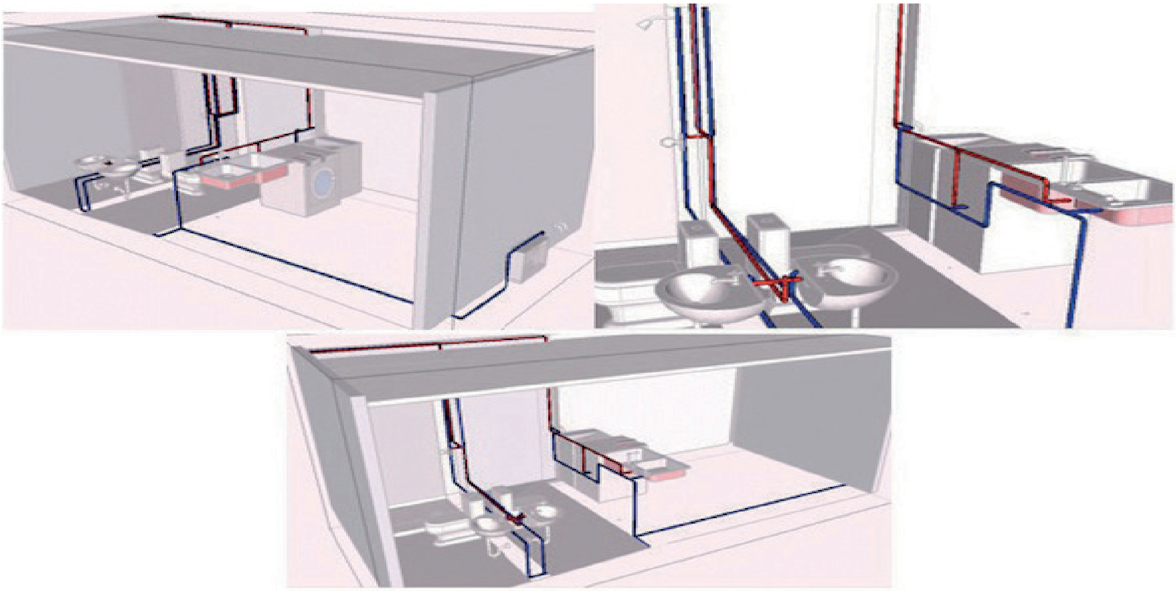
Chapter 2

# Water Management System




Daniel Mauricio González Naranjo[1]

Alejandro Beltrán Márquez[1]

Javier Eduardo López Giraldo[1]

Jeffer Steven Mosquera Castillo[1]

Juan Pablo Trujillo Chaparro[1]

Nicolás Noreña Leal[1]

Javier Ernesto Holguín González[2]

[1] Students of Environmental Engineering. Universidad Autónoma de Occidente.

[2] Engineering Faculty Staff. Universidad Autónoma de Occidente.

## System Design

In this project we considered the rational use of natural resources; therefore, our proposal is to have an integrated water management system that allows us to have sustainable solutions such us: (1) to reduce the consumption of drinking water; (2) to treat and to reuse the greywater for flushing the toilet; (3) rainwater exploitation. In the following section, the strategies for each element of the plumbing system design are described.

The plumbing system is composed by four main components:

- Water tanks: composed by 66 tanks (2 underground drinking water tanks, 2 underground greywater tanks, 60 elevated rainwater tanks and 2 underground rainwater tanks),
- Pumping system: composed by 6 pumps (2 for taking the water from the underground drinking water tanks to the utilities, 2 for taking the water from the underground rainwater tanks to the irrigation system and 2 for taking the water from the greywater tanks to the toilets),
- Conduction and discharge pipes (for hot and cold drinking water, rainwater, greywater and black water),
- Greywater treatment system and drinking water meters.

## Design Criteria

The criteria considered for using and reusing water was developed based on an objective, which is the adoption of alternative sources of water. In the following paragraphs a detailed description of the water storage tanks, and the plumbing system considered in the technical proposal for Mihouse project is presented.

**Water storage tanks – Rainwater.** In general, a rainwater exploitation system for domestic use should have three main sub-systems, a rainwater collection sub-system, an interceptor sub-system and a storage sub-system. These three main sub-systems are composed by several elements such as: a) roof's catchment, b) collection by gutters and downspouts, c) a first flush rainwater interceptor, d) storage tanks, e) a physical treatment unit and, f) a distribution system.

The use of rainwater in this project aims to satisfy the basic needs of the people living in these apartments related to the use of non-potable water (washing floors, watering of plants and so on). Our proposal consists of two elevated storage tanks which are located on top of the roofs and that will be fed by a system of gutters. The rainwater collected in these tanks is afterwards conducted to each apartment. Additionally, the water which is not collected in the storage tanks is drained to the 2 underground rainwater tanks.

The capacity of the two elevated storage tanks is 216 liters. Each of these tanks has the following dimensions: 0,30 cm high, 0,60 cm wide and 0,60 cm long. It should be emphasized that the storage capacity varies because part of the water can be stored along the pipeline or it can decrease due to evaporation of the water. The rainwater collected in these tanks is conducted by gravity to each apartment through a pipe of ½ inches and it may be supplied by a tap located 30 cm above the floor just below the sink and next to the laundry machine.

Each of the buildings has this exploitation system for the rainwater. This system will allow people to reduce water consumption. The total storage capacity associated with elevated tanks is about 6480 liters, distributed in 60 tanks, 2 tanks in each of the 30 buildings of the residential complex.

**Technical and Economic Factors.** From the technical perspective, it should be considered the water demand and the water availability, which is closely related to rainfall during the year and the seasonal variations of it. So, it is essential to work with the rainfall information provided by the competent authorities at the time of designing the catchment system. Moreover, due to the water demand and water availability by rainfall there is a direct relationship between supply and demand for water, which defines the size of the catchment area and the storage volume. Both considerations are intimately connected with the economic aspects, which may preclude access to a collection system of this type.

The implementation of a groundwater system involves knowledge about the type of soil, nearby sources of pollution, large machinery and infrastructure cost. Moreover, it is necessary a rational use of groundwater because an excess of demand could affect the natural ability of the system to recharge.

## System components

- Rainwater Catchment: The area where the project is located has a direct relation with the possible rainwater harvesting. The catchment system is implemented in the roofs of the buildings, by using gutters, tiles, etc.
- Interceptor and rainwater driver: It is a fundamental part of the system collecting rainwater, they are responsible for driving the collected water to the storage tank.

- Collection and conduction gutters: Gutters are accessories to collect and to conduct storm water runoff to a storage system; its dimensions are a function of the duration of precipitation (short and homogeneous), the water concentration time, the length of the passage area and its slope.

In a catchment area, the water concentration time is a fundamental parameter in the hydrological study of a watershed and runoff areas with slope. This time is described by mathematical expressions which, considering physical characteristics of the catchment area or basin, can provide a resultant hydrograph.

Below, are shown the equations for determining the gutter flow transported, depending on the precipitation time, draining and other factors:

1. In order to calculate the concentration time (*tc*), we used the Kirpich's formula:

$$t_c = 0.000325 * \frac{L^{0.77}}{S^{0.385}} \quad (1)$$

where: *S*: is the average slope; *L*: is the length of the catchment area in meters; *tc*: concentration time in hours.

2. Time in which the maximum runoff is reached in the basin or catchment area (*tp*):

$$t_p = 0.5 * D * 0.6t_c \quad (2)$$

where: *D* is the duration of effective rainfall in hours.

If the duration of daily maximum precipitation is unknown, the following equation is used:

$$t_p = 2\sqrt{t_c} + 0.6t_c \quad (3)$$

3. Concentration Time of the maximum flow (*tb*). It is estimated for draining all the surface runoff from impervious catchment area, it is estimated by the following equation:

$$t_b = 2.67t_p \quad (4)$$

4. The maximum Flow (*Qp*). The maximum flow expected to net precipitation in the draining area is estimated by the following expression:

$$Q_p = \frac{0.278 * P * A}{t_p} \tag{5}$$

where: *P* is the effective precipitation (mm); *A*: catchment area (km); 0278: conversion factor ($m^3$/s).

5. Estimation of the gutter area. The water that flows in the conduction gutters behaves as a spatially varied flow, because this water is gradually collected over of the gutter. In order to determine the required conducting area, we used the continuity equation, in which only the area is unknown and average speeds of 0,9 m/s on slopes 2-4 % and 1,2 m/s on slopes 4-6 % are assumed.

$$A = \frac{Q_p}{V} \tag{6}$$

where: *Qp*: channel flow ($m^3$ s); *V*: Gutter flow velocity (m s); *A*: cross sectional area ($m^2$).

6. Storage volume (*VA*). The required volume for storing rainwater (*VA*), is given by the difference between the accumulated rainwater available (*OA*) and the accumulated water demand per month (*DAM'*) (Eq. 7). The highest value of (*VA*) is the value adopted for the tank volume. If (*VA*) has a negative value; it means that catchment areas are not enough to satisfy the rainwater demand.

$$VA = OA - DAM' \tag{7}$$

where: *VA*: storage volume for the "i" month ($m^3$); *OA*: accumulated rainwater offered for the "i" month ($m^3$); *DAM'*: accumulated rainwater demand for the "i" month ($m^3$).

7. Accumulated Offer (*OA*). It is given by the following equation:

$$OA = OA' + OAMP \tag{8}$$

where: *OA*: accumulated offer for the "i" month ($m^3$); *OA'*: previous month accumulated offer "i-1" ($m^3$); *OAMP*: accumulated offer for the "i" month considering losses ($m^3$).

The accumulated offer per month (*OA*) will be included in the equation 7 and thus we can determine the storage volume for the rainwater collection system.

8. Water offer in a month (*OAM*). Considering the average monthly rainfall during the evaluated years, we proceed to determine the quantity of rainwater collected per month.

$$OAM = \frac{P_{pi} . C_e . AC}{1000} \tag{9}$$

where: *OAM*: rainwater offer in the month "i" ($m^3$); *P*: average monthly precipitation ($l/m^2$); *C*: runoff coefficient (0,9); *A*: catchment area ($m^2$).

In order to find the rainwater offered of the month considering the losses (*OAMP*), it is necessary to estimate the rainwater available during the month (*OAM*), both terms are used in Equation 10. It is noteworthy that the runoff coefficient in the Mihouse project takes the value of 0,9, because it is associated with metallic surfaces, which do not resist the flow direction. This feature matches the characteristics of solar panels on the roof of the buildings and the prototype house, moreover, it is important to note that the catchment area is function of the roof surface of the buildings, which in the urban complex consists of three different models.

9. Month Offer "i", considering losses (*OAMP*). According to Abdulla and Al-Shareef (2006), one can assume a value of 20 % of annually rainwater losses because of evaporation, the storage and an inefficient collection system. For this reason, the volume of the available supply is affected for that percentage. This will prevent oversize the system and include in the design related losses.

$$OAMP = 0{,}98 * OAM \tag{10}$$

where: *OAM*: rainwater offer in month "i" ($m^3$); *OAMP*: Accumulated offer of the month "i" considering losses ($m^3$).

10. Pluviometric information. In order to design the rainwater exploitation system, we should have the rainfall information in the study area, and it should be at least from ten consecutive years. With the obtained daily data, the monthly average precipitation is estimated, in accordance with Equation 5. With these results, we can analyze if the available rainwater is enough to implement a system to capture rainwater to fulfill the necessities of the project. Furthermore, the equation 11 is employed for obtaining Ppi which will be necessary to develop Equation 9.

$$P_{pi} = \frac{\sum_{i=1}^{i=n} P_i}{n} \tag{11}$$

where: *P*: monthly precipitation average (l/m²) of the "i" month evaluated every year (mm/month); *n*: number of evaluated years; *Pi*: Monthly precipitation value "i" (mm).

11. Water catchment coefficient. The efficiency of the rainwater catchment depends on the runoff coefficient of the materials used for the catchment area, which varies from 0,0 to 0,9.
12. Monthly Water Demand (*DAM*). The water demand can be estimated in several ways, the most common is by using the water endowment assumed by a person or the used for irrigation. This method calculates the amount of water needed to meet needs in each month.

$$DAM = \frac{N_u * N_d * Dot}{n} \quad (12)$$

Where: *DAM*: Monthly demand ($m^3$); *Dot*: water endowment (l/irrigation/day) (2l/$m^2$); *N*: total irrigation area; *N*: number of days in the analyzed month u d.

13. Accumulated demand per month (*DAM'*). It is determined by the expression proposed by Abdulla and Al-Shareef (2006). The (*DAM'*), is introduced in Equation 7 in order to determine the volume of the storage tank for rainwater.

$$DAM' = DAM + DAM(i-1) \quad (13)$$

Where: *DAM*': accumulated demand per month "i" ($m^3$); *DAM*: Month water demand ($m^3$); *DAM* (i-1): accumulated demand from the previous month ($m^3$).

## Storage

The storage process allows us to accumulate the rainwater in the storage tank to supply a specific population and to provide irrigation to a parkland. The rainwater storage unit must be durable, and it must comply with the following specifications:

- Waterproof to prevent water losses for transpiration or drip.
- In order to minimize over-pressures, it must have a maximum depth of 2 m.
- It must have a lid to keep out dust, insects and sunlight.
- It must have a hatch cover sufficiently large to allow a person to access for cleaning and repairs.

- In order to prevent the entry of insects and animals, the entrance and the overflow should have mesh.
- The tank must be equipped with devices for water removal.

## Rainwater Volume Calculation

Calculations considering the equations 7 and 13, were performed to establish the rainwater volume available to design the storage tank water collection system of the urban complex and the prototype house. These calculations are summarized in the following tables (Table 2.1 and Table 2.2). It is also important to note that the maximum flow transported by gutters was calculated as a function of the roof area (using equations 1 to 6) according to the type of apartment. Moreover, it should be emphasized that the value of the maximum flow is critical when sizing the diameter of the downspouts, overflows, and other hydraulic facilities which formed the catchment system.

Table 2.1. Type A apartment data

| Type A apartment data | |
|---|---|
| Total area for irrigation ($m^2$) | 40 |
| Water endowment ($l/m^2/day$) | 2 |
| Runoff coefficient | 0,9 |

Source: The Authors.

Table 2.2. Values of the necessary variables for the calculation of the catchment area, water demand and water supply

| Catchment area dimensions | | | |
|---|---|---|---|
| Section 1 catchment area ($m^2$) | b (m) | 3,4 | 24,45 |
| | h (m) | 0,89 | |
| | l (m) | 5,7 | |
| Section 2 catchment area ($m^2$) | b1 (m) | 0,77 | 14,87 |
| | b2 (m) | 7,8 | |
| | h (m) | 3,47 | |
| Section 3 catchment area ($m^2$) | b (m) | 3,15 | 10,40 |
| | h (m) | 3,3 | |
| Total catchment area ($m^2$) | 49,72 | | |

Source: The Authors.

**Determine the Volume of the Interceptor**. To determine the volume of the tank that intercepts first wash water, it can be implemented following two recommended methods (CEPIS y OPS, 2004):

## Method 1

*Interceptor Volume = CE*AC*LM* **Equation 14**

where: EC: runoff coefficient, AC: catchment, LM: Water Print.

The runoff coefficient is associated with the roof material, in the case of solar panels a value of (0,9) and even catchment area 49,72$m^2$, previously calculated, so the water level is assumed from 0,4 to 5 according to the quality of water required. In this case a value of 1, due to their type of use; obtaining a value of 44,75 L to be stored in the tank interceptor.

## Method 2

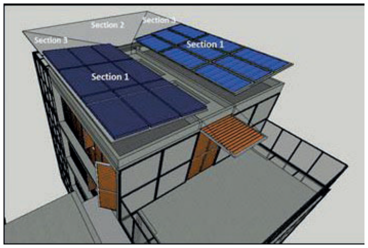
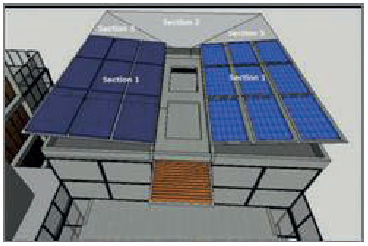
This method does not require a rigorous calculation, because the volume of the interceptor is based on the ratio of one liter of water per square meter of rain draining area ceiling, whereby a volume of 49,72 L. is obtained.

For a greater safety factor with regard to water quality interceptor volume is determined with the method two.

Table 2.3. Calculation of maximum flow that transports the gutters in the apartment

| Concentration time | | | |
|---|---|---|---|
| Variables | Section 1 ( square) | Section 2 (Trapeze) | Section 3 (Triangle) |
| L (m) | 5,7 | 7,8 | 3,15 |
| S (surface slope) | 0,2610 | 0,2610 | 0,2610 |
| Tc | 0,0021 | 0,0027 | 0,0013 |
| Time when the maximum is reached in the runoff area catchment | | | |
| Tp | 0,0925 | 0,1046 | 0,07342 |
| Concentration time of maximum flow | | | |
| Tb | 0,2470 | 0,2792 | 0,19604 |
| Maximum spending | | | |
| P (mm) | 22 | 22 | 22 |

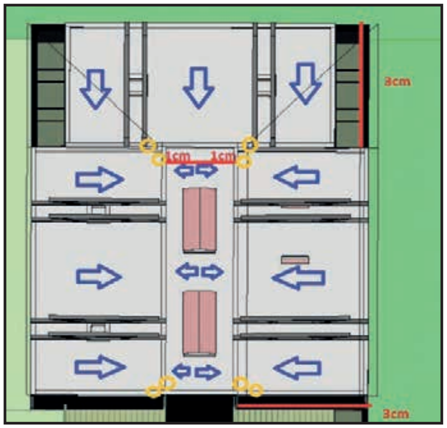
| | | | |
|---|---|---|---|
| Catchment area (km²) Qp (l/s) | 0,000024 | 0,000014 | 0,00001 |
| Qp (l/s) | 1,586696 | 0,818868 | 0,83300 |
| Qp (l/s) total flow | 3,239 | | |
| Estimate of the area of the gutter | | | |
| V(m/s) | 0,15 | | |
| Area of the chute (m²) | 21,59 | | |
| | | | |

Source: The Authors.

With the aim of preventing concrete slabs being affected by moisture due to water accumulation, it will be given a slope of 1 cm per linear meter, guiding its evacuation to the front of the house, each tile will be connected by a 2” hole allowing the exit, as expressed in the image presented below in Figure 2.1.

Figure 2.1. Sloping Slabs.




Note: Blue arrows: direction of the slope, Red line: indication of the value of the slope, Yellow circle: Connection 2” between slabs.

Source: The Authors.

## Size and number of downpipes

Table 2.4. Maximum permissible flows in downspouts

| Diameter (mm) (inch) | Maximum flow rate (l / s) |
|---|---|
| 50(2") | 0,90 |
| 75 (3") | 2,50 |
| 100 (4") | 5,10 |
| Rectangular 60 x 101 | 3,75 |

Source: AMANCO, pipe systems Technical Manual (2016).

In the above table the association of the maximum flow that can be transported to the capacity of the downspouts, in the case of apartment type A with 3,239 l/s where a downpipe 4" is required, is presented.

Table 2.5. Number of required drainpipes

| Ceiling Area ($m^2$) | Nominal size of the drop (mm) (inch) | | | |
|---|---|---|---|---|
| | 50 (2") | 75 (3") | 100 (4") | 60x101 rectangular |
| 10 | 1 | 1 | 1 | 1 |
| 20 | 1 | 1 | 1 | 1 |
| 30 | 2 | 1 | 1 | 1 |
| 40 | 2 | 1 | 1 | 1 |
| 50 | 3 | 1 | 1 | 1 |
| 60 | 3 | 1 | 1 | 1 |
| 80 | 4 | 2 | 1 | 1 |
| 100 | 5 | 2 | 1 | 1 |
| 120 | 6 | 2 | 1 | 2 |
| 140 | 7 | 3 | 2 | 2 |
| 160 | 8 | 3 | 2 | 2 |
| 180 | 9 | 3 | 2 | 3 |
| 200 | 10 | 4 | 2 | 3 |
| 300 | 15 | 5 | 3 | 4 |
| 400 | 20 | 7 | 4 | 5 |
| 500 | 25 | 9 | 5 | 7 |

Source: AMANCO, pipe systems Technical Manual (2016).

To calculate the number of downspouts, it is only necessary to determine the ceiling area which is required to evacuate rainwater and divide it by the factor chosen for the area of the section. This means that our catchment area (49,72 $m^2$) has to have a stud of 4" to evacuate rainwater.

According to the results shown in Table 2.6, the volume of the storage tank corresponds to the highest difference calculated by the accumulated demand and accumulated supply (i.e. 27,7 $m^3$) this value represents the rainwater volume that can be given for irrigation of 40 $m^2$ per month.

Table 2.6. Results of the monthly average precipitation, monthly water demand and water supply, and calculation of the demand and accumulated supply and storage volume

| Month | Ppi L/ $m^2$ | Month of day | Monthly water demand (DA) $m^3$/ month | DAM $m^3$/month | Monthly accumulated offer of the month considering losses OAMP $m_3$/ month |
|---|---|---|---|---|---|
| January | 72,9 | 31 | 2,48 | 2,48 | 3,20 |
| February | 93,5 | 28 | 2,24 | 4,72 | 4,10 |
| March | 126,6 | 31 | 2,48 | 7,2 | 5,55 |
| April | 187,3 | 30 | 2,4 | 9,6 | 8,21 |
| May | 132,0 | 31 | 2,48 | 12,08 | 5,79 |
| June | 45,2 | 30 | 2,4 | 14,48 | 1,98 |
| July | 30,3 | 31 | 2,48 | 16,96 | 1,33 |
| August | 33,4 | 31 | 2,48 | 19,44 | 1,47 |
| September | 62,2 | 30 | 2,4 | 21,84 | 2,73 |
| October | 148,3 | 31 | 2,48 | 24,32 | 6,50 |
| November | 138,7 | 30 | 2,4 | 26,72 | 6,08 |
| December | 116,4 | 31 | 2,48 | 29,2 | 5,11 |

| Accumulated offer $m^3$ | Water offered in month $m^3$ | Previous month accumulated offer $m^3$ | Storage volume $m^3$ |
|---|---|---|---|
| 5,15 | 3,26 | 1,95 | 2,67 |
| 10,23 | 4,18 | 6,13 | 5,51 |
| 17,34 | 5,66 | 11,79 | 10,14 |
| 28,39 | °8,38 | 20,18 | 18,79 |
| 31,87 | 5,91 | 26,08 | 19,79 |
| 30,09 | 2,02 | 28,11 | 15,61 |
| 30,79 | 1,35 | 29,46 | 13,83 |
| 32,42 | 1,50 | 30,96 | 12,98 |
| 36,47 | 2,78 | 33,74 | 14,63 |
| 46,88 | 6,63 | 40,38 | 22,56 |
| 52,66 | 6,20 | 46,58 | 25,94 |
| 56,90 | 5,21 | 51,79 | 27,70 |

**Source: The Authors.**

Note: Results of the monthly average precipitation, monthly water demand and water supply, and calculation of the demand and accumulated supply and storage volume.

**Urban Level:** for the urban design, it has a raceway system that collects water previously collected on the roof, this water is conducted by means of drainpipes, the size of the drop vary according to the type of the apartment and the type of diameter is 4". The water is transported to an intercepting system which has a storage capacity of 700 liter, once filled, clean water will continue its travel and pass to the storage tanks of 80m$^3$, which they will be distributed by the irrigation system on the whole.

**Prototype Design:** the system was implemented in the model home which is based on the apartment type B location on the fifth floor. This consists of a channel system which is covered with a mesh preventing coarse material such as leaves, branches, and other items for entering the system. The rainwater is led to the down comer, due to the inclination it has been provided. After this, the rainwater reaches an interceptor tank where the first flush of the roof (the most polluted part of the rainwater) is retained. In order to prevent that rainwater from the interceptor reach the underground storage tanks, a check valve (which ensures that the water flows in only one way) is used.

Once you reach the underground storage tank, it may provide 250 liters of water to the green area of the house, by a hand pump. (Figure 2.2).

Figure 2.2. Prototype rainwater tank

Source: The Authors.

## Ground Water System

The construction of two wells at a depth of 40 meters will be made. The function of these wells is to collect water from the water table by means of filtration to be used mainly for irrigation of the condominium.

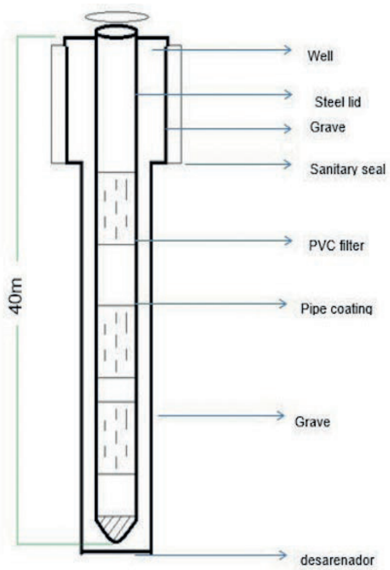
In order to construct these wells, detailed studies of the soil will be made in order to result in a stratigraphic column, which will be needed to see if a coating in the wells is needed in order to protect them from possible leaks of contaminated water or to prevent instability problems (mainly to avoid contact with clays, considering humidity can cause landslides and widening of the well).

Collecting water from these wells is completed at 19 meters depth with a maximum flow of 4,3 m/s, this decision will be made because the specific capacity for wells is approximately 0,4 (L/S)/m, which will generate an efficient well performance.

The wells will be located near the areas of rainwater storage because when no water is taken of this medium, it is recharged by groundwater to be distributed by the irrigation network. Each of the wells will supply half the demand together with a flow of 960 L/d, in total have a 1920 L/d being used for the condominium daily demand for irrigation activities.

**System components Groundwater**. Well components will be primarily a system of filters that allow the entry of water from the water table to the well, this filter system will have two parts, an outer layer of gravel to serve as a filter and gravel PVC after further count with coatings to prevent contact and input unwanted substances; the well count in the background with a sand trap to prevent entry of unnecessary material to storage tanks also the surface of the well will have a tight lid to avoid pollutant emissions source. The components of the groundwater system proposed in this project are shown in Figure 2.3.

Figure 2.3. System components groundwater.




Source: The Authors.

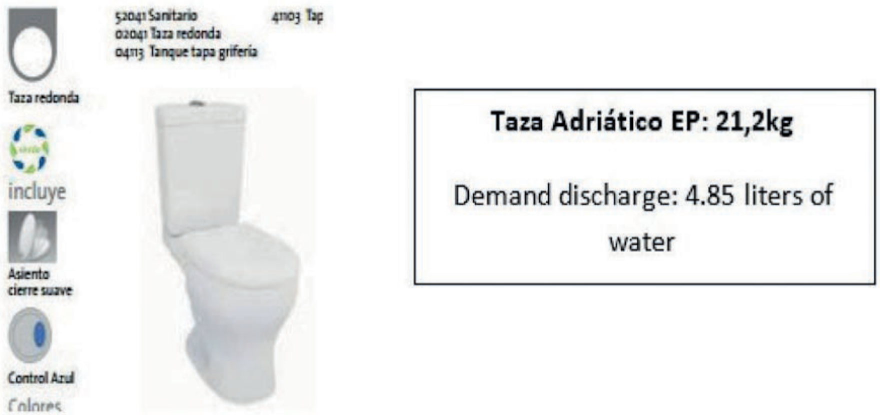
Note: the size and position of components lining the well may vary depending on the study of the soil.

**Urban Level**: It has two underground wells with a depth of 40 meters, which go through different soil types, which causes to vary the type of filtration. At 19 meters of depth extracting fluid with a flow rate of about 0,4 (L/s) are held, supplying the daily needs of the residential complex, equivalent to 1920 L/d for activities of irrigation of green areas. This system will work in combination with rainwater storage tanks because when they are empty, they will be burdened with this type of water for distribution.

**Greywater Tanks**

In this project we plan to have a system for greywater treatment for the entire unit to allow the reuse of greywater from showers, laundry (washing machine and laundry) and sink for toilet flushing. Greywater demand was considered for the critical condition, i.e. assuming the use of six daily toilet flushes per inhabitants per apartment. Considering a low consumption toilet (see Figure 1.7), with a consumption of 4,85 liters of water per flush and a total of five inhabitants by house, the greywater demand would be 29,1 liters per person per day (4,85 L / discharge * 6 downloads / inhabitant = 29,1 L / person / day) and 145,5 liters per apartment (29,1 L / person / day * 5 inhabitants = 145,5 L / day) (Table 2.7).

Figure 2.4. Technical data of low consumption toilet




Source: Taken from Corona.

Table 2.7. Greywater consumption

| Greywater consumption | |
|---|---|
| Demand toilet discharge | 4,85 (L/d) |
| Demand per person (6 discharges) | 29,1 (L/inhabitants/day) |
| Demand for apartment (5 inhabitants) | 145 (L/day) |

Source: The Authors.

**Production, storage and treatment of greywater**. For the management of greywater, we propose to have two underground collection tanks located in the green areas (see Figure 2.5, Figure 2.6, Figure 2.7). The overall output of greywater (AG) per person/day is shown in the following table:

Table 2.8. Devices that generate greywater at home.

| DEVICES THAT GENERATE GREYWATER AT HOME | AG PRODUCTION (L/D-HAB) |
|---|---|
| Showers | 45 |
| Clothes washing | 20 |
| Washbasin | 6 |

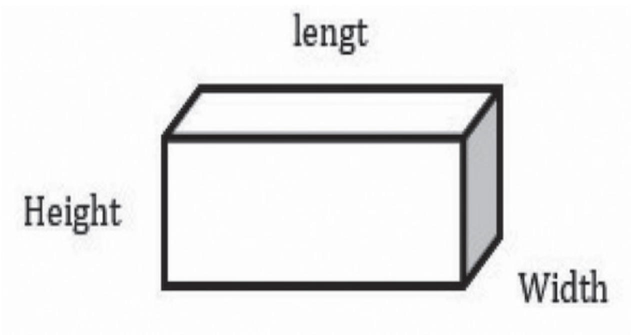
Source. (López, 2003).

For designing the two greywater collection tanks it was considered: (1) production of greywater generated by the use of the showers once a day for five people per apartment (5 hab * 45 L / d * hab = 225 L / d); (2) half of greywater production associated with the consumption of laundry for five people per apartment (5 hab * 20 L / d * hab = 100L / d) and finally (3) the water generated by the sink (5 hab * 6 L / d * hab = 30 L / d).

The total volume of greywater from showers, sinks and clothes washing that is needed to collect should be 355 liters per day per apartment, however an additional volume is considered to prevent overflow of water in the tanks during the critical time of generation of greywater, which corresponds when the washing machine is used. At that time, an additional volume storage is required to collect greywater corresponding to 7 days (5 bed * 20 L / d * hab * 7 d = 700 L), since the frequency of washing clothes is usually once a week.

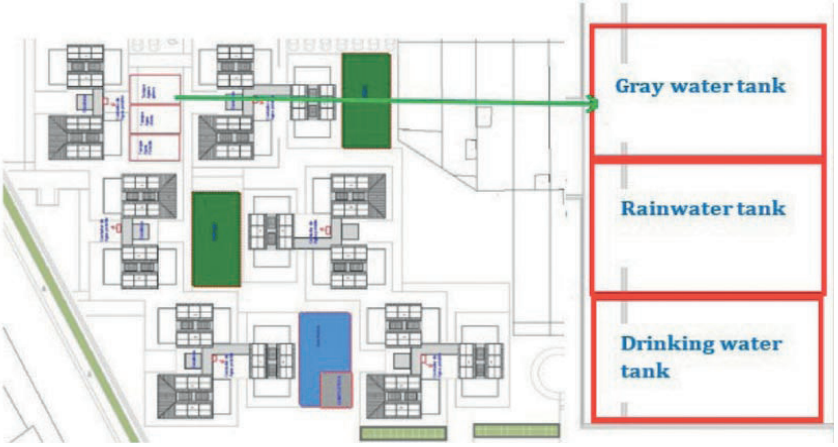
Considering the previous analysis, it is proposed to have two storage tanks for zone 1 (Figure 2.2 and Figure 2.3), with a volume of 26 $m^3$, with the following dimensions: height = 2m, width =2,6m and length = 5m.

Figure 2.5. Greywater storage for 6 apartment blocks (zone 1)




Source: The Authors.

Figure 2.6. Greywater storage for 6 apartment blocks. (zone 1)



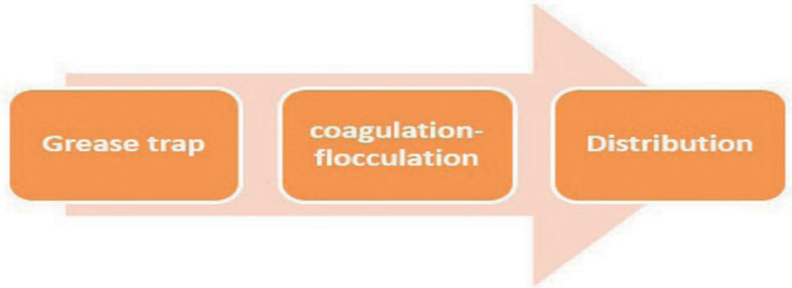

Source: The Authors

Figure 2.7. Greywater storage for 6 apartment blocks. (zone 2)


Source: The Authors.

For the greywater treatment, it is proposed to have a treatment system (see Figure 2.8) composed of a grease trap, followed by a tank where the coagulation and flocculation processes are performed and finally the water distribution is performed by pumps, bringing the treated water to each apartment for toilet flushing.

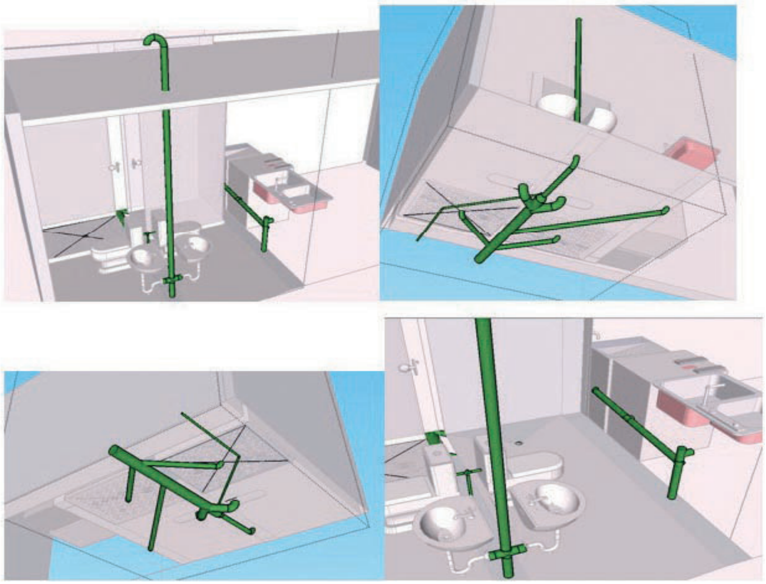
Figure 2.8. Treatment system.




Source: The Authors.

**Prototype Design**. For the production of greywater at the prototype house, it was considered to collect greywater from sinks, washing, laundry and showers. A basic treatment will be performed through a grease trap and a pump to reuse greywater into the toilet tanks, completely satisfying the demand. It should be noted, that in the toilets located at the prototype house, it will not be allowed any physiological activity that affects water quality, making the treatment adopted for the prototype in the Villa Solar very safe (Figure 2.9).

Figure 2.9. Prototype Gray water storage.



Source: The Authors.

## *Drinking Water Tanks*

The Mihouse project comprises a total of 128 apartments with a total of 30 buildings, which are divided into two types of blocks: 22 blocks considered 4 stories and 8 blocks considered 5 stories. The drinking water at all apartments will be supplied by pumping from two underground storage tanks. These blocks have specific conditions such as: number of apartments per block, spatial distribution, number of floors and number apartment per floor.

With that information and the population density in the project (five people/apartment), the total population to be supplied with drinking water is estimated (Table 2.7).

Table 2.9. Apartments Distribution by type

| Total number of apartments in the complex: 128 | |
|---|---|
| Block type A | Block type B |
| Number of blocks: 22 | Number of blocks: 8 |
| Number of floors: 4 | Number of floors: 5 |
| Apartments per floor: 1 | Apartments per floor: 1 |
| Total Population to Supply: 640 people | |

Source: The Authors.

The calculation of the water demand was estimated considering the Technical Rules of Drinking Water and Sanitation in Colombia - RAS 2000 (Ministerio de Desarrollo Económico Colombia [MDE], 2000) and historical records for the year 2014 reported for residential subscribers in Cali.

In order to calculate drinking water demands according to the RAS 2000 (MDE, 2000) the level of complexity of the system was initially calculated, which is determined from the number of people, in this case for the city of Santiago de Cali in 2014 it was about 2 344 703 inhabitants (DAP, 2014). Because the level of complexity is high, the minimum net water dotation is 150 L/ inhabitants*day. From this provision the RAS recommended a correction for effects of population growth and climate. The first aspect was not considered due to the small population of 740 inhabitants in the project, while the second aspect was considered by increasing in a 20 % the minimum net dotation according to table B.2.3. Title B of RAS 2000 (MDE, 2000), setting a value of 180 L/ inhabitants*day.

The project considers the reuse of greywater from showers, washing machines and laundry for toilets flushing. However, this reduction is not considered in the provision of drinking water, because it requires that the water supply will provide water for the toilets in case of maintenance of the greywater system and in case in which the greywater is not enough for toilets flushing.

## Storage volume for the Drinking water tank

In order to calculate the storage volume of the drinking water tank, it must be considered the drinking water demand per apartment, considering the restriction that is needed to have tanks to supply water by pumping to all floors of the buildings. It is assumed that the storage tank must store drinking water for one day of water demand, thus the calculation of the quantity of drinking water to be stored was made (Table 2.10).

Table 2.10. Storage volume for the Drinking water tank

| Drinking water demand per inhabitant | 108 l/hab/day |
| --- | --- |
| Number of people per apartment | 5 |
| Number of apartments | 128 |
| Storage volume for the drinking water tank | 115,2 $m^3$ |

Source: The Authors.

The volume obtained for the storage tank is very large; therefore, two drinking water storage tanks will be built with smaller dimensions. These tanks will be built and buried in the green areas within the complex of buildings. Each tank will supply 64 apartments with a volume of 57,6 $m^3$.

If the tanks are rectangular with a height of 2 m it requires an area of 28,8 $m^2$. This height is appropriate because it allows reducing construction costs and problems with groundwater level (Table 2.11).

Table 2.11. Drinking Water Pre-dimensioning

| PARAMETER | VALUE |
|---|---|
| Volume per tank ($m^3$) | 57,6 |
| Area per tank ($m^2$) | 28,8 |
| Height (m) | 2 |
| Wide (m) | 4,11 |
| Length (m) | 7 |

Source: The Authors.

## Plumbing System

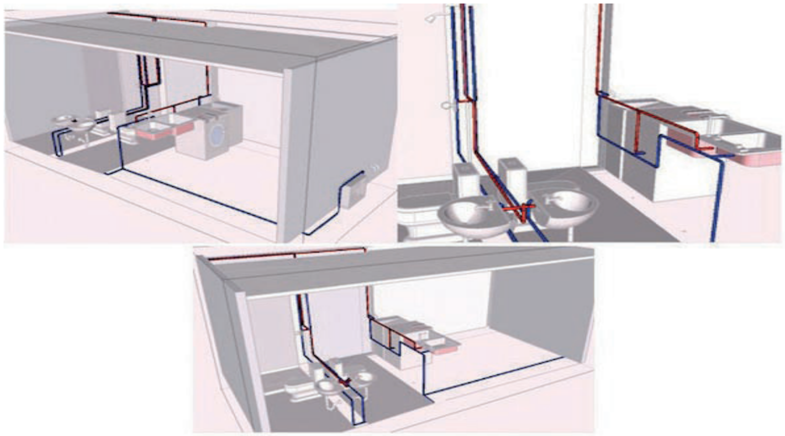
**Drinking water distribution system: PROTOTYPE**

Drinking water pipes are located as near as possible to the solar heating system, so the number of pipes used us reduced. Additionally, the system is also located as near as possible to the utilities, to reduce the loss of heat from the hot water in the water conduction. These pipes are made of PVC with a diameter of ½ inch (1,27 cm). This material is perfect for both types of pipes for transporting hot and cold water (Pérez, 1997). The PVC is ductile, flexible and it is a material chemically and mechanically resistant. It is compatible with the speed required during the assembly of the prototype house and it has no need of welding, it is only necessary anchoring for greater stability of the pipe (Figure 2.10).

In the prototype house it is not necessary to have storage tanks for drinking water, because the Solar Decathlon (SD) Organization LAC2015 provides water connections and drinking water to each team for using it during the contest period.

The SD Organization LAC2015 will provide drinking water by a system of pipes to supply each team batch. The maximum pressure available in the prototype house is 15 meters of water column. The water supply will be monitored; therefore, the organizers will provide measurement instruments of water in a corner of the plot. The outlet pipe is ½ “in diameter.

**Figure 2.10.** Drinking water distribution system



Source: The Authors.

## Greywater collection system

**Urban Context**: Each mezzanine floor of the building has a horizontal drainage system of PVC with a diameter of 2 inches (5,08 cm), which receives greywater discharges from each sanitary appliance and leads greywater until a downspout. This is a vertical downspout pipe passing through the false wall along the whole building, connected by elbows, which collects greywater and evacuated to the storage tank. In this tank the greywater is treated and then it is distributed by pumps to each apartment for toilet flushing.

**Prototype:** To produce greywater, we considered the collection of water from sink, washing machine, laundry and showers with PVC pipes with a diameter of 2 inches (5,08 cm).

Wastewater collection system

**Urban Context:** Each mezzanine floor of the building has a horizontal drainage system that receives wastewater discharges of each toilet and dishwasher and leads it until a wastewater drainpipe. This is a vertical downspout pipe passing through the false wall along the whole building, connected by elbows, which collects wastewater and evacuate it to the primary drainage system. It is important to have a ventilation system for the downspouts in order to prevent the production of odors. This ventilation pipe leads the upper part of the downspouts onto the deck, where it ends in curve with two elbows of 90°, leading to an angle of 180°, which allow us to prevent the entry of rainwater.

Considering the recommendations of Melguizo (1980), in order to evacuate the wastewater from the building to the sewerage system, we propose to have two inspection boxes (each inspection box covers half of the housing complex) in which we have a connection of the downspout pipes with the horizontal pipes. These two inspection boxes will be located underground in two green areas of the housing complex. These boxes allow inspection and cleaning labors. The walls of the inspection box are made of concrete with the following dimensions: 0.1 x 0.2 x 0.4 m, as stipulated (Empresas Públicas de Medellín, 2012). The boxes are built to the level of the platform or green area and they should have concrete lids with metal frame. In order to bury the pipes of the primary drainage network, we should leave a minimum slope of 2 %, i.e. 2 cm per linear meter of pipe.

**Prototype:** Wastewater from toilets and dishwashers will be connected to the same wastewater transport system made of PVC with a diameter of 4 inches (10,16 cm). This system will transport wastewater to finally dispose it into a storage tank.

## Water Budget

### Activities Related to the Water Consumption

The consumption of drinking related to the activities in The Solar Village is as follows.

**Table 2.12.** Activities related to the water consumption

| Activities | Consumption (L/CICLO) |
|---|---|
| Clothes washer | 65 |
| Flushing the toilet | 4,85 |
| Hot water draws | 50 |
| Cooking | 20 |
| Dinner Party | 10 |

Source: The Authors.

Daily activities that take place on The Solar Village and planned water consumption reached a total of 1174,3L water consumption during test of the competition; however, it can be considered that for the test of cooking is not used water since the recipe is based on vegetables.

**Table 2.13.** Daily Cycles

| Contest day | Day 12 | Day 13 | Day 14 | Day 15 | Day 16 | Day 17 | Day 18 | Day 19 | Day 20 | Day 21 | Day 22 | Day 23 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Clothes washer | 0 | 0 | 0 | 2 | 2 | 2 | 0 | 2 | 0 | 0 | 0 | 0 |
| Flushing the toilet | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Hot water draws | 0 | 0 | 0 | 2 | 2 | 2 | 2 | 2 | 2 | 0 | 0 | 0 |
| Cooking | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| Dinner party | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| Garden watering | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| Clothes washer | 0 | 0 | 0 | 130 | 130 | 130 | 0 | 130 | 0 | 0 | 0 | |
| Flushing the toilet | 0 | 0 | 0 | 4,85 | 4,85 | 4,85 | 4,85 | 4,85 | 0 | 0 | 0 | |
| Hot water draws | 0 | 0 | 0 | 100 | 100 | 100 | 100 | 100 | 100 | 0 | 0 | |
| Cooking | 0 | 0 | 0 | 10 | 10 | 10 | 10 | 10 | 0 | 0 | 0 | |
| Dinner party | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | |
| Total volume from clear water (L) | 0 | 0 | 0 | 244,85 | 244,85 | 244,85 | 114,85 | 244,85 | 100 | 0 | 0 | 1942,5 |

Source: The Authors.

The use of greywater and rain system to reduce the water consumption of the prototype is considered at the end, with the following results.

Table 2.14. Total generated volume of water

| | Daily Cycles | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Contest day | Day 12 | Day 13 | Day 14 | Day 15 | Day 16 | Day 17 | Day 18 | Day 19 | Day 20 | Day 21 | Day 22 | Day 23 |
| Greywater waste | 0 | 0 | 0 | 230 | 230 | 230 | 100 | 230 | 100 | 0 | 0 | 0 |
| Black water waste | 0 | 0 | 0 | 14,9 | 14,9 | 14,9 | 14,9 | 14,9 | 0 | 0 | 0 | 0 |
| 1120 L | Total Volume greywater | | | | | | | | | | | |
| 74,25 L | Total volume black water | | | | | | | | | | | |

Source: The Authors.

In the previous table it was obtained that the generated volume of greywater is 1120 L, which can be fully reused for irrigation of gardens and for filling the toilet tanks. The total volume of wastewater comes from flushing the toilets and scheduled tasks for cooking. Thus, the volume of wastewater during the contest days 15 to 19 was 14,9 L, whereas during the entire contest was 74,25 L.