \frac{100}{53.58} \approx 37\%$

4.4.6. Volumes and unit consumptions of devices

In relation to the reference unit values for toilets categories that are part of the case study, the technical specifications provided by the Ecuadorian standards and manufacturers will be considered. Currently, technology has allowed the development of a wide range of high efficiency devices: High Efficiency Urinals: HEU, High Efficiency Faucets: HEF and High Efficiency Toilets: HET.

All of them are commercialized in Ecuador. As a reference of the Ecuadorian standards, that establishes the unit volumes for each device:

- **URINALS:** NTE INEN 1571: PLUMBING FIXTURES. CLASSIFICATION AND REQUIREMENTS.
- **FAUCETS:** NTE INEN 968: PLUMBING FIXTURE FITTINGS. COCKS. REQUIREMENTS.
- **TOILETS:** NTE INEN 1569: PLUMBING FIXTURES. CLASSIFICATION

Table 4.12 shows the proposed classification based on unary consumption that is based on the standards indicated and on the availability of technology and development that manufacturers have managed to execute, to increase the water efficiency of these devices.

Table 4.12 - Unit volumes for urinals

UNIT URINAL VOLUMES			
Urinal	Category	Minimum Volume (liters)	Reference volume for the model
Without water consumption (ASME A112.19.19-2006)	A ⁺⁺	0.0	0.0
HEU: Eco Consumption	A ⁺	0.5	0.5
HEU	A	1.0	1.0
HEU	B	1.9	1.9
Low Consumption	C	3.8	3.8
Medium Consumption	D	4.5	4.5
High Consumption	E	5.0	5.0

Source: Author's own analysis

Table 4.13 shows the proposed classification based on consumption per faucet for washbasins and kitchens, based on the standards indicated and on the availability of technology and development that manufacturers have managed to execute, to increase the water efficiency of these devices. In Ecuador, accessories such as the eco-stop and the aerators that are installed in these devices are also available in order to reduce the flow.

There is no minimum flow value for kitchen faucets according to the standard NTE INEN 968. The maximum tolerated by the standard is 8.3 l/min, which is considered for the present proposal as an average category equivalent to C.

In the case study, the kitchen water faucets are not relevant, because in both buildings there are no areas designed for this purpose. While it is true and there are areas called "cafeteria", the washing activity does not require the same consumption of water compared to a traditional kitchen.

Table 4.13 - Unit volumes for washbasin faucets

UNIT FAUCET VOLUMES				
Flow (l/min)	Washbasin Faucet	Faucets with eco-stop or aerator	Faucets with eco-stop and aerator	Faucets with eco-stop and aerator
$Q \leq 1.9$	A+	A++	A++	1.5
$1.9 < Q \leq 3.0$	A	A+	A++	2.5
$3.0 < Q \leq 5.7$	B	A	A+	4.6
$5.7 < Q \leq 8.3$	C	B	A	7.0
$8.3 < Q \leq 9.0$	D	C	B	8.6
$9.0 < Q$	E	D	C	10.0

Source: Author's own analysis

According to Cevallos (2015), the maximum value of water consumption for toilets in Ecuador is 14 liters per discharge as shows the Table 4.14. Fortunately, companies have gained awareness to reduce water consumption per device to obtain high levels of water efficiency.

Table 4.14 - Unit volumes for toilets

UNIT TOILET VOLUMES			
Toilet	Category	Minimum Volume (liters)	Reference volume for the model
Dual Flush	A ⁺⁺	3.0 – 4.0	3.5
Dual Flush	A ⁺	3.0 – 4.5	3.8
Dual Flush	A	4.1 – 6.0	4.8
Dual Flush	B	4.1 – 7.0	5.5
Dual Flush	C	4.1 – 8.0	6.0
Full discharge	A ⁺	4.3	4.3
Full discharge	A	4.8	4.8
Full discharge	B	6.0	6.0
Full discharge	C	7.0	7.0
Full discharge	D	8.0	8.0
Full discharge	E	9.0 – 14.0	9.0

Source: Author's own analysis

4.4.7. Usage Factors

In Ecuador, there are no experimental studies in this field, however it is admitted that the real values of the case study can be adopted from Figure 4.34.

In Ecuador, the most common devices for residential use are those of the letter D. However, and in the case of educational buildings, such as this case study, the current trend is to implement health devices that are among the A⁺⁺ categories Until the C. This is a positive point for educational institutions, because they contribute with example to a water saving behavior.

The consumption values that have been analyzed in Tables 4.12, 4.13 and 4.14 will be considered as calculation consumptions to determine the factors of use. Based on the value of 50 liters/(student.day) and the methodology followed, these results are obtained:

4.4.7.1. Classroom Building

- **Urinals:** for a reference volume of 3.8 l according with Table 4.12:

$$\frac{0.51 \times 50}{3.8} = 6.71 \text{ uses}/(\text{student. day})$$

- **Bathroom Faucets:** for a reference flow of 8.3 l/min according with Table 4.13:

$$\frac{0.26 \times 50}{8.3} = 1.57 \text{ min}/(\text{student. day})$$

- **Kitchen Faucets:** for a reference flow of 8.3 l/min according with Table 4.13:

$$\frac{0.07 \times 50}{8.3} = 0.42 \text{ min}/(\text{teacher. day})$$

- **Toilets:** for a reference flow of 7.0 l according with Table 4.14:

$$\frac{0.16 \times 50}{7.0} = 1.14 \text{ uses}/(\text{student. day})$$

4.4.7.2. Hydraulics Laboratory

- **Bathroom Faucets:** for a reference flow of 8.3 l/min according with Table 4.13:

$$\frac{0.63 \times 50}{8.3} = 3.80 \text{ min}/(\text{student. day})$$

- **Toilets:** for a reference flow of 7.0 l according with Table 4.14:

$$\frac{0.37 \times 50}{7.0} = 2.64 \text{ uses}/(\text{student. day})$$

According to the applied calculation methodology, it is important to characterize the sanitary devices installed in the buildings that are part of the case study. It is important to consider a correction factor applied to water faucets, because they are not always used, opening them to the maximum, because the water splashes. Generally, it is the user who opens the water faucets according to his perception of comfort, but does not do it to the maximum for the reason indicated above. Therefore, the elaborated Table 4.15 is established on the basis of flow measurements considered as comfort.

Table 4.15 - Comfort Factors for faucets

COMFORT FACTORS	
Water Efficiency Category	Comfort Factor
A	1.0
B	0.9
C	0.8
D	0.7
E	0.6

Source: Author's own analysis

Taking into account these comfort factors in the factors of use previously determined for water taps, the following final results are obtained:

For the Classroom Building:

- **Bathroom Faucets:** $\frac{1.57}{0.70} = 2.24 \text{ min}/(\text{student. day})$
- **Kitchen Faucets:** $\frac{0.42}{0.70} = 0.60 \text{ min}/(\text{teacher. day})$

For the Hydraulics Laboratory:

- **Bathroom Faucets:** $\frac{3.80}{0.70} = 5.43 \text{ min}/(\text{student. day})$

4.4.8. Methodology for flow measurement

It is very important to consider that for the case study, the consumptions in the different sanitary facilities, depend fundamentally on the pressure in the network that is part of the sanitary system of the buildings. Based on the sanitary characterization of the installed devices, it can be noted that some toilets do not have a tank and that their discharge system is directly connected to the sanitary network of the building. The patterns of consumption, peak hours and pressure in the network then play a key role in determining the flow rates, however, and considering that these devices are already installed, it is important to consult in these cases the information that the manufacturer has of its products with respect to the consumption of each device.

The calculation of drinking water consumption in the buildings that are part of the case study is done through the application of two methods: a traditional one and the second, with the help of an electronic gauging device. The application of these two methods has a great importance because they allow to perform key activities: the comparison between obtained results and the data gathering where it is not possible to locate the electronic device by its dimensions and by the characteristics of the sanitary facilities (faucets and washbasins).

- 1. TRADITIONAL METHOD:** Containers plus stopwatches as shows the Figure 4.40. Forty readings were taken for each device, in groups of 10 readings each to discard atypical (outlier) values.



Figure 4.40 - Materials to develop the traditional method of flow meter

Source: Author's own inspection

It is one of the best known and simplest methods for measuring water flow. Its procedure basically consists of gauging flows with the help of a graduated container and a stopwatch. To do this, the water faucets are opened until a constant flow of water is obtained and which is comfortable for the washing activities that each user requires.

Then, the container is filled to a known level (in liters) in order to measure the time (in seconds), in which the flow takes time to fill the said container. By arithmetic calculations the flow (l/s) of each device can be determined using the following equation:

$$\text{Flow(l/s)} = \frac{\text{Volume}}{\text{Time}}$$

[Equation 18]. Equation for calculating the flow in sanitary devices

Another reason why this method is adopted is that the SpotOn® Irrigation Flow Meter²⁰ can not be applied in all sanitary devices because it requires a constant flow until the device is filled and the flow finally can be measured. In some cases, it is impossible for the SpotOn® Irrigation Flow Meter to get a measurement due to the location of the faucets with the washbasins. As the device is not in vertical position, or at such an angle that it can be filled to the required height inside the tank to measure the flow rate, it is not possible to take the measurement because the water is emptied at one end of the device.

2. USE OF PATENTED ELECTRONIC DEVICE: in this case a flow meter device is used, obtaining an immediately result for each sanitary facility in (l/s).

To guarantee the data obtained from referential consumption of each sanitary facility, it is important to use an electronic measurement device that is patented and that can measure flow, especially in water faucets. Taking into account that technology is the dynamics of evolution and innovation, the SpotOn® Irrigation Flow Meter is considered as a measuring device for the present case study. The readings or results from this device are obtained immediately, it does not require calibration depending on the medium in which the operator is and its system allows obtaining the water flow in three different units (l/s), (l/h), Gal/min.

Figure 4.41 details the geometric configuration of the device (circular section) and its main dimensions (20.3cm diameter x 20.3cm tall). Among the most important features of this device that can be consulted in its manual and the official website of its manufacturer are:

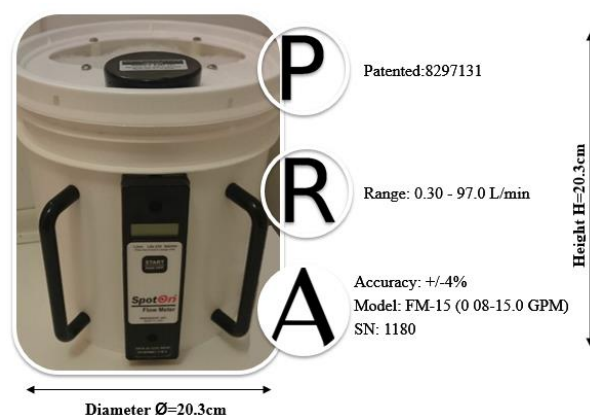


Figure 4.41 - SpotOn® Irrigation Flow Meter used by the analysis of Water Efficiency

Source: Author's own acquisition

²⁰ (Innoquest Inc, 2018)

To have a more real idea of drinking water consumption in the Classroom Building and the Hydraulics Laboratory, it is important to consider the participation of different volunteers who recreate the conditions of use in normal or usual conditions. This process must be applied in such a way that each user feels comfortable with the flow of water that requires to wash the hands or clean the kitchen utensils.

4.5. Selected statistical method to discard data

This section focuses on determining upper outliers to continue and validate the analysis of the results obtained. An outlier is one that apparently is not part of the group of the sample obtained, which is why it is important to determine if it should be discarded or if, in effect, it corresponds to the data group. Depending on the statistical analysis considered, it must be decided if a value is atypical and if it should be discarded from the sample.

For the present case study, the Dixon test is considered as a statistical method. This methodology uses relations of the difference between data with respect to the amount of values in the sample. The Value Rejection Methodology²¹ determines the critical values for outliers in normal samples up to 100 sizes and this can be applied in applications of engineering.

To apply the method, it is necessary to calculate the Dixon index knowing the size of the sample (n), and the relationship used is the space between the outlier (X_n) and its closest neighbour (X_{n-1}) divided by the space between the largest and smallest values in the group.

$$Dixon\ Index = \frac{X_n - X_{n-1}}{X_n - X_1}$$

[Equation 19]. Dixon Index

This index is compared with a critical value established in the divergence table according to Dixon, and the value is declared an outlier if it exceeds that critical value. The critical value depends on the sample size, n , and a chosen level of representativeness, which is the risk of rejecting a valid observation. For the present case, the following parameters are used:

²¹ ASTM International Standards Worldwide (2008)

- $n = 10$ (because to measure the consumptions of each device samples were considered samples with a size of 10 readings).
- $\alpha = 5\%$ (because it is important to consider a low degree of error, taking into account that the consumptions were meticulously measured).

4.6. Results obtained

In order to determine the consumption in each sanitary device of the Classroom Building and the Hydraulics Laboratory, the following results are obtained and tabulated by both flow measurement methods. The partial results of each device can be consulted in the attachments section.

4.6.1. Classroom Building

The result of the sanitary characterization of the Class Building devices is summarized in the Table 4.16 according to the consumption analysis carried out.

Table 4.16 - Characterization of Building Devices – Classroom Building

CHARACTERIZATION OF BUILDING DEVICES			
Device	Number #	Water Efficiency Category	Consumption (l/min) / (l/washing)
Toilet	17	-	5.94
Bathroom Faucets	18	-	4.03
Kitchen Faucets	4	-	6.17
Urinals	10	C	0.50

Source: Author's own analysis

4.6.1.1. Application of calculation model

In accordance with the calculation methodology suggested by the ANQIP and the results obtained in the case of the study developed for university buildings, the water efficiency of

the Classroom Building is determined. For the calculator of water consumption, the following aspects are considered:

- As in the evaluated buildings there are no laundry or washing machines, the multiplicative component that is part of the correction factors established by the methodology is not considered (Multiplicative = 1.00).
- The Classroom Building does not currently count on the contribution of a rainwater harvesting system, or a waste water recycling system, nor with the contribution of a system that uses groundwater water. For this reason the values in liters/(person.day) are equivalent to zero.

Table 4.17 shows the calculation of water consumption of the Classroom Building and its respective classification of water efficiency.

Table 4.17 - Water consumptions calculator – Classroom Building

CALCULATION OF TOTAL CONSUMPTION – CLASSROOM BUILDING				
Device	Units	Volume / Flow (Average)	Usage Factor	Total liters/(person.day)
		(A)	(B)	(C) = (A) X (B)
Toilet	liters	5.94	1.14	6.77
Bathroom faucets	liters/min	4.03	2.24	9.03
Kitchen faucets	liters/min	6.17	0.60	3.70
Urinals	liters	0.50	6.71	3.36
Total calculated consumption (liters/person.day) Sum of Column (C) = (1)				22.86
Correction Factors		Multiplicative	(No laundry or washing machines)	1.00
	l/washing l/(person.day)	Additional CWM	(=0, Teaching Building)	0.00
	l/washing l/(person.day)	Additional DM	(=0, Teaching Building)	0.00
	Contribution of use of rainwater l/(person.day)			
Waste water recycling contribution l/(person.day)				0.00
Contribution of use of groundwater l/(person.day)				0.00
TOTAL WATER CONSUMPTION l/(person.day)				22.86
EXTERNAL USES l/(person.day)				0.00
TOTAL CONSUMPTION l/(person.day)				22.86
WATER EFFICIENCY CATEGORIZATION OF THE BUILDING				A⁺

Source: Author's own analysis

The total water consumption is 22.86 liters/(person.day). Comparing this value with the classification by consumption standard for university buildings of Table 4.9, a category equivalent to "A+" is assigned, since it is within the range of 20 to 25 liters/(person.day).

This category is very encouraging, because it reflects the management system through the university on the acquisition of sanitary devices with high levels of water efficiency. However, it is possible to improve this category and achieve the category equivalent to "A⁺⁺⁺" with the installation of a rainwater harvesting system.

The justification of the consumption detail per device is included below. Table 4.18 shows the consumption of drinking water corresponding to the use of toilets. To determine the liters that each device requires due to load, it is important to follow the following methodology concerning to the consumption in toilets:

1. Fill the toilet tank.
2. Turn off the water supply to the flushing tank.
3. Perform the tank discharge.
4. Finish filling the toilet tank (the amount of water that was used to restore the initial level of water in the cistern corresponds to the consumption of the cistern).
5. Repeat the procedure to check results several times.

Table 4.18 - Auxiliary table for calculating consumption in toilets

CLASSROOM BUILDING ANALYSIS OF WATER CONSUMPTION IN TOILETS							
Level	Area	Sanitary facility	Type of Toilet	Water Efficiency Category	Reference Flow (liters)	Number (#)	Total (liters)
					(A)	(B)	(E) = (D) X (B)
L ± 0.18m	Student's Bathroom	Women	Full Discharge	B	6.00	2	12.00
		Men	Full Discharge	B	6.00	2	12.00
	Concierge	Bathroom	Full Discharge	B	6.00	1	6.00
	Teacher's Office.	Women's Bath.	Dual Flush	A	4.80	1	4.80
		Men's Bath.	Dual Flush	A	4.80	1	4.80
± 3.98	Library	Bathroom	Full Discharge	-	7.30	1	7.30
L ± 7.78m	Student's Bathroom	Women	Full Discharge	B	6.00	2	12.00
		Men	Full Discharge	B	6.00	2	12.00
	Concierge	Bathroom	Full Discharge	B	6.00	1	6.00
L ± 11.58m	Bathrooms	Women	Full Discharge	B	6.00	2	12.00
		Men	Full Discharge	B	6.00	2	12.00
Sum of Column (B) = (F)						17	
Sum of Column (E) = (G)							100.90
AVERAGE CONSUMPTION (liters/min) (H) = (G) / (F)							5.94

Source: Author's own analysis

For the calculation of drinking water consumption in faucets, it is important to differentiate whether their use is for bathrooms or kitchens. Table 4.19 shows the consumption of the bathroom faucets and Table 4.20 the consumption of the kitchen faucets in the Classroom Building.

Table 4.19 - Auxiliary table for calculating consumption in bathroom faucets

CLASSROOM BUILDING ANALYSIS OF WATER CONSUMPTION IN BATHROOM FAUCETS									
Level	Area	Sanitary facility	Type of Bathroom Faucet	Water Efficiency Category	Reference Flow (liters/min)	Number (#)	Comfort Factor	Comfort Flow (liters/min)	Total (liters/min)
					(A)	(B)	(C)	(D) = (A) X (C)	(E) = (D) X (B)
L ± 0.18m	Student's Bathroom	Women	With aerator	-	4.08	1	-	-	4.08
			With aerator	-	4.17	1	-	-	4.17
		Men	With aerator	-	4.38	1	-	-	4.38
			With aerator	-	5.16	1	-	-	5.16
	Concierge	Bathroom	Timer Faucet	-	6.08	1	-	-	6.08
	Teacher's Office	Women's Bath.	With aerator	-	4.57	1	-	-	4.57
Men's Bath.		With aerator	-	5.19	1	-	-	5.19	
3.98	Library	Bathroom	Simple	-	2.38	1	-	-	2.38
L ± 7.78m	Student's Bathroom	Women	With aerator	-	2.32	1	-	-	2.32
			With aerator	-	4.36	1	-	-	4.36
		Men	With aerator	-	4.64	1	-	-	4.64
			With aerator	-	1.71	1	-	-	1.71
	Concierge	Bathroom	With aerator	-	2.05	1	-	-	2.05
			With aerator	-	2.00	1	-	-	2.00
L ± 11.58m	Bathrooms	Women	Timer Faucet	-	3.99	1			3.99
			Timer Faucet	-	5.74	1			5.74
		Men	Timer Faucet	-	5.38	1			5.38
			Timer Faucet	-	4.34	1			4.34
Sum of Column (B) = (F)						18			
Sum of Column (E) = (G)									72.54
AVERAGE CONSUMPTION (liters/min) (H) = (G) / (F)									4.03

Source: Author's own analysis

Table 4.20 - Auxiliary table for calculating consumption in kitchen faucets

CLASSROOM BUILDING ANALYSIS OF WATER CONSUMPTION IN KITCHEN FAUCETS									
Level	Area	Sanitary facility	Type of Bathroom Faucet	Water Efficiency Category	Reference Flow (liters/min)	Number (#)	Comfort Factor	Comfort Flow (liters/min)	Total (liters/min)
					(A)	(B)	(C)	(D) = (A) X (C)	(E) = (D) X (B)
0.18m	Teacher's O.	Cafeteria	With aerator	-	4.64	1	-	-	4.64
3.98m	Library	Cafeteria	With aerator	-	6.91	1	-	-	6.91
7.78m	Dep. School	Cafeteria	With aerator	-	5.05	1	-	-	5.05
11.58m	Post. Dep.	Cafeteria	With aerator	-	8.06	1			8.06
Sum of Column (B) = (F)						4			
Sum of Column (E) = (G)									24.66
AVERAGE CONSUMPTION (liters/min) (H) = (G) / (F)									6.17

Source: Author's own analysis

In the case of urinals, the manufacturer's specifications have been considered because all the devices correspond to the same design. They are low water consumption urinals catalogued in category "C" of water efficiency devices established in Table 4.12. The consumption is the same for all cases, as shows the Table 4.21.

Table 4.21 - Auxiliary table for calculating consumption in urinals

CLASSROOM BUILDING ANALYSIS OF WATER CONSUMPTION IN URINALS							
Level	Area	Sanitary facility	Type of Urinal	Water Efficiency Category	Reference Flow (liters/flush)	Number (#)	Total (liters/flush)
					(A)	(B)	(E) = (D) X (B)
L±0.18m	Student's B.	Men	Low Cons.	C	0.50	2	1.00
	Teacher's O.	Men's Bath.	Low Cons.	C	0.50	2	1.00
L±7.78m	Student's B.	Men	Low Cons.	C	0.50	2	1.00
	Concierge	Bathroom	Low Cons.	C	0.50	2	1.00
L±11.58m	Bathrooms	Men	Low Cons.	C	0.50	2	1.00
Sum of Column (B) = (F)						10	
Sum of Column (E) = (G)							5.00
AVERAGE CONSUMPTION (liters/flush) (H) = (G) / (F)							0.50

Source: Author's own analysis

4.6.2. Hydraulics Laboratory

The result of the sanitary characterization of the Hydraulics Laboratory devices is summarized in the Table 4.22 according to the consumption analysis carried out.

Table 4.22 - Characterization of Building Devices – Hydraulics Laboratory

CHARACTERIZATION OF BUILDING DEVICES			
Device	Number #	Water Efficiency Category	Consumption (l/min) / (l/washing)
Toilet	1	-	8.44
Bathroom Faucets	2	-	4.00

Source: Author's own analysis

4.6.2.1. Application of calculation model

In accordance with the calculation methodology suggested by the ANQIP and the results obtained in the case of the study developed for university buildings, the water efficiency of

the Hydraulics Laboratory is determined. For the calculator of water consumption, the following aspects are considered:

- As in the evaluated buildings there are no laundry or washing machines, the multiplicative component that is part of the correction factors established by the methodology is not considered (Multiplicative = 1.00).
- The Hydraulics Laboratory does not currently count on the contribution of a rainwater harvesting system, or a waste water recycling system, nor with the contribution of a system that uses groundwater water. For this reason the values in liters/(person.day) are equivalent to zero.

Table 4.23 shows the calculation of water consumption of the Hydraulics Laboratory and its respective classification of water efficiency.

Table 4.23 - Water consumptions calculator – Hydraulics Laboratory

CALCULATION OF TOTAL CONSUMPTION				
Device	Units	Volume / Flow (Average)	Usage Factor	Total liters/(person.day)
		(A)	(B)	(C) = (A) X (B)
Toilet	liters	8.44	2.64	22.28
Bathroom faucets	liters/min	4.00	5.43	21.72
Total calculated consumption (liters/person.day) Sum of Column (C) = (1)				44.00
Correction Factors		Multiplicative	(No laundry or washing machines)	1.00
	l/washing	Additional CWM	(=0, Teaching Building)	0.00
	l/(person.day)			0.00
	l/washing	Additional DM	(=0, Teaching Building)	0.00
l/(person.day)	0.00			
Contribution of use of rainwater l/(person.day)				0.00
Waste water recycling contribution l/(person.day)				0.00
Contribution of use of groundwater l/(person.day)				0.00
TOTAL WATER CONSUMPTION l/(person.day)				44.00
EXTERNAL USES l/(person.day)				0.00
TOTAL CONSUMPTION l/(person.day)				44.00
WATER EFFICIENCY CATEGORIZATION OF THE BUILDING				C

Source: Author's own analysis

The total water consumption is equal to 44.00 liters/(person.day) despite having barely three devices. This information is consistent with reality, since the sanitary facilities of this building have not received the necessary remodelling intervention. Comparing this value

with the classification by consumption standard for university buildings of Table 4.9, a category equivalent to "C" is assigned, since it is within the range of 60 to 70 liters/(person.day). It is necessary to improve this category with the installation of a rainwater harvesting system.

The justification of the consumption detail per device is included below. Table 4.24 shows the consumption of drinking water corresponding to the use of toilets. the applied methodology is the same as the detailed one for the Classroom Building.

Table 4.24 - Auxiliary table for calculating consumption in toilets

HYDRAULICS LABORATORY ANALYSIS OF WATER CONSUMPTION IN TOILETS							
Level	Area	Sanitary facility	Type of Toilet	Water Efficiency Category	Reference Flow (liters)	Number (#)	Total (liters)
					(A)	(B)	(E) = (D) X (B)
L±0.18	Hydra. Lab	Bathroom	Full Discharge	-	8.44	1	8.44
Sum of Column (B) = (F)						1	
Sum of Column (E) = (G)							8.44
AVERAGE CONSUMPTION (liters/min) (H) = (G) / (F)							8.44

Source: Author's own analysis

Table 4.25 shows the consumption of the bathroom faucets in the Hydraulics Laboratory.

Table 4.25 - Auxiliary table for calculating consumption in bathroom faucets

HYDRAULICS LABORATORY ANALYSIS OF WATER CONSUMPTION IN BATHROOM FAUCETS									
Level	Area	Sanitary facility	Type of Bathroom Faucet	Water Efficiency Category	Reference Flow (liters/min)	Number (#)	Comfort Factor	Comfort Flow (liters/min)	Total (liters/min)
					(A)	(B)	(C)	(D) = (A) X (C)	(E) = (D) X (B)
L±0.18m	Lab.	Tch. Bathroom	Simple	-	2.75	1	-	-	2.75
	Lab.	Washbasin	With aerator	-	5.25	1	-	-	5.25
Sum of Column (B) = (F)						2			
Sum of Column (E) = (G)									8.00
AVERAGE CONSUMPTION (liters/min) (H) = (G) / (F)									4.00

Source: Author's own analysis

4.7. Solution and measures for the case study

In order to improve the hydric efficiency of the Hydraulics Laboratory, whose category is equivalent to "C" and reach the "A⁺" category for the Classroom Building, the design and dimensioning of a rainwater harvesting system is considered, which will make it possible to provide the water service for non-potable consumptions (toilets, urinals, hydraulic models and even the irrigation of green areas).

The sizing of the rainwater storage system depends on the rain intensity data available for the station closest to the location of the case study. Fortunately, various public institutions in Ecuador have the rainfall data referred to for the calculation of this component.

4.7.1. Rainwater Harvesting System

Here, the objective is to use rainwater as an alternative source for the non-potable consumption of water in sanitary devices. This goal aims to improve the water efficiency of buildings and guarantees the reduction of drinking water consumption in both buildings, in addition to the contribution of reducing the possibility of flooding in the study area.

It is important to consider then, a design that takes advantage of the roofs of the buildings to catch the rainwater and lead it to a storage system that allows to recirculate the water through the buildings under study. Due to its ease of installation and quality of collected water, the rainwater harvesting system becomes one of the best options to apply to the case study. The intense rainfall regime that characterizes Quito is one of the main reasons to ensure that this system will become a permanent source of water supply for both buildings.

Therefore, the design and dimensioning of rainwater harvesting system are made considering the rainfall data available for Quito and the physical characteristics of the study area: roof dimensions, available green areas, topographic, architectural survey, among others.

4.7.1.1. Monthly water consumptions

With the objective of sizing the components of the rainwater harvesting system, it is important to determine the monthly water consumption in both buildings to identify the total volume that will be required to supply through the rainwater harvesting system the non-potable uses.

- **Classroom Building:** From Table 4.17 the total water consumption is 22.86 liters/(person.day). Therefore, to calculate the monthly consumption, 22 days are taken into account due to the fact that, weekends are deducted (Saturday and Sunday) because they are not considered as days in which there is water consumption in the facilities that are part of the case study. The average of users in this building is 228 people, so:

All uses (faucets, toilets and urinals):

$$22.86 \frac{\text{liters}}{\text{person. day}} \times \frac{228 \text{people} \times 22 \text{day}}{1000} = 114.66 \text{m}^3$$

Non – potable uses (toilets and urinals) – RAINWATER HARVESTING SYSTEM:

$$(6.77 + 3.36) \frac{\text{liters}}{\text{person. day}} \times \frac{228 \text{people} \times 22 \text{day}}{1000} = 50.81 \text{m}^3$$

- **Hydraulics Building:** From Table 4.23 the total water consumption is 44.00 liters/(person.day). The average of users in this building is 10 people, so:

All uses (faucets, toilets and urinals):

$$44.00 \frac{\text{liters}}{\text{person. day}} = \frac{10 \text{people} \times 22 \text{day}}{1000} = 9.68 \text{m}^3$$

Non – potable uses (toilets and urinals) – RAINWATER HARVESTING SYSTEM:

$$(22.28) \frac{\text{liters}}{\text{person. day}} \times \frac{10 \text{people} \times 22 \text{day}}{1000} = 4.90 \text{m}^3$$

In spite of the fact that it only has three sanitary devices and a minimum number of 10 people working in this place, the analysis shows that water efficiency does not depend exclusively on the number of installed devices, but on their performance and eco-efficiency. In both cases, the rainwater harvesting system is a very important alternative to improve these categories, especially the Hydraulics Laboratory.

Therefore, the total volume required during each month of the year to satisfy the needs of the users in the both study buildings is equal to:

$$\text{Monthly Consumption} = 50.81 + 4.90 = 55.71\text{m}^3$$

$$\text{Monthly Consumption} \approx 56.00\text{m}^3$$

4.7.1.2. Water catchment area

The roofs of both buildings have flat surfaces to collect and conduct rainwater. They correspond to inaccessible reinforced concrete slabs, which is why a runoff coefficient equal to 0.90 according with the Leadership in Energy and Environmental Design (2018) values.

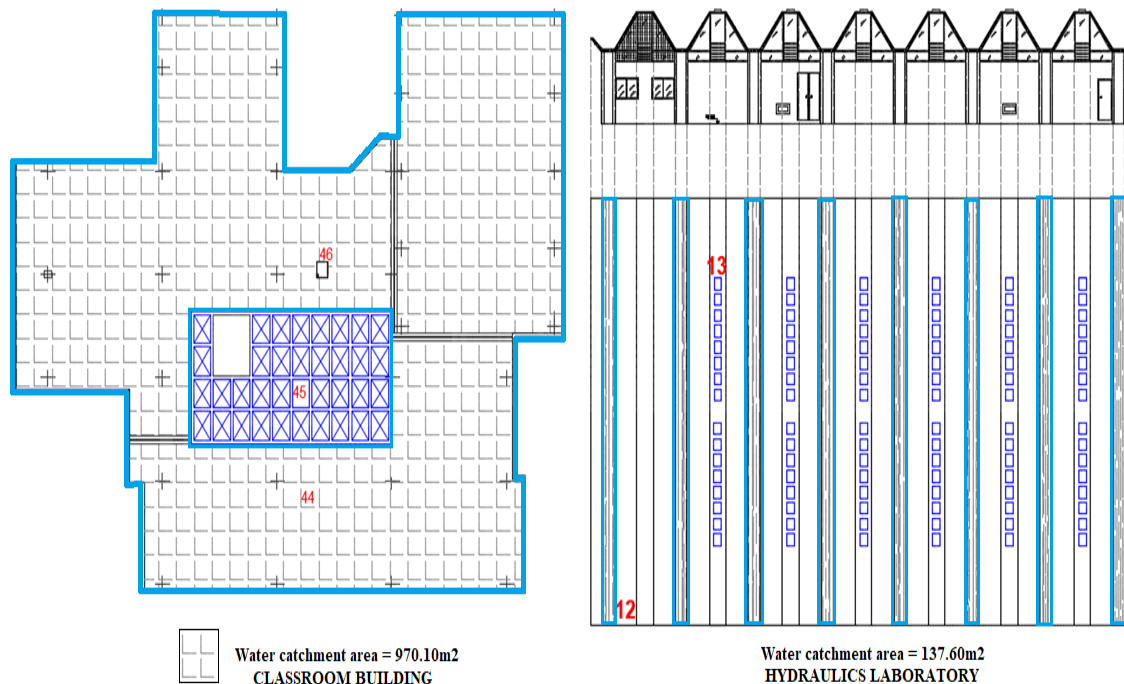


Figure 4.42 - Concrete surface for water collection according to the case study

Source: Author's own drawings

However, and taking into account the high monthly consumption calculated, it is considered as an additional solution, the collection of water infiltrating the green area that is next to the Classroom Building. When it rains, this area becomes saturated and there are filtrations in the Classroom Building subsoil, as well as flooding in the parking area due to the excess of water and the low capacity of the existing drainage system.

Figure 4.43 indicates the area considered as rainwater infiltration zone (yellow polygon) with an extension of 4000 m². Only 1500 m² are considered to catch this water and lead it to the suggested reservoir in the lower area of the Faculty (blue circle).



Figure 4.43 - Green area for water collection according to the case study

Source: Author – DJI Drone

Table 4.26 shows the design parameters that are considered for the calculation of the Usable volume of monthly rain.

Table 4.26 - Runoff Coefficient and Water Efficiency of Filtration

RUNOFF COEFFICIENT						
Zone	Area (m ²)	Area (%)	Ci	Ci x Ai	Weighted Coefficient	Assumed Coefficient
Concrete Roofs	1-107.70	42.48%	0.90	996.93	0.67	0.67
Green area	1500.00	57.52%	0.50	750.00		
TOTAL	2607.70	100.00%		1746.93		

Source: Author’s own analysis

4.7.1.3. Precipitation study

From the pluviometric stations that are located in Quito, the station selected is the one closest to the case study and the one that has a complete data record of the last years. The pluviometric station data is detailed in the Table 4.27.

Table 4.27 - Pluviometric Station Data

PLUVIOMETRIC STATION DATA	
Data	Description
Name	Quito - Iñaquito
Location	Latitude: (00 10 41.89 S) Longitude: (78 29 15.83 W)
Altitude	2789 m.a.s.l.
Code	M0024
Historical Record	1975 - 2018

Source: INSTITUTO NACIONAL DE METEOROLOGÍA E HIDROLOGÍA, (2018)

The consecutive and corrected monthly average rainfall data of the last 6 years is used. This historical record is detailed in Table 4.28 according to the corrected precipitation of each month from 2008 to the present year.

Table 4.28 - Monthly average rainfall

MONTHLY AVERAGE RAINFALL											
Aug	Sep	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul
9.60	46.93	119.35	70.88	47.68	113.78	113.83	173.33	148.24	134.72	28.56	11.90

Source: INSTITUTO NACIONAL DE METEOROLOGÍA E HIDROLOGÍA, (2018)

4.7.1.4. Rainwater Harvesting System design

With the tabulated rainfall data, calculations are made for the sizing of the rainwater harvesting system and the volume of the reservoir. The ANQIP methodology is applied as shows the Table 4.29, with data exclusively for Quito, where the case study is located. The monthly consumption is calculated based on the use of devices that require non-potable water. In this way, it is guaranteed that the rainwater use system will supply the resource exclusively to these facilities.

Table 4.29 - Calculation of Rainwater Harvesting System

CALCULATION OF RAINWATER HARVESTING SYSTEM									
Month	Monthly Average Rainfall	Monthly Consumption	Usable volume of monthly rain	Difference	Calculation differences	Volume adopted for the reserve	Volume of water in the reservoir		Supply
	(mm)	(m ³)	(m ³)	(m ³)	(m ³)	(m ³)	Start	End	(m ³)
	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Jan	113.78	56.00	188.83	132.83	132.83	15.00	15.00	15.00	0.00
Feb	113.83	56.00	188.92	132.92	132.92		15.00	15.00	0.00
Mar	173.33	56.00	287.66	231.66	231.66		15.00	15.00	0.00
Apr	148.24	56.00	246.02	190.02	190.02		15.00	15.00	0.00
May	134.72	56.00	223.58	167.58	167.58		15.00	15.00	0.00
Jun	28.56	56.00	47.40	-8.60	0.00		15.00	6.40	0.00
Jul	11.90	56.00	19.75	-36.25	0.00		6.40	0.00	29.85
Aug	9.60	56.00	15.93	-40.07	0.00		0.00	0.00	40.07
Sep	46.93	56.00	77.88	21.88	21.88		15.00	15.00	0.00
Oct	119.35	56.00	198.07	142.07	142.07		15.00	15.00	0.00
Nov	70.88	56.00	117.62	61.62	61.62		15.00	15.00	0.00
Dec	47.68	56.00	79.12	23.12	23.12		15.00	15.00	0.00
TOTAL	1018.79	672.00							69.92

Use of Total Rainwater [m³] (10)	647.08
--	---------------

→

88.40% (11)

Source: Author's own analysis

Steps of calculation:

- **(1):** Data from Instituto Nacional de Meteorología e Hidrología (INAMHI – Ecuador) for the pluviometric station of Quito closest to the case study.
- **(2):** Monthly consumption obtained in section 4.7.1.1. for non – potable uses.
- **(3):** $C \times P \times A \times \eta$ (C: Table 4.26; P: Table 4.28; A: Table 4.26; η :0.95)
- **(4):** (3) – (2)
- **(5):** 0 if (4) negative and greater than (6)
- **(6):** Volume adopted for the reservoir
- **(7):** Initial volume of the reservoir
- **(8):** = (7) if (5) = 0; (7) – (5) if (5) is positive
- **(9):** (4) – (7) or 0, if (2) < (3)
- **(10):** $\sum(2) - \sum(9)$
- **(11):** (10)/ $\sum(2)$

It is considered a volume of 15.00m³ for the reservoir, that for the calculations made, will allows to use 88.40% of the rainwater. It is guaranteed that the volume considered for the reservoir, may have water for non-potable uses for the Classroom Building and the Hydraulics Laboratory in the month of June, where monthly rainfall does not cover the demand for monthly consumptions of these buildings.

Table 4.29 explains the following:

- The demand for drinking water per month is 56.00 m³.
- The usable volume of monthly rainfall is the amount of water available to cover the 56.00 m³ demand.
- The negative values obtained in the "Difference" column represent the deficiency of rainwater to cover the demand of 56.00 m³.
- Therefore, if the three negative values (8.60, 36.25, 40.07) m³ are added, a reserve of 84.92m³ should be designed to guarantee that the 56.00m³ demand will be covered at 100% during all the months of the year. Economically and because of the space available in the study area, this option is impossible to accept.
- Only June with a deficit of 8.60 m³ can be covered by the help of the 15.00 m³ reserve, existing a volume in favor of 6.40 m³.
- For this reason, a small reserve of 15.00 m³ is adopted as the recommended by the Manual of Water Efficiency in Buildings of the ANQIP in its Annex 1 about the sizing of rainwater harvesting systems., which ensures the supply of rainwater to the system only for 10 months. That is to say, for July where there is a deficit of rainwater of 36.25 m³ and for August of 40.07 m³ there is no rain water supply because the reserve is empty. In the same way, these months are on vacation, which is why it is not necessary to consider the volume of water.
- For these reasons, the use of total rainwater is 88.40%.

4.7.2. System description and technical specifications

Figure 4.45 indicates the components that are part of the rainwater harvesting system. This scheme, conserves some elements like the roofs of the buildings, that are in good condition and are able to collect the required rainwater according to the calculation methodology. It is important to remember that this system in conjunction with the artificial pond, guarantee the volume of water required to meet the demands of water for non-potable consumptions in the Classroom Building and the Hydraulics Laboratory.

ROOFS AND DOWNSPOUTS: Currently, both buildings have a drainage system for rainwater that is collected on the roofs. However, the rainwater is conducted to a catch basin that is connected directly to the Faculty's sewer system. In other words, this alternative water source is wasted and is not used for any type of activity.

According to the inspection carried out, the water drainage system is made up of PVC pipes with a diameter of 110mm. For the Classroom Building, there are three downspouts that conduct rain water from the surfaces of the roofs that make up this building. In the case of the Hydraulics Laboratory, there is an experimental system with 110mm pipe that was installed by the students to collect the rainwater from the roof. However, the pipeline also carries the rainwater to the sewer system, as shows the Figure 4.44.



Figure 4.44 - Roof water drainage in the buildings of the case study

Source: Author’s own drawings

SELF-CLEANING RESERVOIR: While it is true and the roofs of both buildings allow a collection of rainwater for its waterproof characteristics, it is also important to ensure that the first volumes of rainwater are discarded due to the dirt that can accumulate on these surfaces: leaves, dust, and even feces of animals such as birds, cats, among others.

To achieve this goal, a system must be implemented to accommodate the first rainwater that may be contaminated. This will allow that once this system is filled, a relatively cleaner volume of rainwater can be used for the recirculation system that is going to be stored in the reserve structure. Even when rainwater will be used for non-drinking purposes, it must comply with this step of "treatment" to avoid possible risks to the health of users. It is important to remember that rainwater will be used for toilets and urinals, as well as for possible external uses.

There are two options for self-cleaning systems:

- **Self-cleaning Barrel:** Install a system that collects rainwater to perform self-cleaning of the roofs through a barrel that has a capacity of 50 liters according to Dacach (1990). This system will have a downpipe that conducts rainwater from the roof to the barrel. For the present study case, it is not considered appropriate to install barrels as a self-cleaning element, due to the number of students that circulate in the faculty and because it is not an aesthetic solution.
- **Self-cleaning reservoir with float valve:** This system contemplates the construction of a reinforced concrete reservoir that temporarily stores the water that represents the first flow of rain collected through the roofs of buildings. At the entrance of this reservoir a float valve is installed that allows to determine the maximum level of water that will be stored in this structure.

When the rainwater enters this reservoir, the water level begins to rise until it reaches the limit position producing the automatic closing of the float valve. At that time, the rainwater is prevented from entering to the self-cleaning reservoir and the remaining rainwater flow can pass directly to the rainwater reservoir designed according to the requirement.

According to Tomaz (2007) and other bibliographic sources, the volume of water required to perform the self-cleaning of roofs varies within the range of 0.40 l/m² to 1.50 l/m². For the present case, it is considered prudent to take as reference a value equivalent to 0.80 l/m². This will allow to establish the sizing of the self-cleaning reservoir built in reinforced concrete.

RAINWATER RESERVOIR: This component is designed according to rainwater collection areas (roofs and green areas), average rainfall in the region and monthly demands or consumptions that are part of the Classroom Building and the Hydraulics Laboratory.

The adopted reserve of 15m^3 , which was determined by means of Table 4.29, is considered to supply water for non-potable uses in both buildings during the month of June. Thanks to the incorporation of this system, it is guaranteed that 88.40% of the rainwater will be used as a supply for the buildings that are part of the case study.

The reservoirs become the components that require greater investment in this type of rainwater harvesting systems. Considering that the case study is located in a university area, it is important to ensure that this component will be installed under the ground and away from possible sources of contamination. Its installation will allow the water to be kept in a fresh state and to be totally isolated from the presence of ultraviolet rays.

In this case, it is specified that the reservoir is built of reinforced concrete and that its internal and external surfaces are completely smooth. It must be ensured that there is no influence of the sun on the stored fluid to prevent the growth of algae or microorganisms inside the structure. For the present case study, the use of prefabricated concrete elements that allow the structure to conform according to the dimensioning and design requirements is not ruled out. It is essential to disinfect these reservoirs before they become operational.

ARTIFICIAL POND: This option is considered within the design of the system because it allows the formation of a small pond located in the green zone of the Faculty. The case study provides a wide variety of natural depressions in these open areas. The objective of this component is to temporarily store storm water until it can be drained little by little to the 15m^3 tank. It is verified that the level of groundwater at the site where the pond will be located must be below the bottom of the pond. It is recommended the installation of a geomembrane that allows to guarantee the retention of the water in this artificial pond so that it can be used in the rainwater system.

For the sizing of this pond, it is necessary to know two design parameters: the volume of storage and the area considered for the pond. The advantage of these components, like the infiltration ponds, is that they do not require excessive depths for the temporary storage of

the rainwater fluid. For the design are considered: the contributing area that corresponds to this case, to the sum of the impermeable surfaces that drain to the pond and to the area of the pond on which the rainwater is directly received. A value of 0.50 has been considered as a runoff coefficient according to the vegetation and grass of the area.

One of the advantages of this pond is that it allows reducing the maximum volume of surface runoff and the volume of rainwater that reaches the main drainage networks, thereby reducing the risk of flooding downstream. As a result, costs can also be reduced since relief is given to current drainage systems, preventing them from collapsing.

Another advantage is that, when the pond has a small area compared to the contributing area, it can cause the incoming water to be retained for longer periods of time. Thus, the growth of algae and vegetation on this surface is controlled and limited.

RAINWATER PIPELINES: It corresponds to the sizing of the pipe that will lead the rainwater stored in the artificial pond towards the reserve structure. For this, it is thought to use PVC pipe with spigot - bell union with diameters of 160, 90 and 20 mm. This pipeline will be installed from the outlet of the artificial pond to the entrance of the reserve tank, so that the water can be conducted to the plumbing system of the building through the pumping equipment.

PUMPING SYSTEM: This equipment will be used to pump the water stored in the 15m³ reserve to all the sanitary facilities of the two buildings with a power of 0.5HP each pump. Its design will be based on the length of pumping for each building and the water demand required for non-potable uses.

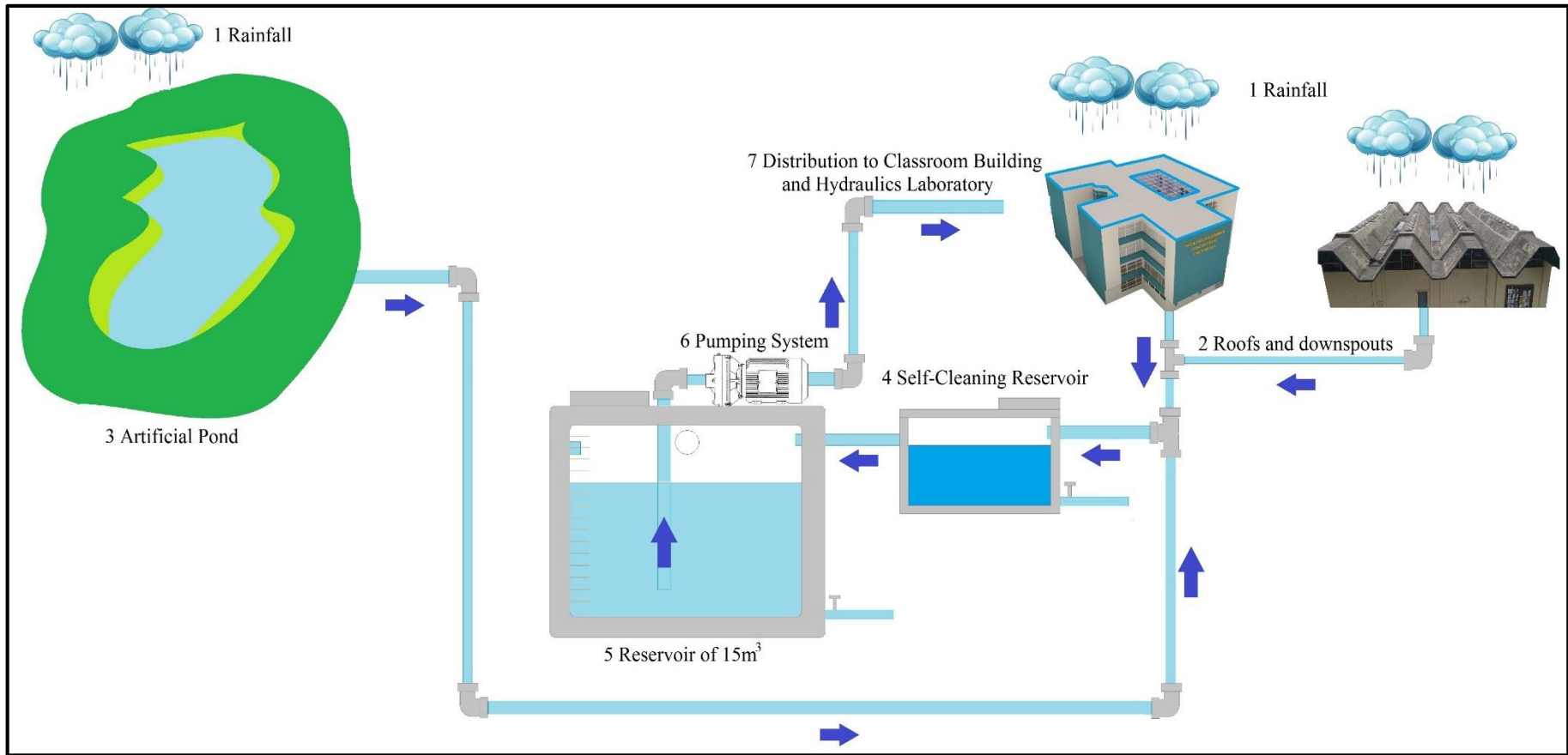


Figure 4.45 - Scheme and operating process of the designed system

Source: Author's own drawings

4.7.3. Design of new components

The design of the new components are made based on the consumption determination and the rainwater requirement to meet the current water demand for non-potable consumptions.

4.7.3.1. PVC Pipelines for rainwater

Currently the downpipes formed by PVC pipes lead rainwater directly to a catch basin in the case of the Classroom Building and to the drainage system directly in the case of the Hydraulics Laboratory. The idea of the present design is to bring the rainwater to the self-cleaning reservoir, therefore, it is important to design the pipe according to the flow that will be transported.

The Intensity, Duration and Frequency equations are also necessary for the pluviometric station that is closest to the case study in Quito. Based on these equations given by the Table 4.30, a return time (RT equal to 5 years) and a duration of 5 minutes will be taken into account.

Table 4.30 - Intensity, Duration and Frequency equations for M0024 pluviometric station

INTENSITY, DURANTION AND FREQUENCY EQUATIONS				
Station	Time interval (minutes)	Equation	R	R ²
Iñaquito M0024	5 < 30	$i = 141.7719 \times T^{0.2071} \times t^{-0.38044}$	0.9896	0.9794
	30 < 120	$i = 418.754 \times T^{0.2196} \times t^{-0.7210}$	0.9864	0.9729
	120 < 1440	$i = 1276.807 \times T^{0.1681} \times t^{-0.9297}$	0.9991	0.9983

Source: INSTITUTO NACIONAL DE METEOROLOGÍA E HIDROLOGÍA, (2018)

Therefore, the Maximum Intensity will be:

$$i = 141.7719 \times 5^{0.2071} \times 5^{-0.38044}$$

$$i = 107.26 \frac{mm}{h}$$

CLASSROOM BUILDING PIPELINES:

- Water catchment area = 970.10 m²
- Runoff coefficient = 0.90
- Maximum Intensity = 107.26 mm/h
- Max. speed for PVC pressure pipes = 4.5 m/s (Standard CO 10.07 601 – Ecuador)
- Roughness coefficient = 140 (PVC)
- Pipe diameter = 110mm or 160 mm (Adopted)
- Length = 80.00 m

For the calculation of the flow to be conducted from the catch basin to the self-cleaning reservoir it is important to apply the following equation:

$$Q_{CB} = \frac{A \times I \times C}{60}$$

[Equation 20]. Volumetric flow rate

$$Q_{CB} = \frac{970.10m^2 \times 107.26 \frac{mm}{h} \times 0.90}{60} = 1560.79 \frac{l}{min}$$

$$Q_{CB} = 26.01 \frac{l}{s}$$

The design of the driving line is made based on the following calculation equations:

$$J = \left[\frac{Q}{C \times 280 \times \left(\frac{Di}{1000} \right)^{2.63}} \right]^{1.85}$$

[Equation 21]. Head loss according with Hazen – Williams [m/m]

Where:

Q: Volumetric flow rate [l/s]

C: 140 (PVC pipes)

Di: internal diameter [mm]

$$H = L \times J$$

[Equation 22]. Loss of hydraulic load (m)

Where:

L: Length [m]

The speed is calculated according to the section of the pipe that is used. In this case it corresponds to a circular section.

$$s = \frac{Q}{A}$$

$$s = \frac{Q}{\pi \times \left(\frac{Di}{2}\right)^2}$$

[Equation 23]. Flow speed

Where:

Q: Volumetric flow rate [l/s]

Di: internal diameter [mm]

Table 4.46 shows the design for the rainwater pipe network from the catch basin to the self-cleaning reservoir. Carrying out the calculation process for a 160mm PVC pipe that is part of the commercial catalogs of Ecuador, the speeds are within the established range (0.45 m/s to 4.5 m/s) and as shown in Table 4.31, all the hydraulic design requirements established by the Ecuadorian standard for water pressure systems are met.

Table 4.31 - Design and sizing of PVC pipe from catch basin to the self-cleaning reservoir

HYDRAULIC CALCULATIONS FOR THE DRIVING OF RAINFALL FROM THE CHECK BOXES TO THE SELF-CLEANING RESERVOIR - PVC (160mm - 1.0MPa)														
SECTION	LENGTH (m)	ABSCSSA	V. FLOW (l/s)		DIAMETER (mm)		PRESSURE DROP		SPEED m/s	LEVEL (masl)		PRESSURE (m)		OBSERVATIONS
			SECTION		EXTERNAL	INSIDE	J (%)	H (m)		GROUND	PIEZOMETRIC	ESTATIC	DINAMIC	
DRIVING WATER FOR THE CLASSROOM BUILDING														
START		0								2,842.50	2,842.50	-	-	Check Box
	20.00		26.01	160	147.6	0.0146	0.29	1.520						
P1		20.00								2,841.15	2,842.21	1.35	1.06	1.0 MPa
	20.00		26.01	160	147.6	0.0146	0.29	1.520						
P2		40.00								2,841.00	2,841.92	1.50	0.92	1.0 MPa
	20.00		26.01	160	147.6	0.0146	0.29	1.520						
P3		60.00								2,840.90	2,841.63	1.60	0.73	1.0 MPa
	20.00		26.01	160	147.6	0.0146	0.29	1.520						
END		80.00								2,840.10	2,841.33	2.40	1.23	SC Reservoir

Source: Author's own design

Therefore, for the rainwater flow that is collected from the Classroom Building, a PVC pipe with a diameter equal to 160mm and a nominal working pressure of 1.0 MPa must be installed.

HYDRAULICS LABORATORY PIPELINES:

- Water catchment area = 137.60 m²
- Runoff coefficient = 0.90
- Maximum Intensity = 107.26 mm/h
- Max. speed for PVC pressure pipes = 4.5 m/s (Standard CO 10.07 601 – Ecuador)
- Roughness coefficient = 140 (PVC)
- Pipe diameter = 63 mm; 75mm or 90 mm (Adopted)
- Length = 80.00 m

For the calculation of the flow to be conducted from the catch basin to the self-cleaning reservoir it is important to apply the following equation:

$$Q_{CB} = \frac{A \times I \times C}{60}$$

[Equation 24]. Volumetric flow rate – Hydraulics Laboratory

$$Q_{CB} = \frac{137.60m^2 \times 107.26 \frac{mm}{h} \times 0.90}{60} = 221.38 \frac{l}{min}$$

$$Q_{CB} = 3.69 \frac{l}{s}$$

The same procedure is realized for this case:

With a diameter of 75 mm the dynamic pressure is positive but it is still small, for which a larger diameter is considered (90 mm), to guarantee a greater dynamic pressure at the entrance to the self-cleaning reservoir. Carrying out the calculation process for a 90mm PVC pipe that is part of the commercial catalogs of Ecuador, the speeds are within the established range (0.45 m/s to 4.5 m/s) and as shown in Table 4.32, all the hydraulic design requirements established by the Ecuadorian standard for water pressure systems are met.

Table 4.32 - Design and sizing of PVC pipe from catch basin to the self-cleaning reservoir

HYDRAULIC CALCULATIONS FOR THE DRIVING OF RAINFALL FROM THE CHECK BOXES TO THE SELF-CLEANING RESERVOIR - PVC (90mm - 1.0MPa)													
SECTION	LENGTH	ABSCISSA	V.FLOW (l/s)	DIAMETER (mm)		PRESSURE DROP		SPEED	LEVEL (masl)		PRESSURE (m)		OBSERVATIONS
	(m)			SECTION	EXTERNAL	INSIDE	J (%)		H (m)	m/s	GROUND	PIEZOMETRIC	
DRIVING WATER FOR THE HYDRAULICS LABORATORY													
START		0							2,842.55	2,842.55	-	-	Check Box
	20.00		3.69	90	83	0.0065	0.13	0.682					
P1	20.00	20.00							2,841.18	2,842.42	1.37	1.24	1.0 MPa
	20.00		3.69	90	83	0.0065	0.13	0.682					
P2	40.00								2,841.18	2,842.29	1.37	1.11	1.0 MPa
	20.00		3.69	90	83	0.0065	0.13	0.682					
P3	60.00								2,841.25	2,842.16	1.30	0.91	1.0 MPa
	20.00		3.69	90	83	0.0065	0.13	0.682					
P4	80.00								2,840.35	2,842.03	2.20	1.68	1.0 MPa
	2.00		3.69	90	83	0.0065	0.01	0.682					
END		82.00							2,840.10	2,842.02	2.45	1.92	SC Reservoir

Source: Author's own design

Therefore, for the rainwater flow that is collected from the Classroom Building, a PVC pipe with a diameter equal to 90mm and a nominal working pressure of 1.0 MPa must be installed.

4.7.3.2. Sizing of Artificial Pond

Table 4.29 allows to determine the usable volume of monthly rain, for the sizing of the rainwater reservoir. However, to design the artificial pond it is important to carry out the breakdown of the volume of water generated by the contribution of the pond itself and of the roofs considered. In this way it is possible to obtain the maximum value of rainwater volume that would be stored and for which, will be calculated the height of the pond.

Therefore, the contributions of each component are calculated in the same way, only that in this time the volume of rainwater is calculated with the runoff coefficient and the area considered for each case separately. That is, it is not considered a weighted coefficient.

$$Q = \frac{A \times I \times C}{1000}$$

[Equation 25]. Volumetric flow rate (m³)

HEIGHT FOR THE ARTIFICIAL POND:

- Water catchment area = 1500.00 m² (Adopted)
- Runoff coefficient = 0.50 (Green area)
- Water efficiency of filtration = 0.95

Table 4.33 shows the contribution values for each component considered within the design of the rainwater harvesting system. It can be verified that the sum of the volumetric flows of both components coincides with the usable volume of monthly rain of Table 4.29.

Table 4.33 - Design and sizing of PVC pipe from catch basin to the self-cleaning reservoir

CONTRIBUTION OF VOLUMETRIC FLOW PER COMPONENT			
Month	Contribution of the artificial pond	Contribution of the roofs	Usable volume of monthly rain
	(m ³)	(m ³)	(m ³)
Jan	81.07	107.76	188.83
Feb	81.11	107.81	188.92
Mar	123.50	164.16	287.66
Apr	105.62	140.40	246.02
May	95.99	127.59	223.58
Jun	20.35	27.05	47.40
Jul	8.48	11.27	19.75
Aug	6.84	9.09	15.93
Sep	33.43	44.44	77.88
Oct	85.04	113.03	198.07
Nov	50.50	67.12	117.62
Dec	33.97	45.15	79.12

Source: Author's own design

Therefore, and considering that the maximum volume that the artificial pond can contribute to the rainwater harvesting system is 123.50m³, it should be dimensioned for this parameter.

$$H_{AP} = \frac{V_{STORAGE}}{A_{POND}}$$

[Equation 26]. Height of artificial pond (m)

$$H_{AP} = \frac{123.50m^3}{1500m^2}$$

$$H_{AP} = 0.08m$$

However, this height is very small and increases the costs in the construction of such a large artificial pond. For this reason, the drainage area of 1500 m² is conserved, but the pond area is reduced. Considered that a shallow value for the water height would be about 0.5 m, the pond area is established.

$$A_{POND} = \frac{V_{STORAGE}}{H_{AP}}$$

$$A_{POND} = \frac{123.50m^3}{0.55m}$$

$$A_{POND} = 224.55m^2$$

As it is verified, one of the advantages of this component is that it does not require great depths to fulfill its function. For constructive reasons, it is important to add more height to locate a kind of curbstone with coarse aggregate to improve its aesthetics and to be able to hold the geomembrane on the edges of the artificial pond.

PIPELINE FROM THE ARTIFICIAL POND TO THE SELF-CLEANING RESERVOIR:

Considering that the water stored in the pond should be led to the self-cleaning reservoir gradually and that the pumping system will pump daily the volume that is required to cover the monthly consumption demand, it should be determined how much water is required from this pond in a day to supply this resource to non-potable uses of buildings. Therefore:

- Contribution of artificial pond (maximum per year) = 123.50m³
- Working month: 22 days are taken into account due to the fact that, weekends are deducted (Saturday and Sunday) because they are not considered as days in which there is water consumption in the facilities that are part of the case study

For the calculation of the flow to be conducted from the artificial pond to the self-cleaning reservoir daily, the following conversion is applied:

$$123.50 \frac{m^3}{month} \times \frac{1month}{22days} = 5.614 \frac{m^3}{day}$$

Considering that 14 hours form the student day in the university, it is important to assume that one day is equivalent to this data, because only during this period there will be consumptions of non-potable water in the buildings.

$$5.614 \frac{m^3}{day} \times \frac{1day}{14hours} \times \frac{1hour}{3600s} \times \frac{1000l}{1m^3} = 0.111 \frac{l}{s}$$

$$Q_{AP} = 0.111 \frac{l}{s}$$

The same procedure is realized for this case:

- Maximum flow = 0.111 l/s
- Max. speed for PVC pressure pipes = 4.5 m/s (Standard CO 10.07 601 – Ecuador)
- Roughness coefficient = 140 (PVC)
- Pipe diameter = 63 mm; 75mm or 90 mm (Adopted)
- Length = 40.00 m

Carrying out the calculation process for a 20mm PVC pipe that is part of the commercial catalogs of Ecuador, the speeds are within the established range (0.45 m/s to 4.5 m/s) and as shown in Table 4.34, all the hydraulic design requirements established by the Ecuadorian standard for water pressure systems are met.

Table 4.34 - Design and sizing of PVC pipe from catch basin to the self-cleaning reservoir

HYDRAULIC CALCULATIONS FOR THE DRIVING OF RAINFALL FROM THE ARTIFICIAL POND TO THE SELF-CLEANING RESERVOIR - PVC (20mm - 1.25MPa)														
SECTION	LENGTH	ABSCISSA	V. FLOW (l/s)		DIAMETER (mm)		PRESSURE DROP		SPEED	LEVEL (masl)		PRESSURE (m)		OBSERVATIONS
	(m)		SECTION	EXTERNAL	INSIDE	J (%)	H (m)	m/s		GROUND	PIEZOMETRIC	ESTATIC	DINAMIC	
DRIVING WATER FOR THE ARTIFICIAL POND														
START		0								2,844.67	2,844.67	-	-	Artificial Pond
	20.00		0.11	20	17.8	0.0177	0.35	0.446						
P1		20.00								2,842.51	2,844.32	2.16	1.81	1.25 MPa
	20.00		0.11	20	17.8	0.0177	0.35	0.446						
END		40.00								2,840.10	2,843.96	4.57	3.86	SC Reservoir

Source: Author's own design

Therefore, for the rainwater flow that is collected from the Artificial Pond, a PVC pipe with a diameter equal to 20 mm and a nominal working pressure of 1.25 MPa must be installed.

4.7.3.3. Artificial Pond Architecture

It is very important that the artificial pond contributes with a high aesthetic value to the zone, especially that it is in harmony with the environment that exists in the area planned for its construction. Its architectural conception should pursue to enhance this space by implementing irregular shapes that allow playing with the landscape without altering it and without falling into an excess of simplicity. The proposal is the detailed in the Figure 4.46 and the dimensions of the artificial pond detailed in Figure 4.47, guarantee an area of 225m².



Figure 4.46 - Artificial Pond Architecture

Source: Author's own drawings and design

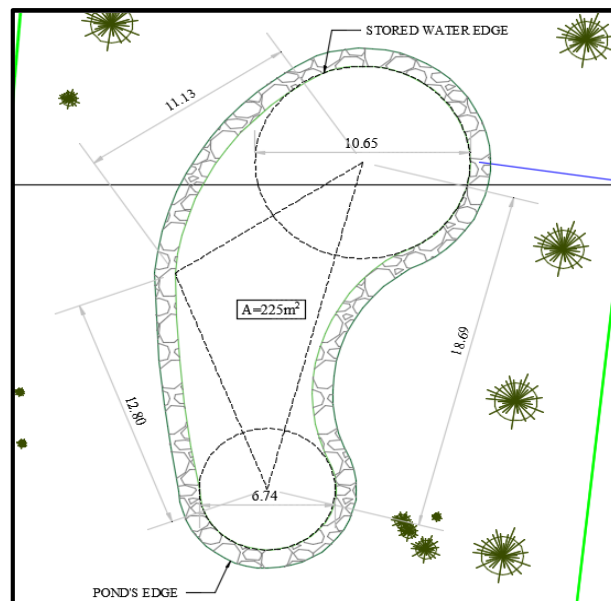


Figure 4.47 - Design of artificial pond

Source: Author's own drawings and design

At the end of the analysis of the design proposal it is established as necessary that the waters collected by the roofs that are not used for the water supply to the buildings also reach the artificial pond. This measure guarantees that the artificial pond will always be full and that, due to its shallow height, it does not represent a risk for people. Its architectural design creates a pleasant space around it.

The sum of the third column of values in Table 4.35 shows the amount of water that reaches the artificial pond and the roofs during the year. Considering that the demand of water for non-potable uses per year is 672 m³, then the reserve volume of this element can be established.

Table 4.35 – Analysis of water amount

ANALYSIS OF WATER AMOUNT						
Month	Contribution of the artificial pond	Contribution of the roofs	Usable volume of monthly rain	Monthly Consumption	Difference	Accumulated reserve volume of the pond
	(m ³)	(m ³)	(m ³)	(m ³)	(m ³)	(m ³)
Jan	81.07	107.76	188.83	56.0	132.83	132.83
Feb	81.11	107.81	188.92	56.0	132.92	265.74
Mar	123.50	164.16	287.66	56.0	231.66	497.40
Apr	105.62	140.40	246.02	56.0	190.02	687.42
May	95.99	127.59	223.58	56.0	167.58	855.00
Jun	20.35	27.05	47.40	56.0	-8.60	846.40
Jul	8.48	11.27	19.75	56.0	-36.25	810.15
Aug	6.84	9.09	15.93	56.0	-40.07	770.08
Sep	33.43	44.44	77.88	56.0	21.88	791.95
Oct	85.04	113.03	198.07	56.0	142.07	934.03
Nov	50.50	67.12	117.62	56.0	61.62	995.65
Dec	33.97	45.15	79.12	56.0	23.12	1018.77
TOTAL	725.89	964.88	1690.77	672.00		

Source: Author's own design

Thus:

- **Volume of artificial pond:**

$$V_{AP} = A_{POND} \times H_{POND}$$

$$V_{AP} = 225m^2 \times 0.55m = 123.75m^3$$

- **Reserve volume of artificial pond per year:**

$$V_{R(AP)} = 1690.77m^3 - 672.00m^3$$

$$V_{R(AP)} = 1018.77m^3/year$$

This volume represents the rainwater reserve of the artificial pond in order to cope with the fluctuations of precipitation and consumption.

4.7.3.4. Self-cleaning reservoir

According with the volume of water required to perform the self-cleaning of roofs established in the previous section (Description and Technical Specifications) and the total water catchment area of the buildings, the structure in reinforced concrete is dimensioned. Therefore, the volume of the self-cleaning reservoir is:

$$V_{SCR} = 0.80 \frac{l}{m^2} \times 1107.70m^2$$

$$V_{SCR} = 886.16l$$

$$V_{SCR} = \mathbf{0.89m^3}$$

Therefore, a base of 1 meter wide and 1 meter long is considered for this reservoir. Depending on the useful area, then at least a height of 0.89 meters will be required to consider the first flush of rain as discarded. Once the water inside the self-cleaning reservoir reaches this level, it will enter through a PVC pipe that will lead the water to the reserve tank of 15m³. However, considering that there must be at least 30 to 40 centimeters free at the maximum water level and the lower surface of the reservoir cover, the following value is given as height:

$$H_{SCR} = \text{MAXIMUM RAINWATER LEVEL} + \text{FREE HEIGHT}$$

$$H_{SCR} = 0.89m + 0.40m$$

$$H_{SCR} = 1.29m$$

$$H_{SCR} = \mathbf{1.30m (Adopted)}$$

To treat the sediments that may come from the artificial pond, special constructive considerations will be taken into account to filter the stored water before it reaches the self-cleaning reservoir. It is recommended to review the detail plans.

Using a wall thickness of 20 centimeters, Figure 4.48 shows the final design of this component.

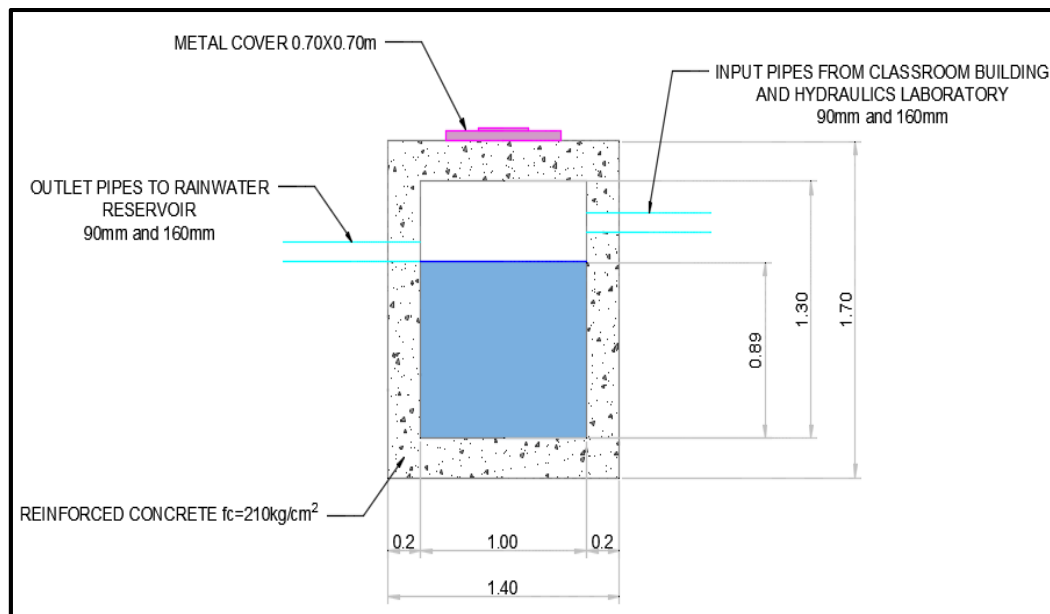


Figure 4.48 - Self – cleaning reservoir

Source: Author's own drawings and design

4.7.3.5. Rainwater Reservoir

According to the options of the dimensions that the rainwater reserve tank could have as shows the Table 4.35, it is established that the most suitable sections depending on the space available and the control with respect to the height of the tank to avoid the increase of reinforcing steel, are around 1.65 to 1.70 meters.

The square section of a tank is very convenient when the storage volume is not very high, due to the considerations that must be taken on the reinforcing steel especially in the four corners of the walls that make up the tank. The circular section, on the other hand, admits a single steel mesh that can be installed along the perimeter since this section is continuous and does not have corners. In addition, it is more suitable for cleaning and maintenance activities. For this reason, the following internal dimensions are adopted in order to store a volume of 15m³:

- Section: circular
- Radius = 1.70 m
- Maximum rainwater level = 1.65 m

Table 4.36. Sizing of the rainwater tank

SIZING OF THE RAINWATER RESERVE TANK			
Height	Square Section		Circular Section
	L	W	R
(m)	(m)	(m)	(m)
1.50	2.50	4.00	1.78
1.55	2.60	3.72	1.76
1.60	2.70	3.47	1.73
1.65	2.80	3.25	1.70
1.70	2.90	3.04	1.68
1.75	3.00	2.86	1.65
1.80	3.10	2.69	1.63
1.85	3.20	2.53	1.61
1.90	3.30	2.39	1.59
1.95	3.40	2.26	1.56
2.00	3.50	2.14	1.55
2.05	3.60	2.03	1.53
2.10	3.70	1.93	1.51
2.15	3.80	1.84	1.49
2.20	3.90	1.75	1.47
2.25	4.00	1.67	1.46

Source: Author's own design

However, it is important to add safety heights between the lower edge of the upper slab of the tank and the maximum level of rainwater. Therefore, its final height is as follows:

$$H_R = \text{MAXIMUM RAINWATER LEVEL} + \text{FREE HEIGHT} + 2(\text{WALL THICKNESS})$$

$$H_R = 1.65 + 0.40 + 2 \times (0.20)$$

$$H_R = 2.45m$$

Figures 4.49 and 4.50 respectively show the design in top view and front view of the reserve tank for the rainwater harvesting system. As it is observed, its section is circular and has a catch basin where the pipes that collect the waters of the roofs of the buildings and the artificial pond arrive. It is also foreseen the installation of a pipe to drain the tank when there is an excess of water inside, ensuring that there is no overflow of water through the metallic cover. The installation of a stainless steel ladder system for cleaning and maintenance activities is essential, so that at least one person can descend to the bottom of the tank and perform periodic inspections.

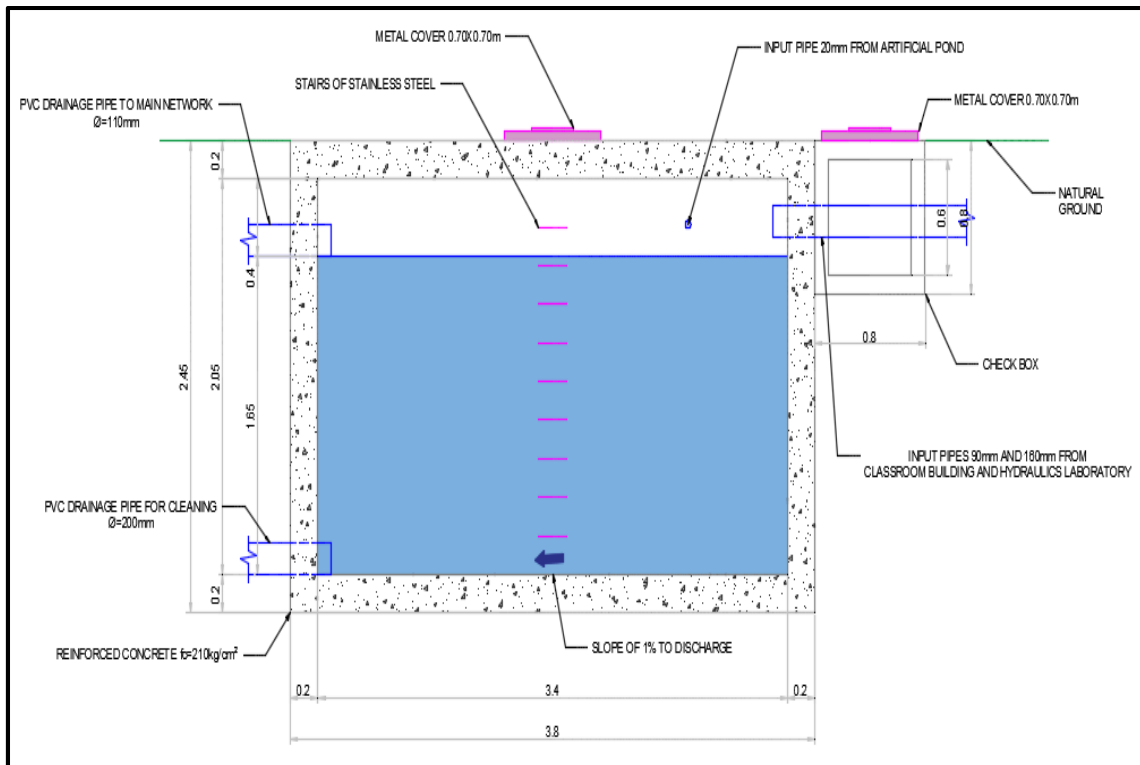


Figure 4.49 - 15m^3 Rainwater Tank - Elevation View

Source: Author's own drawings and design

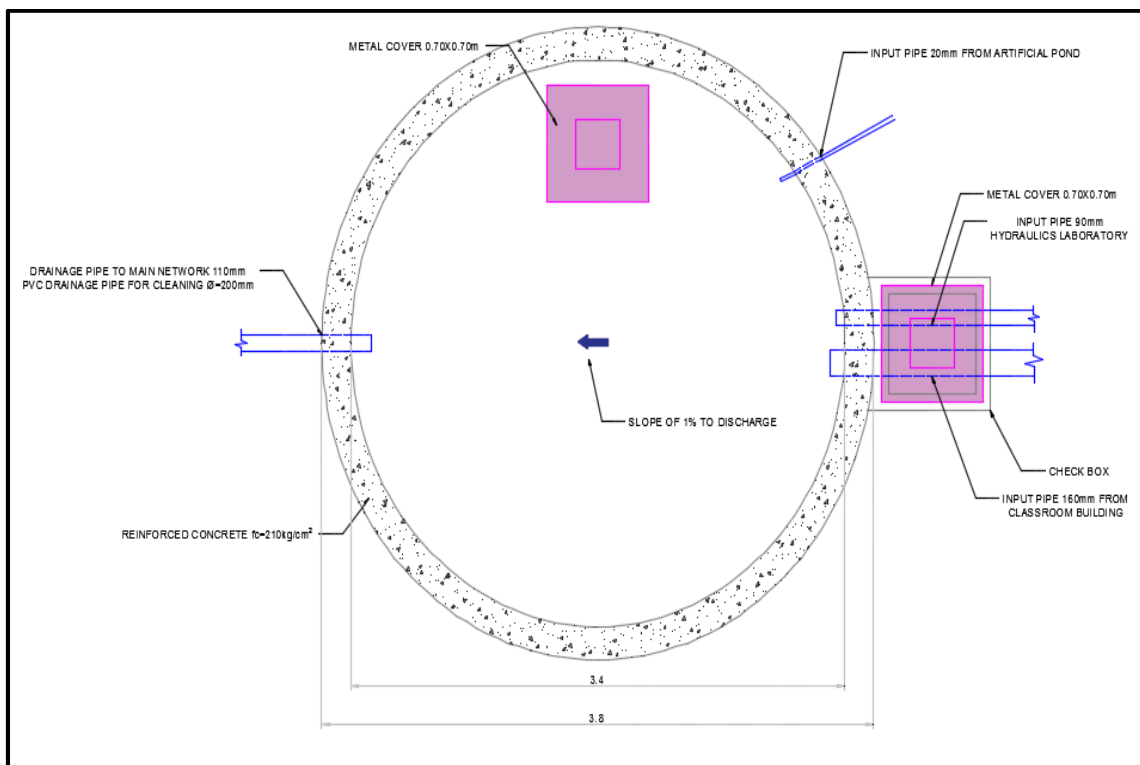


Figure 4.50 - 15m^3 Rainwater Tank – Top View

Source: Author's own drawings and design

4.7.3.6. Pumping System

For the calculation of the pumping system, two procedures are performed. The first of them, in which the losses of water are discarded by the pipe and the accessories where the installation of a PVC pipe of 32mm of nominal diameter is assumed.

The second process considers the design of a pumping system taking into account the losses by pipe and accessories installed in the system with a galvanized steel pipe of 32mm diameter. For this, different types of abacus are used. In both cases the power of the pump is determined. The volumetric flow is calculated per second.

Volumetric Flow required per month = 61.0 m³

$$61.0 \frac{m^3}{month} \times \frac{1month}{22days} \times \frac{1day}{14hours} \times \frac{1hour}{3600s} = 5.5 \times 10^{-5} \frac{m^3}{s}$$
$$Q_{PUMPED} = 5.5 \times 10^{-5} \frac{m^3}{s}$$

1. PUMP'S POWER WITH A PVC PIPE LINE (HEAD LOSS IS DISCARDED)

- Volumetric Flow (Q) = 5.5 x 10⁻⁵ m³/s
- Total Pumping Height (H) = 17.38 m (reservoir position on the top of the building)
- Water density = 1000 kg/m³
- Gravity force = 9.81 m/s²

$$P = \rho \times g \times H \times Q$$

[Equation 27]. Required power of the pump [W]

$$P = 1000 \frac{kg}{m^3} \times 9.81 \frac{m}{s^2} \times 17.38m \times 5.5 \times 10^{-5} \frac{m^3}{s}$$
$$P = 9.38 \frac{Nm}{s} \approx 10W = \mathbf{0.013HP}$$

The power required for the pump is only 0.013 HP.

2. PUMP'S POWER WITH A GALVANIZED STEEL PIPE LINE (HEAD LOSS IS CALCULATED)

- Temperature = 20°C
- Water density = 1000 kg/m³
- Viscosity = 0.001003 kg/ms (for the temperature assumed)
- Material = Commercial Steel
- Pipe diameter = 32mm (nominal); 28.8mm (internal)
- Length of the pipe = 50.0 m
- Volumetric Flow (Q) = 5.5 x 10⁻⁵ m³/s
- Total Pumping Height (H) = 17.38 m
- Gravity force = 9.81 m/s²

2.1. Flow Speed

$$S = \frac{Q}{A}$$

[Equation 28]. Flow velocity inside the pipeline

$$S = \frac{Q}{\pi \times \frac{D^2}{4}}$$
$$S = \frac{5.5 \times 10^{-5} \frac{m^3}{s}}{\pi \times \frac{(0.0288m)^2}{4}}$$

$$s = 0.084m/s$$

2.2. Relative roughness

It must be entered with the diameter in inches of the pipe and intercept the curve of the material used, which in this case is commercial steel. The relative roughness is read on the vertical axis as shows the Figure 4.51. Therefore, the relative roughness is equal to **0.002**.

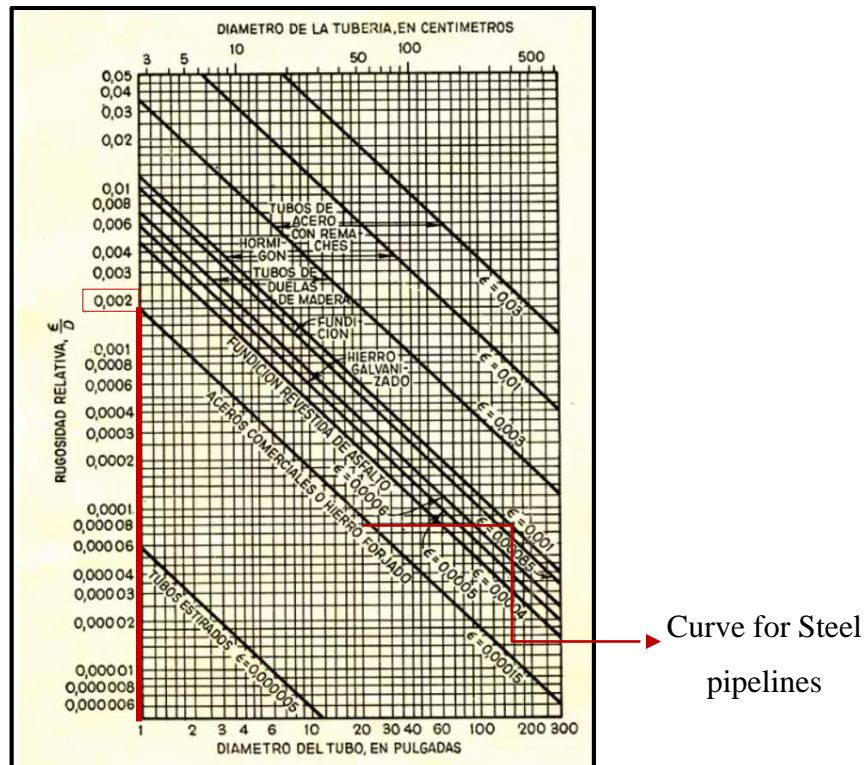


Figure 4.51 - Relative roughness ϵ/D

Source: Class notes (abacus) – Hydraulics Laboratory

2.3. Reynolds number

$$Re = \frac{s \times \rho \times D}{\mu}$$

[Equation 29]. Reynolds Number equation

$$Re = \frac{0.084 \frac{m}{s} \times 1000 \frac{kg}{m^3} \times 0.0288m}{0.0001003 \frac{kg}{ms}}$$

$$Re = 24119$$

2.4. Friction Coefficient

Figure 4.52 shows the process to determine the Reynolds number. The curve for the relative roughness calculated with the corresponding Reynolds number must be intercepted. The coefficient of friction f for the pipeline considered can be determined on the left side of the Moody diagram.

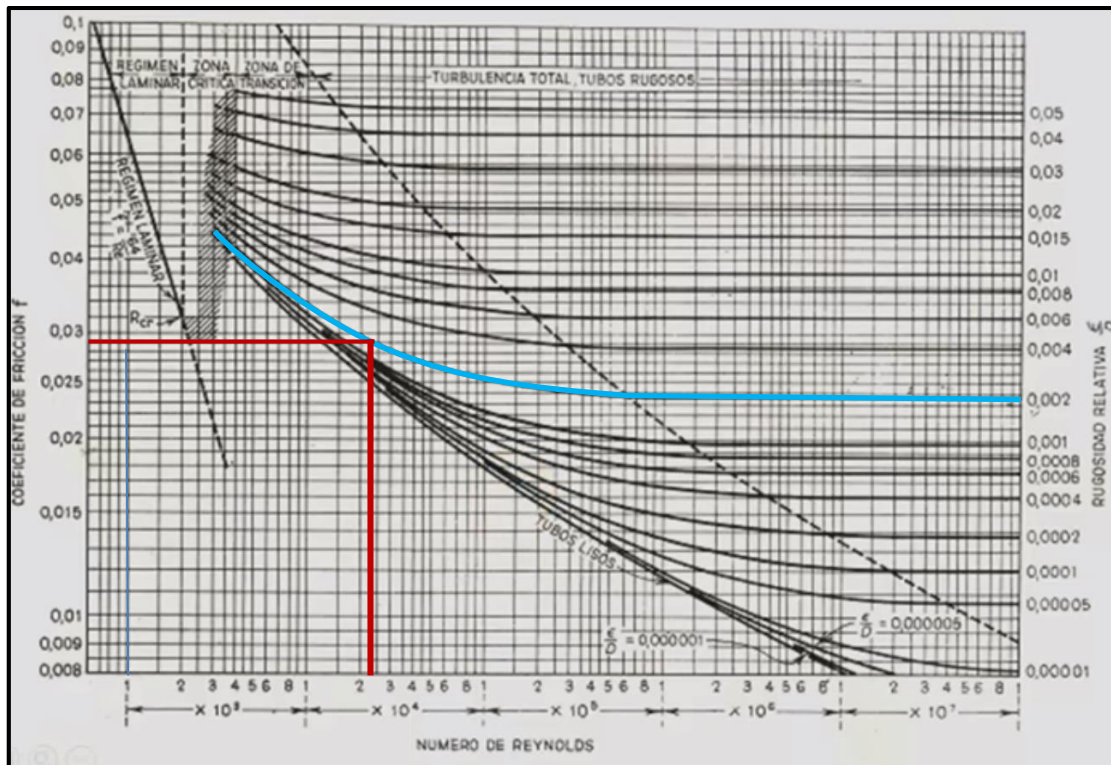


Figure 4.52 - Moody's diagram

Source: Class notes (abacus) – Hydraulics Laboratory

Therefore:

$$f = 0.029$$

2.5. Major Hydraulic Losses

Head loss calculated by the action of the water with the walls of the pipe and the friction generated between the contact.

$$h_f = f \times \frac{L}{D} \times \frac{S^2}{2g}$$

[Equation 30]. Pressure drop according Darcy-Weisbach

$$h_f = 0.029 \times \frac{50.0m}{0.0288m} \times \frac{\left(0.084 \frac{m}{s}\right)^2}{2 \times 9.81 \frac{m}{s^2}}$$

$$h_f = 0.019m$$

2.6. Losses due to expansion and contraction of the pipeline

- Coefficient K for narrowing = 0.50

$$h_N = K \times \frac{S^2}{2g}$$

[Equation 31]. Head loss due to narrowing effect (steel pipes)

$$h_N = 0.5 \times \frac{\left(0.084 \frac{m}{s}\right)^2}{2 \times 9.81 \frac{m}{s^2}}$$
$$h_N = 1.80 \times 10^{-4} m$$

- Coefficient K for broadening = 1.00

$$h_B = K \times \frac{S^2}{2g}$$

[Equation 32]. Head loss due to broadening effect (steel pipes)

$$h_B = 1 \times \frac{\left(0.084 \frac{m}{s}\right)^2}{2 \times 9.81 \frac{m}{s^2}}$$
$$h_B = 3.6 \times 10^{-4} m$$

2.7. Water losses due to the use of accessories

According to the plans and the established design of the whole system, three elbows and one check valve are required for the control of the water that is driven to the tank.

Based on the design abacuses, the head loss produced by the use of these accessories is determined.

It is necessary to draw a line from the right vertical axis where there are the diameters in inches of the pipes, which in this case is 0.0288m and extend it to the left axis, where the accessories to be used in the system are located. As shown the Figure 4.53, for the elbow the value of the equivalent length in water loss is equal to 2.0 meters.

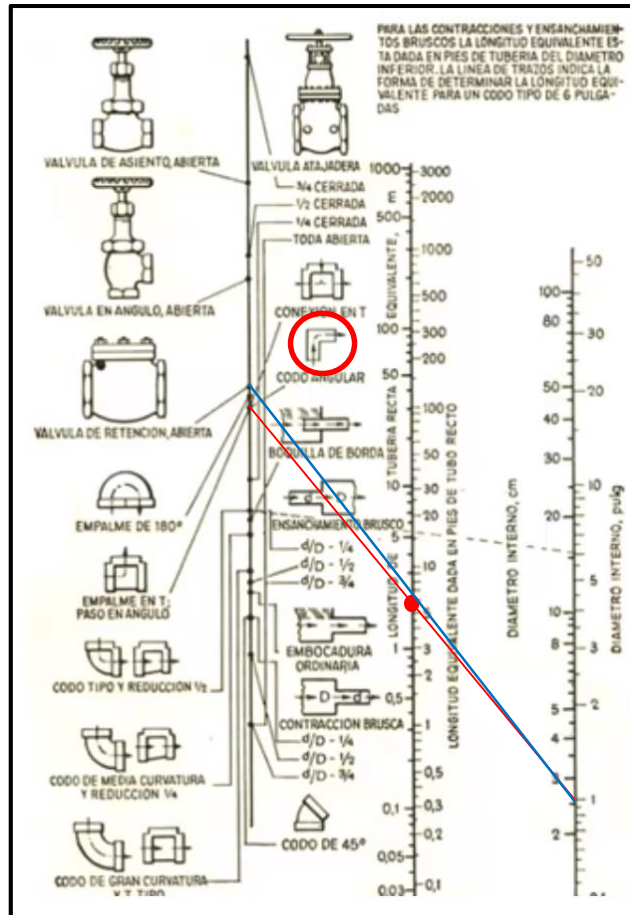


Figure 4.53 - Equivalent lengths depending on accessories

Source: Class notes (abacus) – Hydraulics Laboratory

According with the Figure 4.53:

- Steel elbow = 2.00m x 3 = 6.00m
- Check valve = 2.60m x 1 = 2.60m
- Total equivalent length = 8.60 m

$$h_a = f \times \frac{\sum L_{eq}}{D} \times \frac{S^2}{2g}$$

[Equation 33]. Pressure drop due to accessories

$$h_a = 0.029 \times \frac{8.60m}{0.0288m} \times \frac{\left(0.084 \frac{m}{s}\right)^2}{2 \times 9.81 \frac{m}{s^2}} = 3.11 \times 10^{-3}m$$

2.8. Total head loss of the pumping system

The sum of all the losses calculated will be the determined value for the hydraulic losses of this system.

$$\begin{aligned}h_T &= h_f + h_N + h_B + h_a \\h_T &= 0.019m + 1.80 \times 10^{-4}m + 3.6 \times 10^{-4}m + 3.11 \times 10^{-3}m \\h_T &= 0.02265m \\h_T &= \mathbf{0.03m}\end{aligned}$$

As it is verified, the value of losses in the system is minimal.

2.9. Dynamic height according to Bernoulli

$$h_D = \Delta Z + \frac{\Delta S^2}{2g} + \frac{\Delta P}{\gamma} + h_T$$

[Equation 34]. Dynamic Height

$$\begin{aligned}h_D &= 17.38m + \frac{(0^2 - 0.084^2) \frac{m^2}{s^2}}{2 \times 9.81 \frac{m}{s^2}} + \frac{0.17 \times 101 \times 10^3 Pa}{9810 \frac{kg}{m^2 s^2}} + 0.03 \\h_D &= \mathbf{19.16m}\end{aligned}$$

2.10. Calculation of Pumping Power

$$P = \rho \times g \times H \times Q$$

$$\begin{aligned}P &= 1000 \frac{kg}{m^3} \times 9.81 \frac{m}{s^2} \times 19.16m \times 5.5 \times 10^{-5} \frac{m^3}{s} \\P &= 10.33 \frac{Nm}{s} = 10.33W = \mathbf{0.014HP}\end{aligned}$$

The power required for the pump is only 0.014 HP. Both values are practically the same and are very small. This indicates that pumps with minimum power (0.50HP) must be used for the Classroom Building and for the Hydraulics Laboratory. It is not worth repeating the calculation process for the Hydraulics Laboratory because the pumping height is lower and therefore the result of the pump's power will also be lower. It is enough to consider two pumps of 0.5HP for each building.

5. Conclusions

In fact, this research work suggests an integral solution for improving the water efficiency of the Classroom Building and the Hydraulics Laboratory located in the Faculty of Engineering, through the evaluation of their hydro-sanitary systems, certification and labeling of its water performance. The Classroom Building attains a category “A⁺” and the Hydraulics Laboratory a category equivalent to “C”, according with the proposed certification system with respect to the water endowment established by the Ecuadorian standard for university buildings. It is very satisfying to be able to reach these categories, taking into account that the buildings evaluated are quite old.

The present work allows to conclude that the methodology provided by the ANQIP can be applied successfully in Ecuador. This process is able to evaluate the water efficiency of buildings and design the rainwater harvesting system to supply an alternative water resource. Taking into account the rain regime in Quito, the advantages of implementing potable water systems that can be used to supply water for non-potable consumption are amplified. The scope may include consumptive uses, but it is important to establish treatment mechanisms for rainwater that do not harm the health of the users in this cases.

It is concluded according with Tables 4.17 and 4.23 that, mathematically the water efficiency of a non-residential building is not only linked to the number of users, but also to the efficiency of each sanitary device that is installed. As it was possible to verify, the Hydraulics Laboratory has old sanitary devices and although there are only 10 users, its water efficiency compared to the Classroom Building is lower. In both cases, the use of alternative water resources substantially improves their water performance, resulting in the reduction of drinking water consumption and the billing associated with the expenditure of this resource.

It is verified that the reduction of drinking water consumption is obtained through the design of a rainwater use system that is composed of different hydraulic and architectural elements. Its effect on the current sanitary facilities, produces a reduction of 31% of the consumption of potable water, which is supplied by the system of use of rainwater for non-potable uses

(urinals and toilets). This reduction in drinking water consumption translates into a benefit in billing and water expenditure of 45.04% due to the demand of both buildings.

Eco-efficient health devices are very important in the installation of buildings to improve their water efficiency. However, this type of solution is not enough as can be established for the Classroom Building. It is important to consider the implementation of rainwater harvesting systems, gray water reuse systems, wastewater treatment systems, construction of green roofs, renovation of pipe networks, change of the obsolete fixtures and identification of water losses. The joint analysis of these alternatives will substantially increase the water efficiency of the building and therefore the system that is part of the solution.

Rainwater harvesting systems have a promising potential in the countries of the region. Thanks to the geographical location of Ecuador and its climatic conditions, it is possible to guarantee the efficiency of these systems as an alternative water resource. The obstacles that may arise are related to the scarcity of codes, regulations or standards that verify the water efficiency of buildings and that control the responsible use of water.

The volume of water that is collected through the roofs and the green areas that are next to the study buildings, considerably reduces the possibility of floodings. The rainwater harvesting system considers a 123.75 m³ artificial pond and a reservoir of 15m³ to temporarily store rainwater before driving it through the networks to the hydro sanitary facilities of the buildings. This system alleviates and reduces the work of the current drainage systems that, due to their age, collapse when the rains are of high intensity.

The design of the artificial pond complements the collection of rainwater from the roofs and does not transgress the natural environment of the green spaces of the study area. This solution becomes a nice aesthetic complement necessary for the area.

The design of the artificial pond complements the collection of rainwater from the roofs and does not transgress the natural environment of the green spaces. This solution becomes a pleasant complement that with the passage of time, can be extended and provide a greater volume of rainwater according to the growing demand for potable water in both buildings.

One of the great advantages of this alternative water supply system is that it does not require a complex water treatment package, because its function is to provide water for non-potable uses within buildings. However, with the passage of time, a small treatment and disinfection system can be installed allowing the proposal to be used as a potable water supply system. For the case study, the self-cleaning reservoir is the required component according on the contribution of both buildings roofs.

Water is an indispensable natural resource for the development of life. Its use must be responsible and all social, economic and scientific resources must be focused to guarantee its preservation. Water efficient solutions are part of the innumerable ways to provide future generations with drinking water.

No proposal or technical solution applied to the improvement of water efficiency can achieve results of positive impact, if there is no awareness of users around the world. South America must now be concerned about preserving its superficial and subterranean fresh water resources through permanent evaluation and audit systems that protect them. Each user is responsible for permanently practicing actions that are within the 5R principle, in order to guarantee their commitment with the environment and the natural resources that we still have.

The condition of renewable resources is currently uncertain. If high water efficiency systems are not established for buildings, homes and industries, the availability of fresh water for human consumption within the next few years will be drastically reduced. The moment to establish radical changes that motivate the application of sustainable projects is now and must start from educational establishments, where science should be the dynamo of change and the growth of water efficiency.

This document is a reference at a national level, of the calculation methodology applied on the basis of international studies, for the determination of water efficiency in non-residential buildings. The certification and labeling suggested, should be considered as a contribution to the development of a scientific system that allows to qualify our buildings and turn them into sustainable projects for the development of Ecuador. The example of a friendly change with the environment, should start at home, especially in the country that represents the center of our beautiful planet.

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7. Appendices

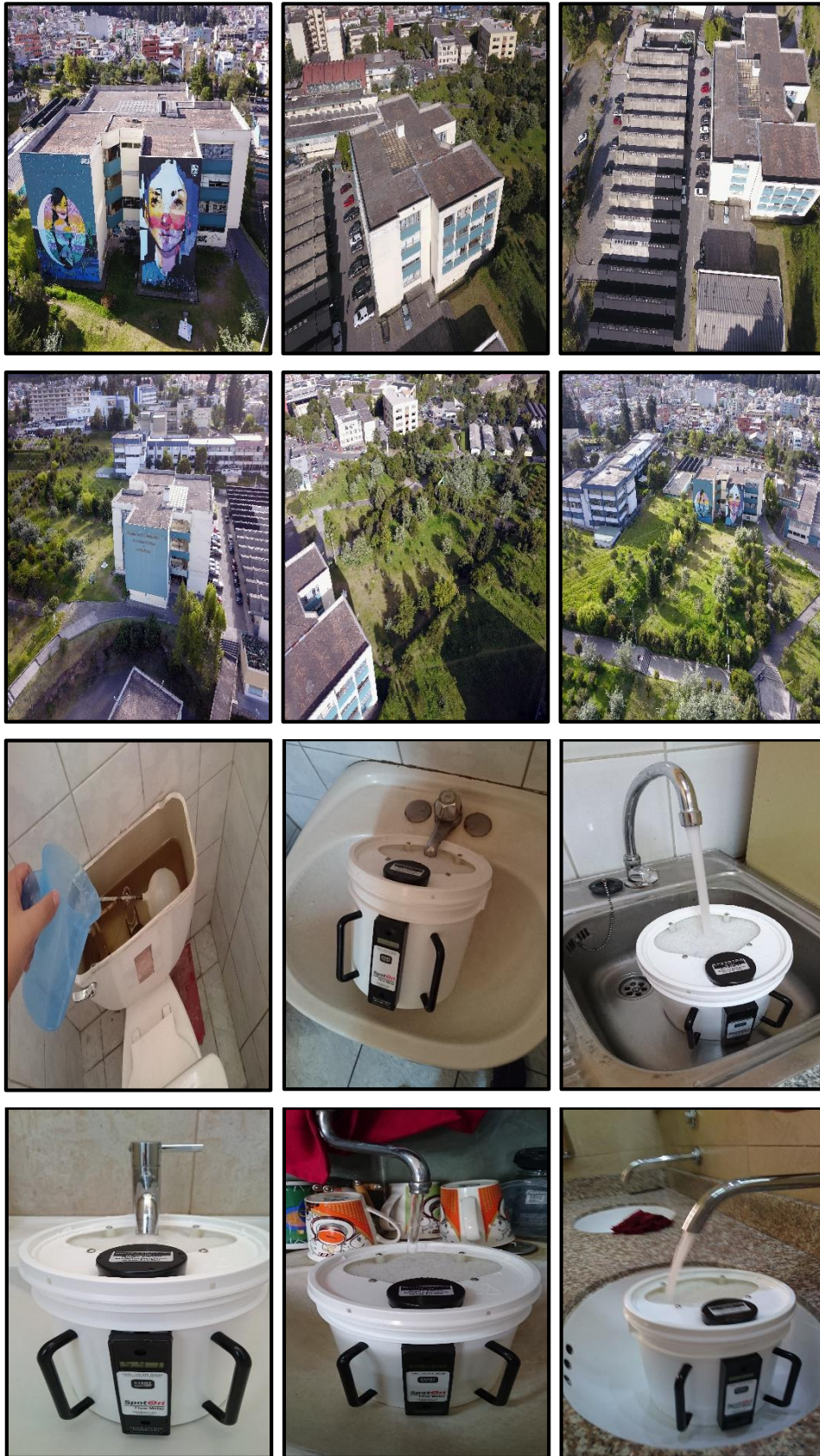
ANNEX 1: Tabulation of results on users in Classroom Building

THESIS ATTACHMENT WATER AUDIT IN BUILDINGS CHARACTERIZATION DATA SHEET			
Case Study:	BUILDING "A" - FING (U.C.E.)		
Tutor:	Ing. Ricardo Gomes PhD (Portugal); Ing. Freddy Muñoz MSc. (Ecuador)		
Responsible:	Ing. Carlos Andrés Valenzuela Portilla		
Place:	Facilities of Building A (Classrooms Faculty of Civil Engineering)		
City / Country:	Quito - Ecuador	Hours:	72 hours
Date:	2018-02-21 (Wednesday)	Data Sheet #:	U - R1
Assessment:	Sanitary Facilities Users		
RESULTS OF USERS			
1.- USERS BY GENDER			USERS OF SANITARY FACILITIES BY GENDER <p>Women 28.51%</p> <p>Men 71.49%</p> <p>■ Women ■ Men</p>
USER	TOTAL	%	
Women	65	28.51%	
Men	163	71.49%	
TOTAL	228	100.00%	
<p>The users who make the most use of the sanitary facilities on the ground floor are men, more than twice as many as women.</p>			
2.- USE OF DEVICES (WOMEN)			USE OF DEVICES BY WOMEN <p>100.00%</p> <p>50.00%</p> <p>0.00%</p> <p>Women 72.31% 0.00% 100.00%</p> <p>■ Toilet ■ Urinal ■ Faucet</p>
DEVICE	TOTAL	%	
Toilet	47	72.31%	
Urinal	0	0.00%	
Faucet	65	100.00%	
<p>72.31% of women use the sanitary device, while 100% of the sample washes their hands by activating the faucets.</p>			
3.- USE OF DEVICES (MEN)			USE OF DEVICES BY MEN <p>100.00%</p> <p>50.00%</p> <p>0.00%</p> <p>Men 5.52% 74.23% 100.00%</p> <p>■ Toilet ■ Urinal ■ Faucet</p>
DEVICE	TOTAL	%	
Toilet	9	5.52%	
Urinal	121	74.23%	
Faucet	163	100.00%	
<p>The use of toilets is reduced in the case of men, of course the urinals are the most used and 100% wash their hands after using.</p>			
<p>NOTE: The surveys were filled with the respective authorization of the Authorities of the Faculty. At no time was concerned with the privacy of users or with the activities that take place in the building.</p>			

ANNEX 2: Referential Budget according with materials and equipment in Ecuador

REFERENTIAL BUDGET					
QUANTITIES OF MATERIAL AND EQUIPMENT					
Item	Description	Unit	Quantity	Unit Value	Total Value
1 SELF-CLEANING RESERVOIR					
1.1	Topographic stakeout	m ²	2.00	\$ 0.84	\$ 1.68
1.2	Manual Excavation	m ³	3.50	\$ 4.53	\$ 15.86
1.3	Timber temporary shoring	m ²	14.00	\$ 6.13	\$ 85.82
1.4	Compaction with vibratory rammer	m ³	0.40	\$ 12.11	\$ 4.84
1.5	Simple concrete slab f c=180kg/cm2	m ³	0.20	\$ 68.75	\$ 13.75
1.6	Concrete f c = 210kg / cm2 for the walls of the reservoir	m ³	0.77	\$ 119.10	\$ 91.71
1.7	Electrowelded steel mesh 10mm 15X15	m ²	8.91	\$ 15.67	\$ 139.62
1.8	Plastering the walls of the tank with mortar thickness = 3mm	m ²	5.72	\$ 1.87	\$ 10.70
1.9	Metalic Cover 0.70X0.70m	U	1.00	\$ 75.00	\$ 75.00
SUBTOTAL 1					\$ 438.97
2 ARTIFICIAL POND					
2.1	Topographic stakeout	m ²	230.00	\$ 0.84	\$ 193.20
2.2	Mechanical excavation	m ³	135.00	\$ 4.18	\$ 564.30
2.3	Compaction with vibratory rammer	m ³	45.00	\$ 12.11	\$ 544.95
2.4	Geomembrane placement thickness = 1.2mm (31.5kN/m)	m ²	230.00	\$ 3.79	\$ 871.70
2.5	Laying of granular material on the edges of the pond D <15cm	m ³	22.50	\$ 17.50	\$ 393.75
SUBTOTAL 2					\$ 2,567.90
3 RAINWATER RESERVOIR 15m³					
3.1	Topographic stakeout	m ²	12.00	\$ 0.84	\$ 10.08
3.2	Mechanical excavation	m ³	28.99	\$ 4.18	\$ 121.18
3.3	Timber temporary shoring	m ²	28.35	\$ 6.13	\$ 173.79
3.4	Compaction with vibratory rammer	m ³	1.20	\$ 12.11	\$ 14.53
3.5	Simple concrete slab f c=180kg/cm2	m ³	11.34	\$ 68.75	\$ 779.63
3.6	Concrete f c = 210kg / cm2 for the walls of the reservoir	m ³	10.55	\$ 119.10	\$ 1,256.51
3.7	Electrowelded steel mesh 10mm 15X15	m ²	28.35	\$ 15.67	\$ 444.24
3.8	Plastering the walls of the tank with mortar thickness = 3mm	m ²	28.35	\$ 1.87	\$ 53.01
3.9	Metalic Cover 0.70X0.70m	U	1.00	\$ 75.00	\$ 75.00
SUBTOTAL 3					\$ 2,927.96
4 PUMPING SYSTEM					
4.1	Water Pump 0.5HP	U	2.00	\$ 73.88	\$ 147.77
4.2	PVC elbows 90°	U	3.00	\$ 7.81	\$ 23.43
4.3	Retention - Check valve	U	1.00	\$ 242.18	\$ 242.18
SUBTOTAL 4					\$ 413.38
5 PVC PIPE LINES (Buildings - Self Cleaning Reservoir - Reservoir - Pumping system)					
5.1	PVC D=160mm; 1.0MPa X 6m (Classroom Building to Reservoir L=81.53m)	U	14.00	\$ 11.13	\$ 155.87
5.2	PVC D=90mm; 1.0MPa X 6m (Hydraulics Laboratory to Reservoir L=92.70m)	U	16.00	\$ 10.00	\$ 160.00
5.3	PVC D=40mm; 1.25MPa X 6m (Hydraulics Laboratory to Reservoir L=40.00m)	U	7.00	\$ 4.79	\$ 33.54
5.4	PVC elbows 90°	U	2.00	\$ 7.81	\$ 15.62
5.5	PVC elbows 45°	U	8.00	\$ 5.96	\$ 47.67
5.6	Retention - Check valve	U	2.00	\$ 242.18	\$ 484.37
SUBTOTAL 5					\$ 897.06
TOTAL COST OF THE RAW WATER UTILITY SYSTEM					\$ 7,245.27
SEVENTHOUS AND TWO HUNDRED FOURTY-FIVE DOLLARS WITH 27/100					

ANNEX 3: Figures of architectural and hydro-sanitary characterization



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