CASE STUDIES

Dimensioning a Drinking Water Distribution Network in Collique (Lima): Introduction to the Human Right to Water and Sanitation

Helena Grau Huguet and Emeka Okpala

PHOTO: “Illegal right”. Lima. Miren Etxeberria

GDEE GLOBAL DIMENSION IN ENGINEERING EDUCATION

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5 Dimensioning a Drinking Water Distribution Network in Collique (Lima): Introduction to the Human Right to Water and Sanitation

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INDEX

1. INTRODUCTION

In 2010, the UN General Assembly and the UN Human Rights Council recognized water and sanitation as a Human Right (HR). Undoubtedly, this milestone represents a great advance in the water, sanitation, and hygiene sector (WaSH) as it gives all humans the right to the provision of minimum standards in relation to these services (Flores-Baquero, 2015).

The 2030 Agenda for Sustainable Development, adopted by the UN General Assembly in 2015, integrates a specific objective for water and sanitation (SDG 6). This Objective pursues the ambitious goal of "ensuring the availability of water and its sustainable management and sanitation for all". Clearly, SDG 6 reflects the human right to water and sanitation (HRtWS). However, there are still many millions of people who do not enjoy their fundamental rights of access to drinking water and sanitation. Many of them face significant barriers to access because of where they live and who they are. Water and sanitation for all will not be achieved without paying special attention to the needs of vulnerable and marginalized groups.

For HRtWS realization, it was proposed to define and act over 5 dimensions; availability, accessibility (physical), quality, affordability, and acceptability. In this case study, we will focus on drinking water access from a Human Right approach. In this sense, we will briefly introduce the current situation regarding access to this service, and we will go in more depth into the meaning of the HRtWS dimensions, and specifically, in the case of drinking water. Secondly, we will introduce the situation of access to this service in a peri-urban area of the metropolitan city of Lima. Finally, we will synthetically present a research work carried out with the inhabitants of this area in relation to HRtWS. Altogether, this will make up the work context in which the students will carry out the proposed activities

1.1. DISCIPLINES COVERED

The distribution of a drinking water service is usually found in the field of civil engineering, and usually in subjects of urban planning, urban services, or hydraulics. With this case study, we aim to put into practice different theoretical knowledge for the calculation and pre-dimensioning of drinking water supply networks.

In addition, the background that it will provide in regard to non-conventional water distribution approaches will help future professionals, who are willing to dedicate themselves to basic services management, to gain a broader perspective.

1.2. Learning outcomes

As a result of this case study, students are expected to be able to:

- Pre-dimension a water supply network based on public fountains for an unconventional urban sector;
- Analyze the impacts associated with the Human Right to Water (HRtW) compliance;
- Understand the different methods of the drinking water supply, as well as the management and associated payment processes for it;
- Analyze the impact associated with these management aspects.

1.3. Activities

This case of study is based on two activities. A first class activity is subdivided into two blocks. The first block will be invite to reflect on the importance of access to water services. This reflection will be carried out from a Human Right perspective. The second block, in the form of a "guided workshop", aims to provide the basic knowledge on the dimensions of a water distribution network.

The second activity will be carried out autonomously, but in small groups (of 3 to 4 people). The purpose of this activity is for the students to apply the knowledge they acquired in the classroom to consider a larger water supply network. Likewise, it will be urged that they extend their previous reflections on the managerial aspects of this service.

2. Description of the context

In this section, we introduce the basic concepts associated with the Sustainable Development Goals (SDGs) and their monitoring, as well as the different dimensions of the HRtWS. Next, we provide detailed information of the context that this case study addresses. Specifically, we present data associated with water management approaches and the perception of a number of inhabitants as far as the relative importance of HRtW dimensions. Finally, we introduce a possible way of quantifying / evaluating this information.

2.1. Water, sanitation, and hygiene global context

In 2015, the United Nations General Assembly adopted the 2030 Agenda for Sustainable Development, a plan of action in favor of people, the planet, and prosperity, which also intends to strengthen universal peace and access to justice. This agenda establishes 17 SDGs and 169 goals designed to be universally relevant and applicable to all countries. The SDGs require an integrated approach with respect to social, economic, and environmental dimensions. As for the Millennium Development Goals (MDGs) formulated for the period between 2000 and 2015, the SDGs integrate a specific objective for water and sanitation (SDG 6).

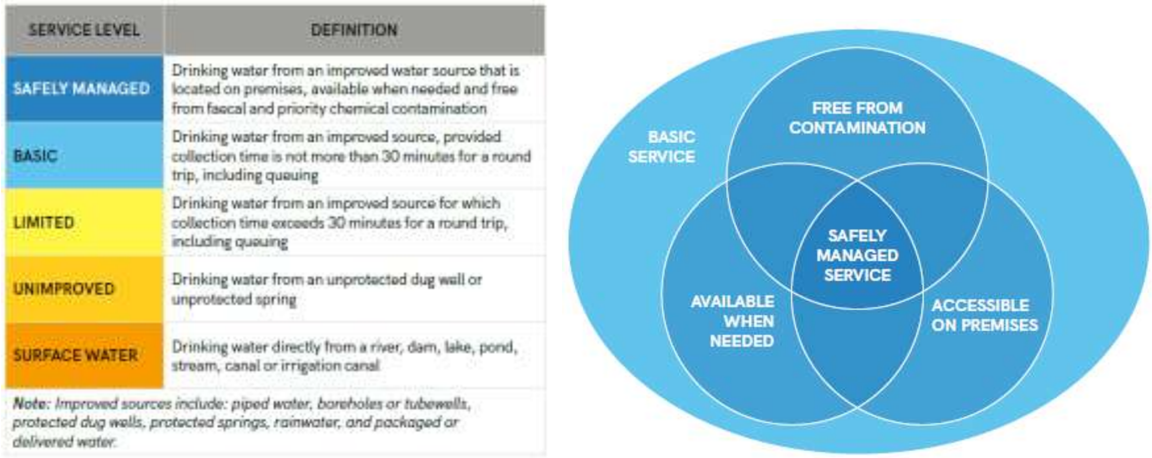
This deserved prominence is based on the recognition of access to water, sanitation, and hygiene (WaSH) as fundamental aspects for human development and well-being (Carter et al., 1999; Cairncross & Valdmanis, 2006). Additionally, the improvement of these aspects in households, health centers, schools, and workplaces, complemented with the treatment of wastewater, is a way to reduce the risk of waterborne diseases, to achieve adequate nutrition, to support education and work, and to address overarching issues, such as poverty eradication and gender inequality and other inequalities (Joint Monitoring Program, 2015, UN-Water, 2016).

What SDG 6 proposes is "to guarantee the availability of water and its sustainable management and sanitation for all". With this in mind, eight specific targets have been formulated, six of which are based on expected outcomes and the remaining two, based on the means of implementing these outcomes. *Table 1* briefly details the proposed targets.

Table 1 *Specific targets integrated in SDG 6.*

TARGET	DESCRIPTION
6.1	Achieve universal and equitable access to safe drinking water at an affordable price for all
6.2	Achieve access to adequate and equitable sanitation and hygiene services for all
6.3	Improve water quality and reduce pollution
6.4	Increase the efficient use of water resources
6.5	Implement Integrated Water Resource Management (IWRM)
6.6	Protect and restore water-related ecosystems
6.a	Expand international cooperation
6.b	Support and strengthen local community participation

In this context, monitoring and evaluation have been fundamental for sound decision-making, since governments, civil society, and donors need objective and reliable data on which to base planning, prioritization, and accountability mechanisms. In this regard, the World Health Organization (WHO) and the United Nations Children's Fund (UNICEF) combined efforts in 1990 with the Joint Monitoring Program (JMP) for Water Supply and Sanitation, whose main objective was and is to monitor national progress towards the universality of access to safe water and sanitation. Since then, the water and sanitation sector has undergone an important transition in the way it evaluates access to these services. Initially, basically only indicators quantifying the mere access to water or sanitation infrastructure (in terms of coverage) were used. Progressively, sector monitoring was carried out in broader terms of "level or quality of service". Currently, the JMP proposes three "ladders" to monitor the specific targets 6.1 and 6.2. In *Figure 1*, the indicators proposed for access to water are presented, as this service will be the main focus of this case study.



SERVICE LEVEL	DEFINITION
SAFELY MANAGED	Drinking water from an improved water source that is located on premises, available when needed and free from faecal and priority chemical contamination
BASIC	Drinking water from an improved source, provided collection time is not more than 30 minutes for a round trip, including queuing
LIMITED	Drinking water from an improved source for which collection time exceeds 30 minutes for a round trip, including queuing
UNIMPROVED	Drinking water from an unprotected dug well or unprotected spring
SURFACE WATER	Drinking water directly from a river, dam, lake, pond, stream, canal or irrigation canal

Note: Improved sources include: piped water, boreholes or tubewells, protected dug wells, protected springs, rainwater, and packaged or delivered water.

Figure 1 *The new JMP ladder for drinking water services. Source: Joint Monnitoring Programme, 2017.*

The global situation in 2015, as reflected in JMP (2017), reflects that 71% of the world population (5.2 billion people) use a safely managed drinking water service, i.e., one that is located on premises, available when needed, and free from contamination (*Figure 1*). In relation to this figure, one in three people live in rural areas. On the other hand, 89% of the world population (6.5 billion people) uses at least a basic service, i.e., an improved water source with a location that requires a maximum of 30 minutes to make a round trip to collect water (including queuing). The most worrisome figures, which represent the important challenge facing the sector, show that 844 million people lacked a basic drinking water service in 2015, with 263 million people spending more than 30 minutes per round trip to fetch water from an improved source (which constitutes a limited drinking water service), and that 159 million people still collected water for consumption directly from surface water sources (58% of whom live in sub-Saharan Africa).

2.2. Human Right to water and sanitation

Human rights are universal, inalienable, interdependent, and interrelated. The Universal Declaration of Human Rights stipulates that "all human beings are born free and equal in dignity and rights". Having access to drinking water and sanitation is fundamental for living a dignified life and defending Human Rights (United Nations and World Health Organization, 2012).

The recognition of the HRtWS by the resolutions of the General Assembly and the United Nations Human Rights Council in 2010 (United Nations General Assembly, 2010a; 2010b) represents a great advance in the WaSH sector, as it grants all human beings the right to the provision of minimum standards in relation to these services (Flores-Baquero, 2015). Undoubtedly, SDG 6 reflects the impregnation of the recognition of water and sanitation as a human right.

Thus, HRtWS has been interpreted as the right of everyone to have access to a water (and sanitation) service that is sufficient, safe, accessible, culturally acceptable, and affordable for personal and domestic use, and that must be provided in a participatory manner that is responsible and non-discriminatory (Flores-Baquero, 2015). In this sense, and for the realization of this human right, five dimensions were proposed: availability, (physical) accessibility, quality, affordability, and acceptability. Flores-Baquero (2015) makes a descriptive synthesis that is detailed below.

> **“Availability**
>
> The water supply for each person must be sufficient and continuous for personal and domestic uses. These uses ordinarily include drinking, personal sanitation, washing of clothes, food preparation, personal and household hygiene. The quantity of water available for each person should correspond to World Health Organization (WHO) guidelines. Neither continuity nor exact quantity required can be determined in the abstract, since individual requirements for water consumption vary, for instance due to climatic conditions, level of physical activity and personal health conditions.
>
> **Accessibility**
>
> Water facilities must be physically accessible for everyone within, or in the immediate vicinity of, each household, health or educational institution, public institutions and places, and the workplace. Even where water facilities exist, they are frequently inaccessible for different reasons. Around the world, water points are often a long distance from the home, so people, especially girls and women, spend major portions of their day walking to collect water for their daily needs. The distance to the water source should be in reach

of every household, bearing in mind the special needs of certain groups and individuals; a high source:person ratio is often a reason that undermine physical accessibility; People's security is often threatened on their way to or while using the service. The path leading to the facility or water source itself, should be safe and convenient for all users, including children, older people, persons with disabilities, women, including pregnant women, and chronically ill people; the facility itself should be accessible for all users and easy to use.

Quality

Water must be of such a quality that it does not pose a threat to human health. The transmission of water-borne diseases via contaminated water must be avoided. In its *Guidelines for Drinking-water Quality,* WHO defines safe drinking water as water that "does not represent any significant risk to health over a lifetime of consumption, including different sensitivities that may occur between life stages". The maximum limits provided in the *Guidelines* for a wide range of potentially harmful substances can serve as a reference point.

Affordability

Water facilities and services must be available for use at a price that is affordable to all people. The provision of services includes construction, maintenance of facilities and treatment of water. Paying for these services must not limit people's capacity to acquire other basic goods and services guaranteed by human rights, such as food, housing, health services and education. Affordability does not necessarily require services to be provided free of charge. Special caution must be exercised and due process guaranteed in cases of disconnection from the water supply due to a user's inability to pay. Measures must be in place to ensure that such users are not deprived of access to safe water to meet their most basic personal and domestic needs.

Acceptability

Perspectives differ with regard to which water supply solutions are acceptable in a given context. Acceptability is relevant for encouraging people to use safe water sources. In particular, water should be of an acceptable color, odor and taste. The placement of a water point or the actual water source should also be acceptable to them. Cultural prescriptions may also apply to conditions for use of these facilities."

As stated above, there are still billions of people who do not enjoy their fundamental rights of access to safe drinking water (and sanitation). Many of them face significant barriers to access due to where they live and who they are. Are they women? Do they belong to an ethnic minority? Are they poor? Do they live in a slum or in an impoverished rural area?

Governments have an obligation to ensure access to water and sanitation for all members of the population, regardless of whether they are rich or poor, male or female, living in formal or informal settlements, or in urban or in remote rural areas (United Nations and World Health Organization, 2012).

Water and sanitation for all will not be achieved unless we pay particular attention to the needs of vulnerable and marginalized groups. Human right principles highlight the need to actively design water and sanitation policies that prioritize and address the needs of vulnerable and marginalized groups, rather than treating all persons as if they faced identical challenges in accessing safe water and improved sanitation. Water and sanitation for vulnerable and marginalized groups is often a social exclusion issue, and not just a water issue (United Nations and World Health Organization, 2012).

2.3. Case study: Collique (Lima, Peru)

Peru is divided into three macro regions called Costa, Sierra, and Selva. The first of these regions is a desert area in which most of the population lives (INEI, 2015). Strikingly, it is the hydrographic area that possesses only 2.2% of the total fresh water available in the country (ANA, 2016). According to the report presented by the JMP (2017), 95% of the urban population has access to a basic service (see the JMP ladder), while the percentage corresponding to the rural population is reduced to 72%. In this regard, it should be noted that there are no estimations regarding safely managed access or estimations associated with peri-urban areas.

The Peruvian capital, Lima, is the second largest city in the world (after Cairo) that is located on top of a desert. Its territory is formed by “cerros” (mountains of low altitude), and river degradation and aquifer overexploitation reinforce the scarcity of the resource (Ioris, 2016). The Lima Metropolitan comprises 30% of the country’s population, with 9,904,000 inhabitants (INEI, 2015), although the exact numbers are difficult to specify due to the high number of informal neighborhoods (known as human settlements) located in the periphery of the city. Regarding the central theme of this case study, the figures recorded show a drinking water coverage of 92.7%, whereby 83% of the connections have a water meter, and a sanitation coverage of 89.4% (SUNASS, 2015).

The high population growth of 1.8% per year (Municipalidad Metropolitana de Lima, 2016) is especially due to the migration of people with fewer resources, which generates additional pressure in areas of Lima that lack adequate supplies of water and sanitation as well as electricity (see *Table 2*).

Table 2 *Socio-spatial inequalities in the municipalities of Metropolitan Lima in terms of water access. Source: Ioris, 2016.*

ECONOMIC CONDITION	NUMBER OF HOUSEHOLDS	HOUSEHOLD PERCENTAGE WITH WATER SERVICE
High-income municipalities	92,276	99.8
Medium-income municipalities	184,187	77.9
Low-income municipalities	712,878	68.1

Collique

The neighborhood of Collique is part of the Comas district (fourth largest population district of Lima), located in the northeast of it.

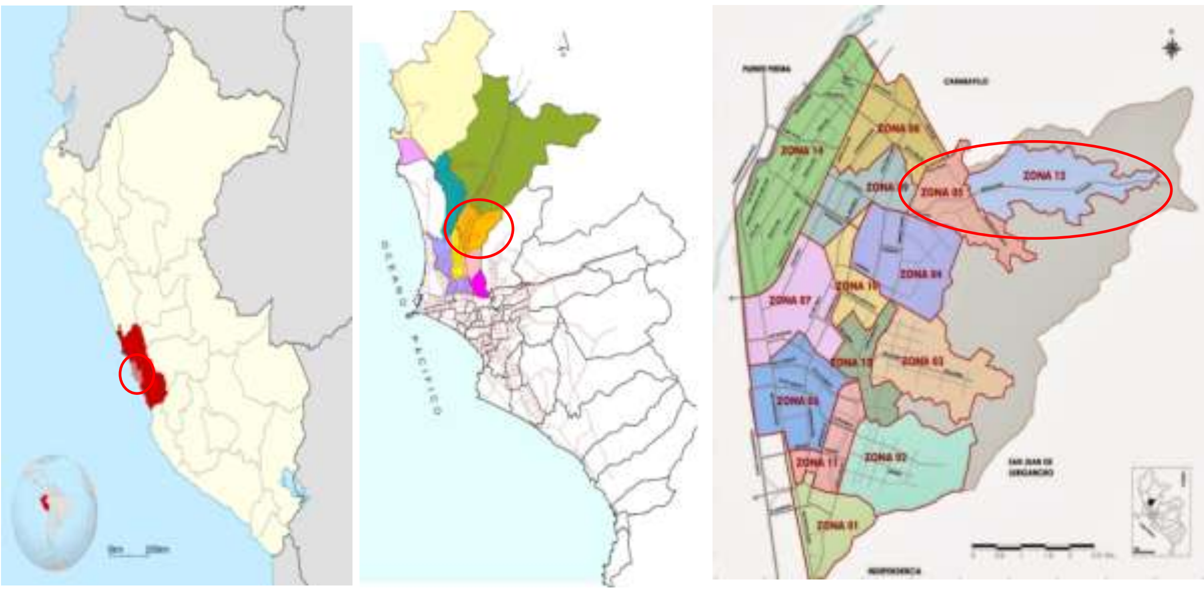


Figure 2 *Geographic location of the study area. Source: Own elaboration.*

Collique comprises 8 zones and has approximately 116,000 inhabitants, although this figure is difficult to know exactly due to the problems with the census in the most peri-urban areas of the metropolis. The size of the neighborhood is approximately 5 km^2, and population density reaches more than 23,200 $inhab/km^2$. For comparison, *Table 3* presents the figures for the city of Lima, the district of Comas, and the neighborhood of Collique.

Table 3 *Comparison among locations of population, area, and density*

	INHABITANTS	AREA (km^2)	POPULATION DENSITY (inhab/km^2)
Lima	7,605,742	2,670	2,854
Comas	525,000	48,72	11,000
Collique	116,000	5	23,200

The urban planning of Collique is developed from the “Avenida Revolución” (*Figure 3*). This avenue runs through the lower part of the valley, where the neighborhood is located, and is the starting point for the rest of the urban roads that leave for the “cerros”. The avenue is the central axis of Collique in all aspects—most of the facilities are grouped around it; it connects the neighborhood with the rest of the district in terms of mobility; and it is the axis of the urban services (among them, drinking water and sanitation).

Figure 3 *Distribution of Collique neighborhood around Avenida Revolución. Source: Own elaboration, from Google Maps.*

It must be borne in mind that as the distance from a residence to the central avenue, access to urban services decreases. Building processes in Collique have taken place faster than the urbanization processes, which has produced a late supply of services to many areas that have already been built. This urbanization was made *a posteriori* thanks to citizen protests. The division of the neighborhood into eight different areas with some autonomy resulted in unequal access to services. The central Lima administration proposed a co-payment to these peri-urban areas for the provision of water and sanitation services, while many of the neighborhoods demanded the services to be 100% funded with public funds. Those districts that accepted the co-payment had a faster access to the services.

Another noteworthy aspect is the expansion of the neighborhoods that has been carried out in the “cerros”. Normally, the land for houses is built by dynamiting areas of the mountain to break the rock and to produce as flat a surface as possible. In many cases, house foundations are built with the dynamited stone. In these sectors, streets are either inexistent or are minimal and very thin, which limits physical access to all homes (*Figure 4*). In short, this unequal growth of the neighborhood produced the low homogeneity of the supply system in Collique.

Figure 4 *Household distribution of homes in the neighborhood of Collique. Source: Own elaboration.*

2.4. Water management in Collique

Drinking water distribution networks, as well as their management, are fundamental for guaranteeing a correct level of service to the population. Drinking water infrastructure and service in Lima are mainly the responsibility of the public company SEDAPAL (Servicio de Agua Potable y Alcantarillado de Lima; “Lima Potable Water and Sewage Service”). However, in Collique, it is possible to find four different forms of supply, which are presented below.

Community “Pilón”

The community “pilón” (community fountain) is one of the most common forms of supply in the area of the “cerros”, where human settlements are located. These systems have been built and financed by NGOs, which have trained the population in their organization and proper functioning and management of the system (creation of the “pilón” committee).

The operation of the “pilón” consists of storing the water in a tank, which can be supplied by SEDAPAL network or by tanker trucks (see *Figure 5*). These trucks distribute the water through pipes to each “pilón” (access points to water), generally distributed by block, and for which a hose is connected to bring the water point closer to the storage places of the households. Water distribution can be periodic (every "x" days), or unrestricted, which means that there should be the possibility of being supplied when needed. The water amount, when it is not restricted, depends on the storage capacity of each household; when the storage tanks are located on the roof, it favors the possibility of having an intra-household connection.

The price of the service is determined by the type of supply of the distributor tank. Provision by tanker trucks is more expensive than provision by SEDAPAL, since it is a private service. The payment system depends on each committee organization and this can either be equitable among users (i.e., the total price is divided by the number of users) or by quantity consumed.

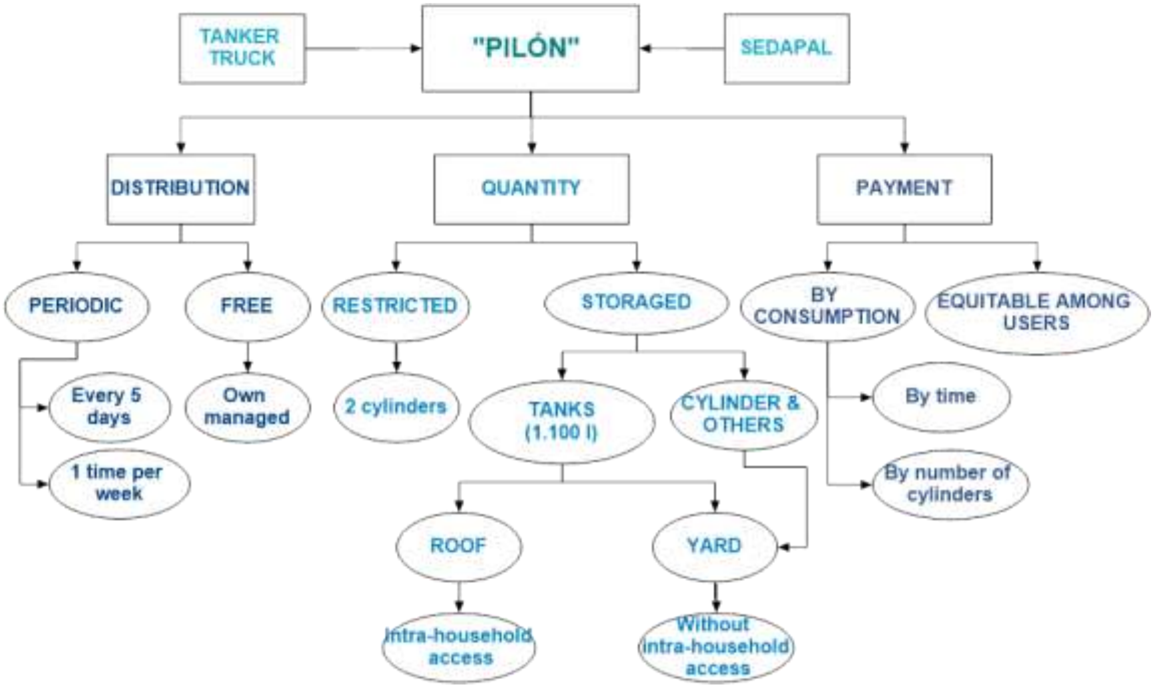


Figure 5 *Community "pilón" distribution scheme in Collique. Source: Own elaboration.*

Because it is a community system, its management through a committee is a determining factor for ensuring a good level of service for all users. It has been observed that most of the committees charge a price over the water cost in order to generate some funds for the maintenance of the facilities or for paying electricity when pumps are required. For example, in the seventh zone of Collique, the tanker truck sells the "tank" for 130 soles[1] (12 m^3, which equals 60 cylinders), so that the price of a single cylinder is about 2.16 soles; however, the committee charges 2.30 per cylinder to pay the electricity bill for the pump and maintenance of the system. In contrast, in the eighth zone, where the "pilones" are supplied by SEDAPAL,

[1] *The Sol is the currency of Peru since 1991. Initially called Nuevo Sol (S /.), since 2015, the government ordered that this currency be simply called "Sol (S /)", also suppressing the use of the dot (S /.) in the monetary sign. 1 S / equals 0.25 euros (€) and 0.31 US dollars (US $).*

the price is 0.5 soles per cylinder. This was initially the end price for the users until the committee, together with the users, decided to increase the price to 1 sol to raise funds for maintenance. Some—but not all—committees are transparent with respect to their accounts, sharing with their users the state of funds and what they are used for.

SEDAPAL

The most widespread form of water supply in Collique is the connection to SEDAPAL network, with the largest number of connected users located near the main avenue. As shown in *Figure 6*, having a connection to the network is not a guarantee for a 24-hour permanent service, as there are areas where the availability is only two hours per day and at different times.

The amount of water available depends on the storage capacity of each household and the pressure of the network. Likewise, for community “pilón” systems, intradomiciliary access depends on the infrastructure (e.g., tank on the roof, and pump in case of little pressure) and therefore on the economic resources of each residence.

This supply form is the most economical as long as water consumption is metered (payment for consumption). Otherwise, the price can be harmful if the consumption is low and charged at a fixed rate (e.g., constant price regardless consumption), or beneficial if the actual consumption is greater than the invoiced consumption (as observed for large families).

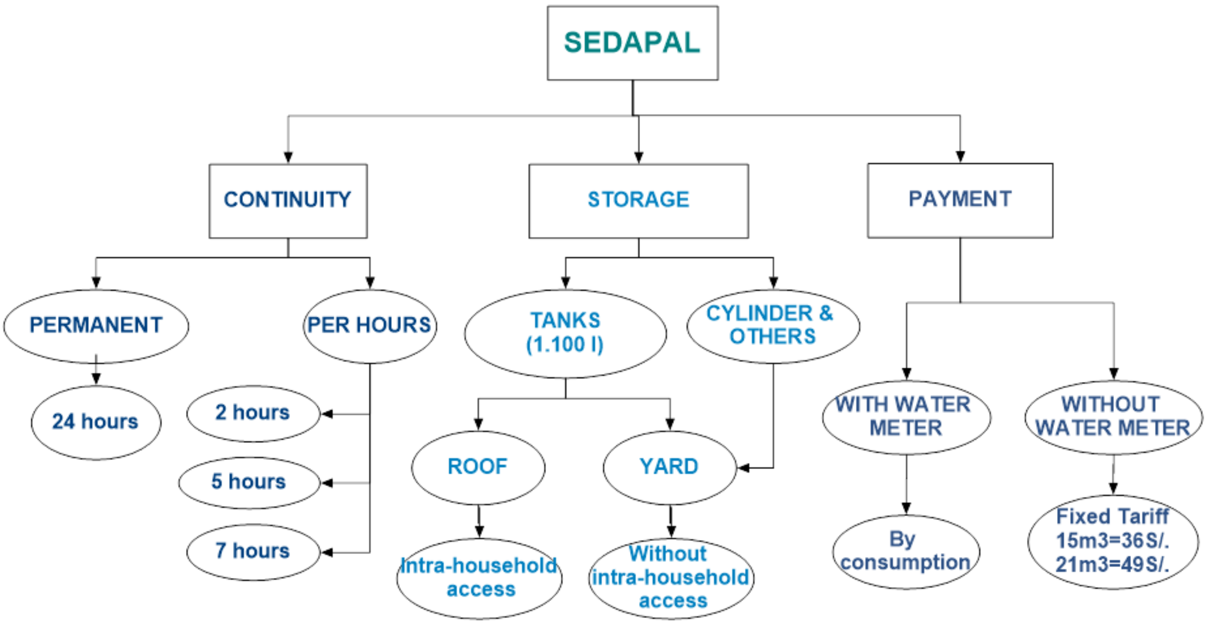


Figure 6 *SEDAPAL distribution scheme in Collique. Source: Own elaboration.*

As an example, in the first zone, which has a fixed rate due to the lack of a water meter, users pay 49 soles for 21 m^3 and have 7 hours of daily water service. In contrast, in the fifth zone, where users likewise do not have a water meter, users pay a fixed fee of 36 soles for 15m^3 and 2 hours of daily service.

Tanker truck

Supply by tanker truck that been reduced in Collique due to an increased coverage of SEDAPAL network and to alternative forms of supply, such as the "pilón".

Tanker trucks transport the water collected from SEDAPAL dispensers, which guarantee the "quality" of the water, or from clandestine dispensers, which do not clarify water origin or quality. This service is usually from individuals in the water distribution business, in a coordinated or periodic way (see *Figure 7*), to places where there are no other forms of supply. These trucks mainly supply storage tanks for the "pilones", charging for the "tank" from 120 soles (in the fifth zone) to 160 soles (in the eighth zone). The cost of water directly sold to individuals is more expensive due to the fact that water distribution requires more time, reaching 4.20 soles per cylinder (200 liters), which means a price that is more than 16 times higher than the price of SEDAPAL.

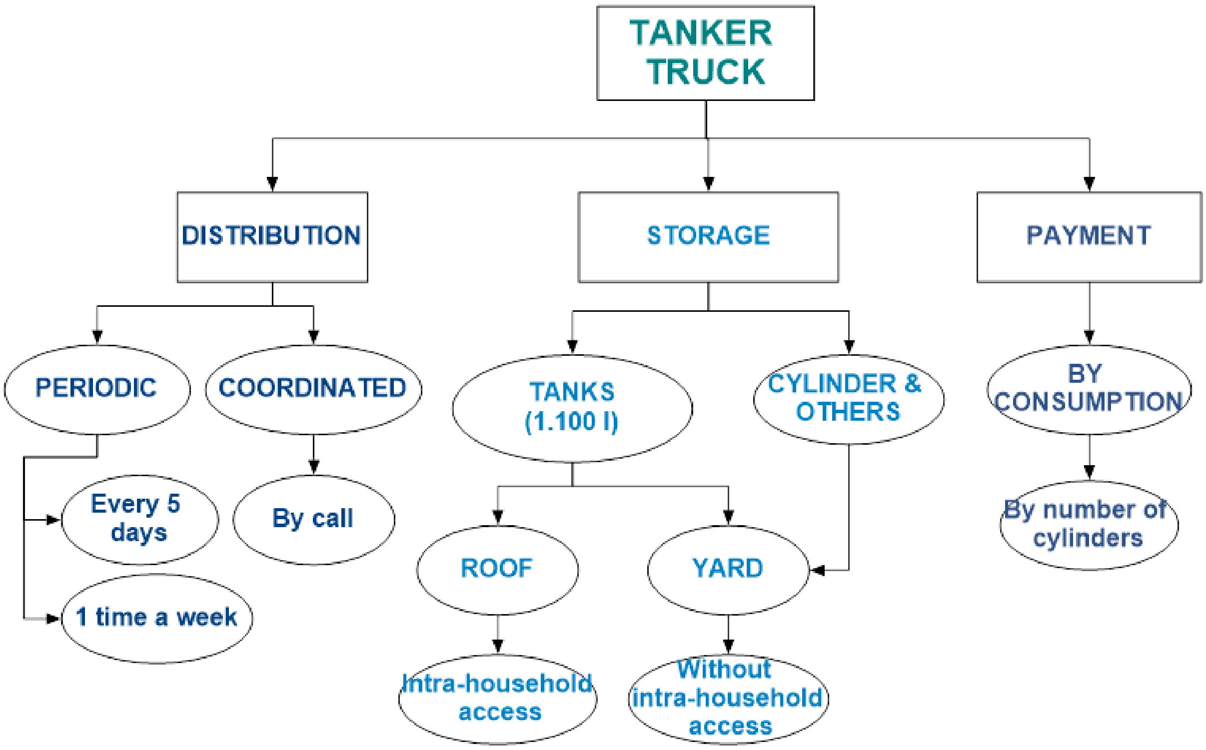


Figure 7 *Tanker trucks distribution scheme in Collique. Source: Own elaboration.*

Community members (neighbors)

This is a supply form that arises from necessity when water access from the other forms presented above is impossible. The main reason for sourcing from neighbors is the lack of a communication channel that reaches households without service, either due to the slope of the land, the high density of households, or the impossibility of truck access through a road.

Several cases have been observed in which there was a community "pilón" near these households without water. In such situations, neighbors usually negotiate with the "pilón" committee in order to be allowed access to water. However, they are required to pay the fee and to install the necessary pump and hose to supply water to their homes. If this does not happen, neighbors ask water users (usually those connected to the network) to provide them with water or to sell it to them.

In Collique, where most households that are connected to the network pay a fixed fee, giving water away does not represent any expense. Nevertheless, there are cases neighbors who do business by selling water for which they do not pay.

Water storage is similar to previous cases ("pilón", SEDAPAL, or tanker truck), with the same advantages and disadvantages depending on where the water is stored. However, in this case, because water is not available, households usually do not have intrahousehold facilities. The price of this "service" is the most expensive form of water supply.

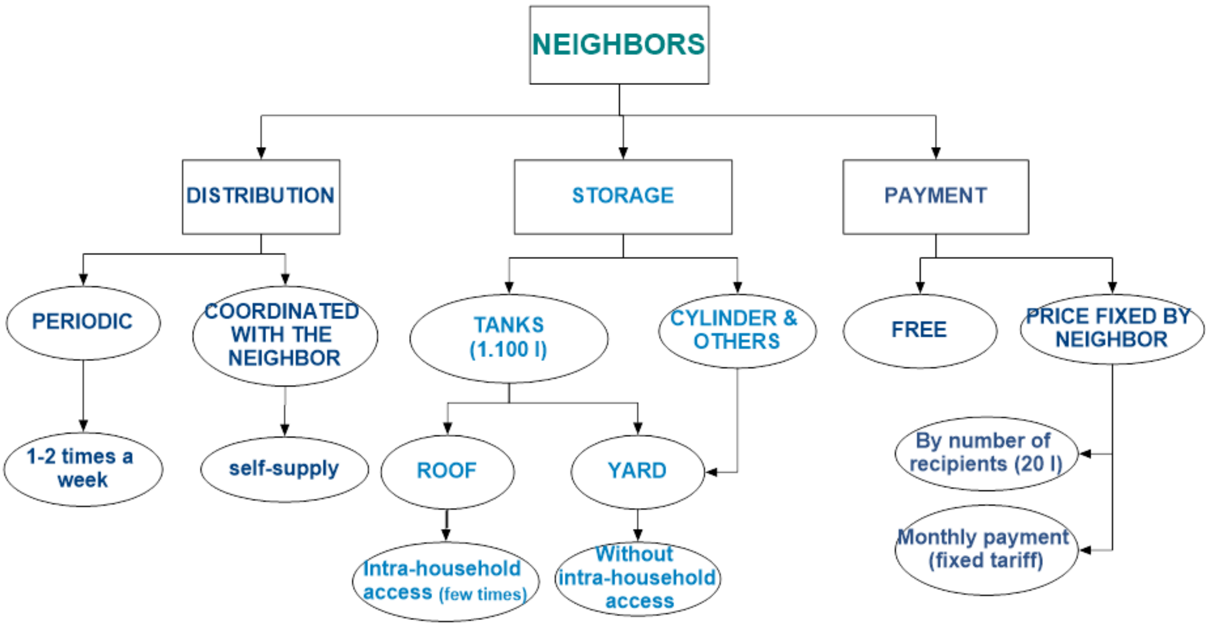


Figure 8 *Distribution scheme through the neighbors in Collique. Source: Own elaboration.*

Summary

To facilitate a comparison between the management systems presented, *Table 4* summarizes some of the most noteworthy aspects.

Table 4 C*omparison among the different management systems.*

MANAGEMENT SYSTEM	PRICE (S/) / CILINDER	OBSERVATIONS
Community "Pilón"	Tanker truck: 2.16 (final price 2.30) SEDAPAL: 0.5 (final price 1)	- Additional fee charged by committee (community management) - Variable water availability
SEDAPAL	0.48	- Better water quality - Variable water availability
Tanker truck	To community "pilón": 2–2.67 To household: 4.20	- Uncertain water quality - Variable water availability
Community members	Variable price (most expensive option)	- Greater difficulty in terms of water accessibility

2.5. Collique and HRtWS

This overview finishes by briefly presenting a research work carried out with a limited number of Collique inhabitants. This work aimed to obtain information from all areas of Collique through the opinion of different population groups (children, youth, and women), to generate a proposal of indicators that measure water service levels taking into account a HRtWS approach and its five dimensions.

To achieve this objective, a series of participatory workshops were held, selecting different age groups of population. Thus, a qualitative analysis on water services (and sanitation) perception of the participants was obtained. The outcomes of these workshops resulted in 59 individual prioritizations associated with the dimensions of the Human Right to Water (HRtW).

Figure 9 *Responses in relation to the prioritization among HRtW dimensions. Priority order is shown on the x-axis. On the y-axis, the number of answers for each dimension was prioritized for each position.*

As a result, the order of the dimensions provided by the participants was as follows:

Table 5 *Dimension prioritization with respect to Human Right to Water.*

HRtW prioritization				
1	2	3	4	5
Quality	Accessibility	Availability	Acceptability	Affordability

From this qualitative research and a literature review, we propose a multidimensional index i based on five dimensions of HRtW. For each dimension, five service levels have been defined according to numerical values, with 1 the most optimal situation, and 0, the least optimal situation. This index, although applied to the specific case of Collique, could serve as the basis for carrying out the same multidimensional assessment in any context, allowing any comparison that is considered appropriate. The concepts of each category are shown in *Table 6*, and the different level of service for each category, in *Table 7*.

Table 6 *Service level definition according to the five dimensions of HRtW.*

HRtW category definition: water service level				
Availability (AVA)	Accessibility (ACC)	Quality (QUA)	Affordability (AFF)	Acceptability (ACP)
Enough water and continuous supply	Nearby water and easy to obtain	Water apt for human consumption	Affordable water for all	Water acceptable in color, smell, and taste

Table 7 *Proposal of service levels for the five dimensions of HRtW.*

HRtW conceptual framework proposal: water service level					
Level	Availability (AVA)	Accessibility (ACC)	Quality (QUA)	Affordability (AFF)	Acceptability (ACP)
1	24-hour on-premise service	Service on-premise with intra-household facilities in use (B)	Service on-premise or by “pilón” (supplied by Sedapal), apt for human consumption; storage recipients cleaned appropriately and frequently	Service Provision Utility (SPU) tariff, fixed or by consumption (without meter), which is fair and affordable according to purchasing power (G)	Water with mountain spring appearance, transparent, without a bad smell or chlorine taste
0.75	Service on-premise, continuity of 7 to 24 hours, with sufficient storage capacity (A)	Service on-premise without intra-household facilities (C)	Service on-premise or by “pilón” (supplied by Sedapal); water is boiled before consumption (D)	SPU tariff, fixed or by consumption (without meter), which represents an important part of the expenses for basic services	Transparent water but with a slight chlorine taste
0.50	Service on-premises, from 2 to 7 hours, supplied by “pilón”, tanker truck, or other means; sufficient storage capacity	Service through “pilón” or tanker truck, with storage tanks on the roof and intra-household facilities	Service through “pilón” (supplied by tanker truck) or Sedapal tanker truck (E)	Payment by cylinder from the “pilón” (10 to 15 times higher than the SPU price)	Whitish water with a strong chlorine taste
0.25	Service on-premise, from 2 to 7 hours, supplied by “pilón”, tanker truck, or other means; insufficient storage capacity	Service through “pilón”, tanker truck, or other means, without intra-household facilities	Service through “pilón” (supplied by tanker truck) or clandestine tanker truck; water presents turbidity or strange elements (F)	Payment by cylinder from the tanker truck or other (40 times higher than the SPU price)	Water turbid or with strange elements
0	Supply from surface water (e.g., rivers, ditches, etc.)				

A. Sufficient storage capacity means that there is enough space to store the necessary water to carry out the daily activities of the whole family.

B. Intra-household facilities in use means that there is a 24-hour continuous service or that there are storage tanks on the roof that allow water to be used through a pipe.

C. Without intra-household facilities means that the infrastructure does not exist or that it is not used because there is no 24-hour service continuity or because there are no storage tanks on the roof that allow its use.

D. Boiling water before consumption is based on doubts about its quality that can be either due to network cuts, or to not knowing whether hygiene measures in network and distribution tanks maintenance are correct or not.

E. Hygiene of the tankers trucks depends on their care and maintenance directly from the tanker owners. It is often not adequate. If the tanker truck is supplied by Sedapal, the water comes from the treatment plant and is collected with enough residual chlorine to reach the households with 0.5 mg/l of residual chlorine.

F. The water in Collique network is pumped to different tanks distributed throughout the area, and water is then distributed to the households from these tanks. If the tanks are not properly maintained, and when water is not available over 24 hours, the water that arrives to the households might be turbid or dirty after the system is restarted.

G. Affordability includes being able to pay for the construction of intra-household facilities and can also include receiving subsidies (when necessary).

We would like to note, after having introducing the conceptual framework, that the five dimensions are not weighted equally. Rather, a specific weight is assigned to each dimension according to the prioritization presented in *Table 4*. However, it is important to highlight that Human Rights principles point out the importance of evaluating all categories equally. In this case, there is no intention to belittle any dimension, but rather to propose a conceptual framework that reflects the specific needs of study area.

For weight definition, the methodology called "centroid" (Shepetukha & Olson, 2001) is applied, which proposes to define those weights once the order of the categories is available. This methodology assigns weight w_1 as the most important, w_2 as the second most important, and so forth.

$$w_1 = \frac{(1 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{k})}{k}$$

$$w_2 = \frac{(0 + \frac{1}{2} + \frac{1}{3} + \cdots + \frac{1}{k})}{k}$$

$$w_k = \frac{(0 + 0 + 0 + \cdots + \frac{1}{k})}{k}$$

The sum of these weights will be equal to the unit. The more categories there are, the lower the implied error will be (Shepetukha & Olson, 2001). For the five categories that correspond to the HRtW five dimensions, the following weights are obtained (*Table 7*):

Table 7 *Weights ordered for HRtW according to the proposed methodology.*

Quality (QUA)	Accessibility (ACC)	Availability (AVA)	Acceptability (ACP)	Affordability (AFF)
w_1	w_2	w_3	w_4	w_5
0.45	0.26	0.16	0.09	0.04

Finally, the multidimensional index is formulated based on the geometric (or multiplicative) mean of the different dimensions. It is very important to keep in mind that this formulation does not allow any compensation among the variables. That is, if any of the dimensions is evaluated as zero, the final value of the index will be zero as well.

$$Index_{HRtW} = QUA^{w_1} \text{ x } ACC^{w_2} \text{ x } AVA^{w_3} \text{ x } ACP^{w_4} \text{ x } AFF^{w_5}$$

Substituting both the values of the service level associated with the context of Collique and the values of the weights, the final value of the proposed index is obtained:

$$Index_{HRtW} = 0.5^{0.45} \text{ x } 0.25^{0.26} \text{ x } 0.25^{0.16} \text{ x } 0.5^{0.09} \text{ x } 0.25^{0.04} = 0.37$$

3. Class Activity

The class activity proposed in this case study is structured in two different blocks:

Block I. Students will work in small groups of 3 to 4 people. Afterwards, a general debate will take place. The duration of this activity is estimated to be 1 hour and 15 minutes: 45 minutes of group discussion and 30 minutes of general discussion. It is suggested that the professor acts as moderator.

To facilitate the development of this block and successive activities, it is recommended that students receive all the information presented in Section 2. Ideally, the contextualization of the case study should be provided before the development of the activities in order to provide adequate time for reading.

Block II. This is a workshop guided by the professor, in which students should work individually. This block takes an estimated 45 minutes to complete. Specifically, the workshop consists in providing the students with enough information to perform the dimensioning of a small water supply network. The objective is to be able to scale this design to a larger area (as homework activity).

BLOCK I

The objective of this first activity is to raise awareness about the importance of accessing water services. This exercise will be carried out from a Human Rights perspective. In this sense, and after having presented the theoretical content of this case study, it is proposed to complete the attached table, by indicating the direct and indirect impacts associated with the deprivation of the HRtW dimensions. Impacts can be identified from different perspectives, such as health, development, and environment, among others. Likewise, each group is encouraged to identify and to justify the dimension that they consider to be the most important. Finally, and based on the current situation of Collique (service level) and the prioritization carried out, it is proposed that the students recalculate the proposed $\text{Index}_{\text{HRtW}}$.

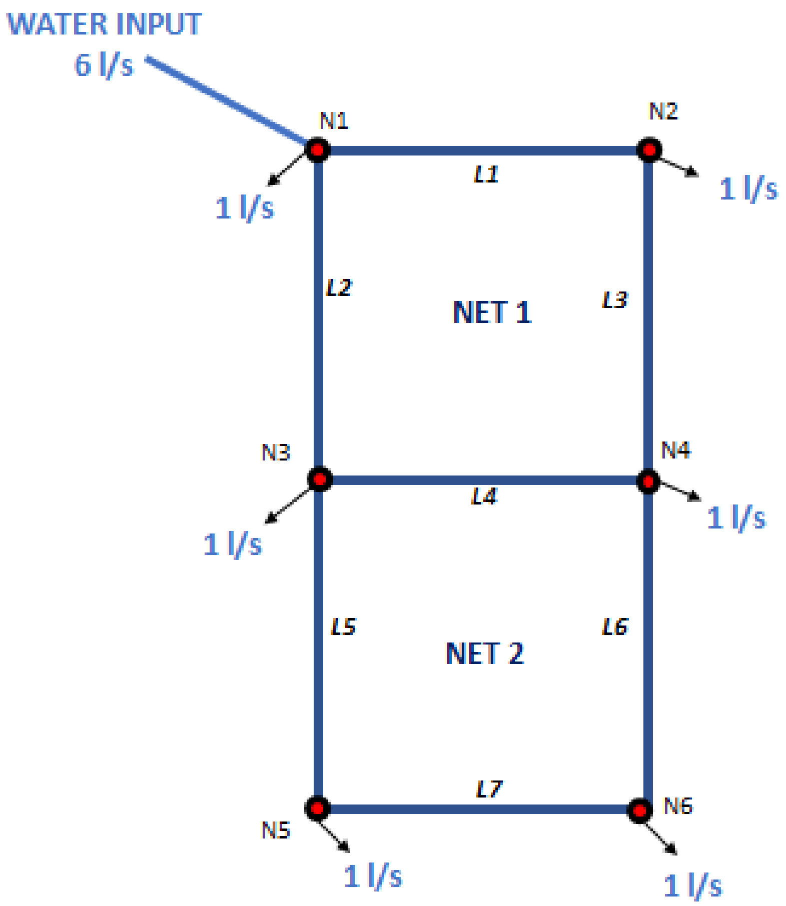
Ranking	DIMENSION (lack)	DIRECT IMPACTS	INDIRECT IMPACTS
	Availability		
	Accessibility		
	Quality		
	Affordability		
	Acceptability		

BLOCK II

The aim of this guided workshop is to provide students with an illustrative example of the dimensioning of a small water supply network. Thus, the homework activity should be carried out autonomously.

The approach of this workshop will be at individual level. In this sense, it is expected that students will be able to follow and materialize the relevant calculations explained by the professor. The background and starting data are the following:

A drinking water distribution network should be dimensioned for the neighborhood of Collique that covers two blocks of 200 m × 200 m. The water input that feeds the meshes is located 20 m above nodes 1 and 2. In each node, there is a hydrant with a peak demand of 1 l/s, so that the consumption of the net is 6 l/s. In addition, all the sections are formed by equal pipes of 90 mm exterior diameter. The meshes that make up the network are square and equal, as shown in the following figure:



Nodes	Height
N1	20
N2	20
N3	10
N4	10
N5	0
N6	0

Sections	Length
L1	200 m
L2	200 m
L3	200 m
L4	200 m
L5	200 m
L6	200 m
L7	200 m

With this starting data, the students should calculate the internal flow of the network and the pressure that each hydrant will have, taking into account the pressure losses of pipe sections.

3.1. Solution and evaluation criteria

Class activity solution: Block I

It must be taken into account that the answers are open (i.e., no set answers that are right or wrong), especially for the proposal of the HRtW dimension prioritization. This of course does not mean that the students (who are also possibly inexperienced in the subject) are always "right" with their reflections; rather, the mere task of reflecting is one of the objectives of this activity. Nonetheless, we have presented some possible answers here in order to guide the professor (moderator) during the general debate.

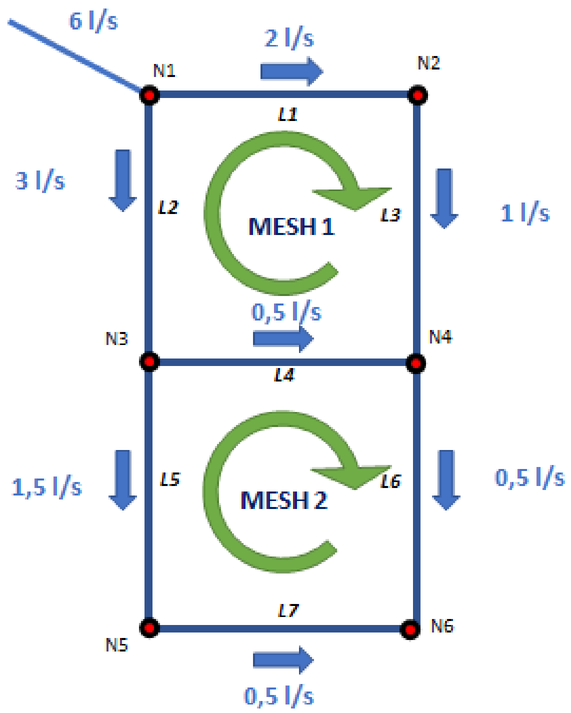
DIMENSION (lack)	DIRECT IMPACTS	INDIRECT IMPACTS
Availability	- Needs cannot be met when needed (drinking and cooking, hygiene, washing food and clothes)	- Economic investment in household deposits, for example, for storage
Accessibility	- Water needed for consumption (drinking and cooking, hygiene, washing food and clothes) cannot be guaranteed in cases when the water source is very far away - Leads to increased insecurity (especially when women and girls collect the water and when distances are long)	- Difficulty for the development of vital and economic activities - Possibility of increasing aggression against girls and women
Quality	- Effects on human health (including death) - Deterioration of ecosystems (pollution)	- Difficulty to develop capacities (poverty growth); health expenditures increase - Decreased resources for subsistence (decreased food security and increased poverty)
Affordability	- Discrimination against the most unfavorable population sectors - Possible generation of social conflicts	- Difficult to access to other services; increase in the gap between those who have more and those who have less - Increase in the gap between public institutions or agents responsible for the management of the service; decrease in citizen participation
Acceptability	- Search for alternative water sources (possible synonymous with health risk)	- Expenditure increase household and public health levels

As far as ranking elaborations and new index recalculations, each group is expected to will its own result. Therefore, no specific answer is provided for this section.

Class activity solution: Block II

First, it is necessary to consider an internal water flow distribution to the mesh that meets each hydrant demand. Likewise, a water circulation direction of the mesh is established to identify the sign (positive or negative) of the flows in each section. The detailed procedure is shown in *Annex II*.

Additionally, the necessary iterations will be performed to obtain a residual (ΔQ) of zero. In this case, 2 and 3 iterations will suffice for mesh 1 and mesh 2, respectively.



Mesh 1

STARTING DATA						
Section	D_{ext} (mm)	D_{int} (mm)	L (m)	Roughness	r_i (mm)	Q_1 (m^3/s)
L1	90	73.6	200	150	65,313.9	0.0020
L2	90	73.6	200	150	65,313.9	–0.0030
L3	90	73.6	200	150	65,313.9	0.0010
L4*	90	73.6	200	150	65,313.9	0.0005

ITERATION 1		
Δh	$\Delta h/Q_1$	$Q_2 = Q_1 + \Delta Q$
0.66	327.70	0.0023
–1.39	462.93	–0.0027
0.18	181.55	0.0013
–0.05	100.58	–0.0005
$\Sigma\Delta h$	$\Sigma(\Delta h/Qi)$	ΔQ
–0.6	1,072.77	0.0003

ITERATION 2		
Δh	$\Delta h/Q_2$	$Q_3 = Q_2 + \Delta Q$
0.851	369.56	0.0023
–1.140	422.77	–0.0027
0.296	227.49	0.0013
–0.054	104.07	–0.0006
$\Sigma\Delta h$	$\Sigma(\Delta h/Qi)$	ΔQ
–0.047	1,123.90	0.0000

Mesh 2

STARTING DATA						
Section	D_{ext} (mm)	D_{int} (mm)	L (m)	Roughness	r_i (mm)	Q_1 (m^3/s)
L4*	90	73.6	200	150	65,313.9	0.0005
L5	90	73.6	200	150	65,313.9	-0.0015
L6	90	73.6	200	150	65,313.9	0.0005
L7	90	73.6	200	150	65,313.9	-0.0005

ITERATION 1		
Δh	$\Delta h/Q_1$	$Q_2 = Q_1 + \Delta Q$
0.05	100.58	0.0005
–0.38	256.47	–0.0012
0.05	100.58	0.0008
–0.05	100.58	–0.0002
$\Sigma\Delta h$	$\Sigma(\Delta h/Qi)$	ΔQ
–0.33	558.22	0.0003

ITERATION 2		
Δh	$\Delta h/Q_2$	$Q_3 = Q_2 + \Delta Q$
0.0005	0.054	104.07
–0.0012	–0.245	208.53
0.0008	0.127	153.86
–0.0002	–0.007	41.43
$\Sigma\Delta h$	$\Sigma(\Delta h/Qi)$	ΔQ
–0.072	507.89	0.0001

ITERATION 3		
Δh	$\Delta h/Q_3$	$Q_4 = Q_3 + \Delta Q$
0,065	113,18	0,0006
–0,217	196,94	–0,0011
0,149	165,93	0,0009
–0,003	25,57	–0,0001
$\Sigma\Delta h$	$\Sigma(\Delta h/Qi)$	ΔQ
–0,005	501,63	0,0000

*L4 section belongs to both meshes.

At the calculation level, the iteration would be as follows:

Mesh 1

Section 1

$Q_2(1)=Q_1(1)+\Delta Q_1(1)=2.0+0.3=2.3 l/s$

$Q_3(1)=Q_2(1)+\Delta Q_2(1)=2.3+0.0=2.3 l/s$

$Q_4(1)=Q_3(1)+\Delta Q_3(1)=2.3+0.0=2.3 l/s$

Section 2

$Q_2(1)=Q_1(1)+\Delta Q_1(1)=–3.0+0.3=–2.7 l/s$

$Q_3(1)=Q_2(1)+\Delta Q_2(1)=–2.7+0.0=2.7 l/s$

$Q_4(1)=Q_3(1)+\Delta Q_3(1)=–2.7+0.0=2.7 l/s$

Section 3

$Q_2(1)=Q_1(1)+\Delta Q_1(1)=1.0+0.3=1.3 l/s$

$Q_3(1)=Q_2(1)+\Delta Q_2(1)=1.3+0.0=1.3 l/s$

$Q_4(1)=Q_3(1)+\Delta Q_3(1)=1.3+0.0=1.3 l/s$

Section 4

$Q_2(1)=Q_1(1)+\Delta Q_1(1)–\Delta Q_1(2)=–0.5+0.3–0.3=–0.5 l/s$

$Q_3(1)=Q_2(1)+\Delta Q_2(1)–\Delta Q_2(2)=–0.5+0.0–0.1=–0.6 l/s$

$Q_4(1)=Q_3(1)+\Delta Q_3(1)–\Delta Q_3(2)=–0.6+0.0–0.0=–0.6 l/s$

Mesh 2

Section 4

$Q_2(2)=Q_1(2)+\Delta Q_1(2)–\Delta Q_1(1)=0.5+0.3-0.3=0.5 l/s$

$Q_3(2)=Q_2(2)+\Delta Q_2(2)-\Delta Q_2(1)=0.5+0.1-0.0=0.6 l/s$

$Q_4(2)=Q_3(2)+\Delta Q_3(2)-\Delta Q_3(1)=0.6+0.0-0.0=0.6 l/s$

Section 5

$Q_2(2)=Q_1(2)+\Delta Q_1(2)=-1.5+0.3=-1.2 l/s$

$Q_3(2)=Q_2(2)+\Delta Q_2(2)=-1.2+0.1=1.1 l/s$

$Q_4(2)=Q_3(2)+\Delta Q_3(2)=-1.1+0.0=1.1 l/s$

Section 6

$Q_2(2)=Q_1(2)+\Delta Q_1(2)=0.5+0.3=0.8 l/s$

$Q_3(2)=Q_2(2)+\Delta Q_2(2)=0.8+0.1=0.9 l/s$

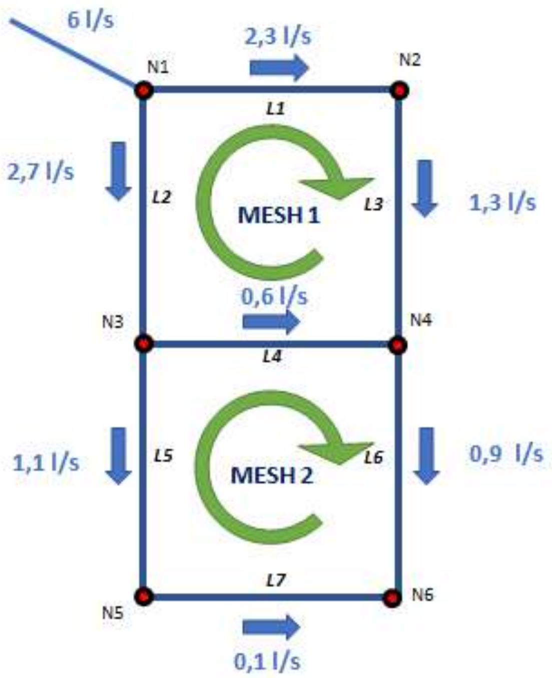
$Q_4(2)=Q_3(2)+\Delta Q_3(2)=0.9+0.0=0.9 l/s$

Section 7

$Q_2(2)=Q_1(2)+\Delta Q_1(2)=-0.5+0.3=-0.2 l/s$

$Q_3(2)=Q_2(2)+\Delta Q_2(2)=-0.2+0.1=-0.1 l/s$

$Q_4(2)=Q_3(2)+\Delta Q_3(2)=-0.1+0.0=-0.1 l/s$



As it can be seen in section 4, which belongs to both meshes, the calculation is balanced by taking the ΔQ of each mesh, but of an opposite sign. Thus, the final result of the flow within the mesh is presented above.

Once the solution of the flows in each section has been found, it is necessary to determine the pressure losses to guarantee that the pressure in each node is adequate (between 30 and 60 meters water column). Likewise, circulation velocities must be checked so that they are included between the values 0.6 and 1 m/s (see *Annex I*).

Section	D_{ext} (mm)	D_{int} (mm)	L (m)	Rough.	Q (l/s)	v (m/s)	H (m)	Δz (m)	P (mwc)
1	90	73.6	200	150	2.33	0.55	0.87	40	39.13
2	90	73.6	200	150	2.67	0.63	1.12	40	38.88
3	90	73.6	200	150	1.33	0.31	0.31	50	49.69
4	90	73.6	200	150	0.57	0.13	0.06	50	49.94
5	90	73.6	200	150	1.09	0.26	0.21	50	49.79
6	90	73.6	200	150	0.91	0.21	0.15	60	59.85
7	90	73.6	200	150	0.09	0.02	0.00	60	60.00

Evaluation criteria

To evaluate this class activity, the use of the attached rubric is proposed (see *Annex VII*). Briefly, this rubric details: i) the knowledge that students are expected to acquire, and ii) the criteria that will be used to evaluate the resolution content associated with the activities proposed. This way helps to provide an objective and transparent evaluation system for the students.

Firstly, students should be informed about the existence of the rubric. That is, they must be provided the rubric along with the information related to the contents to be evaluated. Thus, some guidance should be given to students to allow them to carry out the proposed activities.

For the evaluation of Block I, each group must submit a written document answering the questions raised. These answers will be evaluated based on the proposed rubric. However, the professor is free to choose an alternative evaluation method if she/he considers it more appropriate. On the other hand, Block II will not be evaluated, as it is a guided workshop with the sole objective of providing the necessary knowledge to develop the autonomous activity that is proposed.

4. HOMEWORK ACTIVITY

In this activity, students will work in small groups of 3 to 4 people (note that maintaining the same working groups as in the previous activity would make it easier to evaluate the overall work). The main reason for group work is to encourage internal debate. The activity is estimated to require approximately 15 to 20 hours of work.

From a more technical perspective, and in methodological terms, it is proposed to solve the exercise through the use of an excel spreadsheet, posing the problem in a simplified manner but considering the main phenomena for dimensioning the water supply network. However, the existence of specific software for hydraulic networks calculation should be highlighted. In this sense, it is possible to find the tool which is presented under the name of EPANET[2] and is distributed openly by the Environmental Protection Agency (EPA) of the United States. In addition, and in contrast, a commercial tool named WaterGEMS[3], developed by Bentley, can be found as well.

The aim of this activity encourages the students to apply the knowledge they acquired both through the guided workshop and through the contextualization of this case study. Specifically, the students are expected to be able to dimension a larger water distribution network and to be able to reflect on the service management. Under these premises, the problem that arises is the following.

In its eagerness to improve the level of water service, the government of the city of Lima (through the public company SEDAPAL) decides to expand the water supply network in the neighborhood of Collique. One of the agreements reached guarantees the execution of the work with the commitment of neighborhood residents, who should participate in the service management.

The final technical decision lies in the construction of a series of public water sources located in different parts of the neighborhood. The location criterion is to provide each household with access to a source located between 50 and 100 meters away.

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[2] *Access and information regarding EPANET software at: https://www.epa.gov/water-research/epanet*.
[3] *More information as far as WaterGEMS commercial software at: https://www.bentley.com/es/products/product-line/hydraulics-and-hydrology-software/watergems*

In order to simplify the problem, the focus in this case study will be directed to a limited set of households (see *Figure 10*), which belong to the upper part of zone 6 of Collique.

Figure 10 *Project service area. Source: Own elaboration, from Google Earth.*

The designed water endowment is fixed at 120 l/inhabitant per day. The justification resides, on the one hand, in that endowments greater than 100 liters per day satisfy all the needs of consumption and hygiene, thus reducing the impact on health almost completely (WHO, 2003). On the other hand, it includes a more-than-likely consumption increase in the future.

Further, the service area is approximately 10.2 ha (hm^2). Assuming a homogeneous population distribution in Collique, which has a population density of 23,200 inhabitants / km^2 (see *Table 3*), it can be estimated that 2,366 people live in the area. If a population growth of 1.5% per year is assumed, the predicted population in 2035 is estimated to be 3,187 inhabitants who live in the study area. Therefore, the starting data is detailed as follows:

Table 8 *Starting data for water distribution network dimension.*

VARIABLE	VALUE
Current population	2,366 inhab
Estimated population in 2035	3,187 inhab
Daily consumption	382,464 L/day
Daily peak consumption (+10%)	38,246 L/day
Design flow	10.6 L/s

Therefore, a future peak flow of 10.6 l/s is estimated to be required to serve the study area. In addition to this, the geometry of the network must be defined. In this sense, a network with 6 meshes, 21 sections, and 16 nodes has been designed. The reason for choosing such geometry of redundant meshes lies in the possibility of guaranteeing flow circulation in case of breakage of any section. The system of water sources is distributed in 12 of network nodes, which will have an identical output flow rate of 0.883 l/s. The location of these hydrants has been made based on the accessibility criteria detailed above (see *Figure 11*).

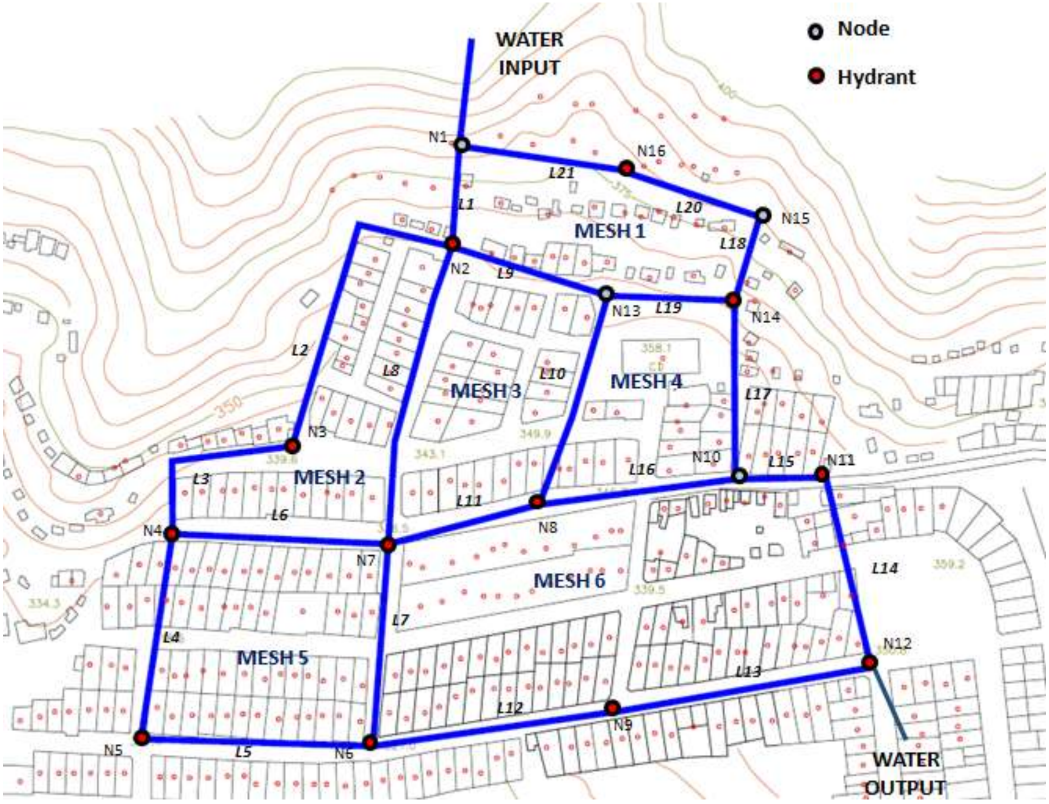


Figure 11 *Proposal for water distribution network geometry*

Finally, data associated with network pipe sections and nodes are provided to support carrying out the activity.

SECTION	LENGTH (m)
L1	47.6
L2	146.3
L3	81.0
L4	94.7
L5	109.6
L6	101.9
L7	95.4
L8	141.2
L9	77
L10	103.7
L11	73.6

SECTION	LENGTH (m)
L12	117.8
L13	120.3
L14	92.2
L15	42.8
L16	93.4
L17	84.2
L18	41.2
L19	60
L20	70
L21	75.8

A storage tank will be built at water input point, located 8 meters above node N1. This height allows water to flow by gravity and to be distributed to the public water sources, overcoming the hydraulic gradient. The capacity of the deposit is estimated to be 1,000 m^3. These data have no influence on dimensioning the distribution network but facilitate understanding of system operation.

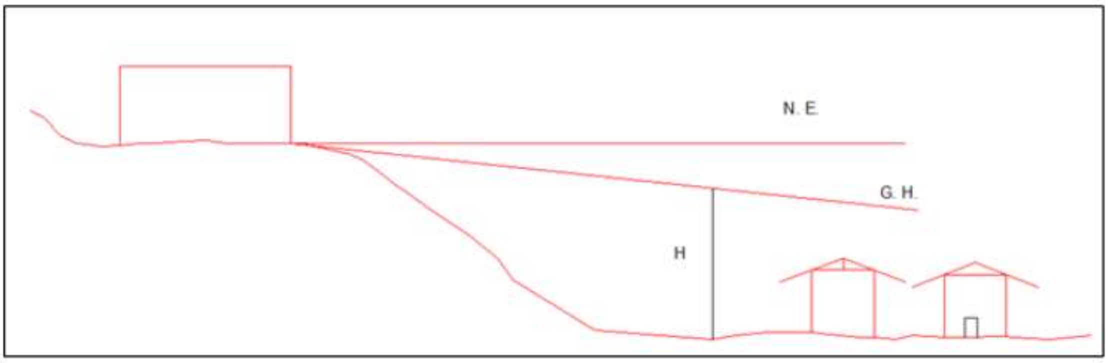


Figure 12 *Height storage tank distribution scheme. Source: Jiménez Terán, 2013.*

NODE	HEIGHT (m)
N1	382
N2	360
N3	360
N4	333
N5	311
N6	321
N7	336
N8	340

NODE	HEIGHT (m)
N9	335
N10	350
N11	355
N12	350
N13	362
N14	372
N15	380
N16	377

Once starting data for developing the proposed technical activity have been provided, students are required to reflect and state their response to the six questions indicated below. Additionally, students are requested to link these reflections to the ethical code of the profession. For this purpose, the given deontological codes can be taken as examples (see *Annexes III* and *IV*). However, similar documents can be used if convenient.

Task 1. Analyze and discuss the obtained technical results.

Task 2. Propose a management scheme related to the water distribution network (maximum 2 pages). In this proposal, it is suggested that students discuss aspects related to the organization among the residents of the neighborhood, the relationship with SEDAPAL, the control of the water supply (e.g., quality, consumption, etc.), the medium / long-term strategy, the potential actions regarding the most vulnerable populations in the neighborhood, transfer of knowledge, etc. Additionally, and from an ethical point of view, students should reflect about the need / responsibility of the engineer to participate in the process of defining the management system.

Task 3. Detail the possible reasons why a project to bring water into household premises has not been carried out.

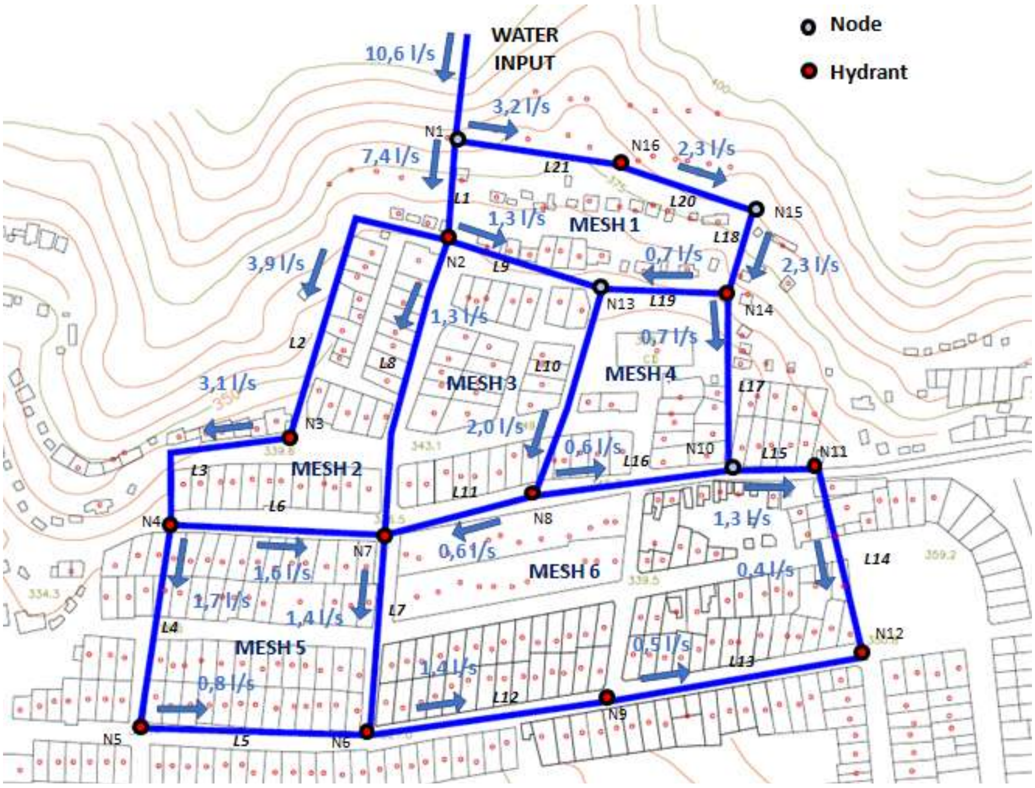
Task 4. If a distinct ethical code of the profession is used for consultation, briefly compare the main similarities and differences with those codes that have been provided herein (*Annexes III* and *IV)*.

Task 5. Compare the result of building public water sources and household connections from the perspective and methodology of the multidimensional index proposed ($Index_{HRtW}$). For this purpose, students should rely on the conceptual proposal outlined in *Table 7*.

Task 6. Reflect on the suitability of using the proposed multidimensional index to assess the level of water service. Do you consider that the HRtW dimensions should be included to evaluate the performance of a service provider, such as SEDAPAL? Evaluate the pros and cons of implementing this proposal.

4.1. Solution y evaluation criteria

Hydraulic calculations must be carried out for each section. To do this, a first assumption of each mesh flow distribution should be done, assigning random flow directions. These flows and directions will serve to perform the first iteration of the calculation process. Possible flow distributions could be the following:

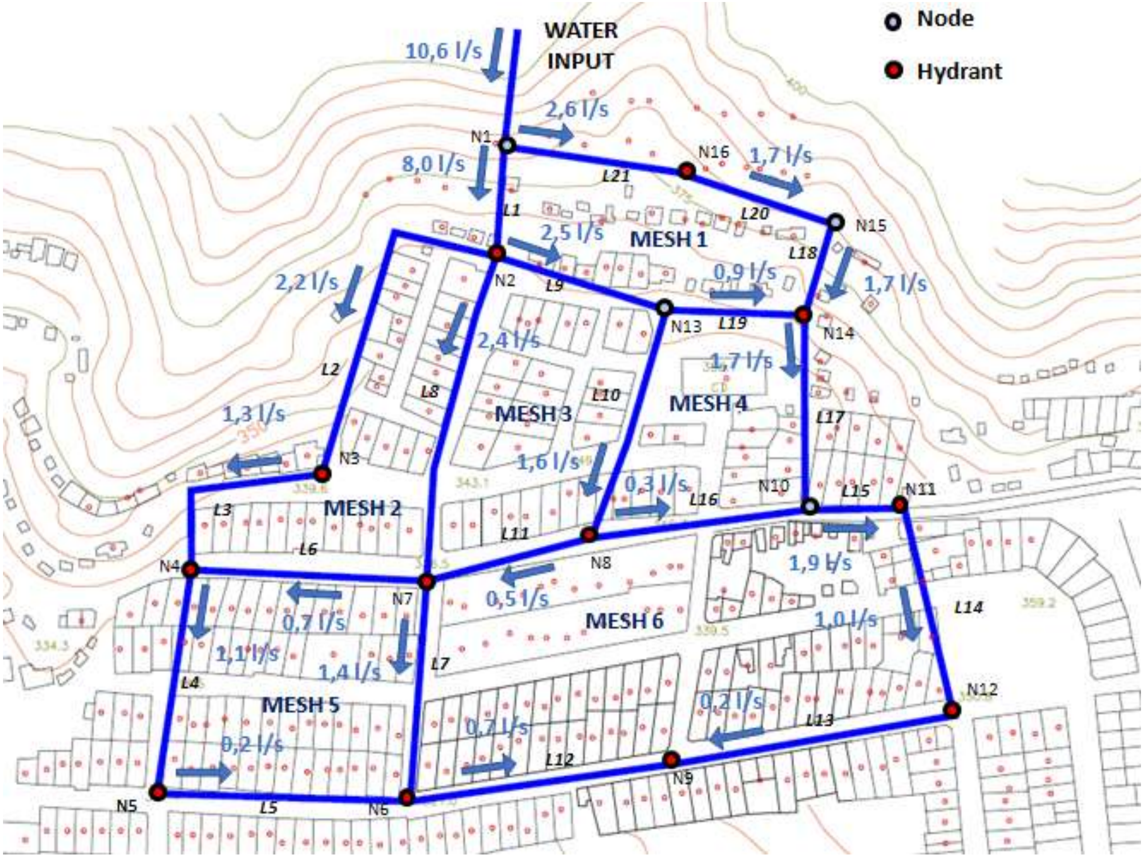


For pipe diameter calculation, the Hardy-Cross iterative method should be used (see *Annex I*). First, a flow equilibrium is made among the nodes, and the theoretical internal diameter (D_t) is calculated. Once D_t has been obtained, the nearest commercial diameter, which guarantees specific velocities, is chosen. For example, if a velocity of 0.5 m/s is reached, the commercial diameter with the smallest radius (in this case, 90 mm) will be chosen. In this way, the results obtained are presented in the following table:

REQUIRED DIAMETER ESTIMATION						
Node	**Q (l/s)**	**v (m/s)**	**D_{int} (mm)**	**D_{int} comer. (mm)**	**D_{ext} comer. (mm)**	**Check v**
1	10.623	1,00	116.30	130.80	160 (P.N.16 ESP.)	0.79
2	6.551	1,00	91.33	114.60	140 (P.N.16 ESP.)	0.64
3	3.045	1,00	62.27	73.60	90 (P.N.16 ESP.)	0.72
4	2.160	1,00	52.44	73.60	90 (P.N.16 ESP.)	0.51
5	0.843	1,00	32.76	73.60	90 (P.N.16 ESP.)	0.20
6	1.381	1,00	41.93	73.60	90 (P.N.16 ESP.)	0.32
7	1.424	1,00	42.57	73.60	90 (P.N.16 ESP.)	0.33
8	1.133	1,00	37.98	73.60	90 (P.N.16 ESP.)	0.27
9	0.496	1,00	25.12	73.60	90 (P.N.16 ESP.)	0.12
10	1.275	1,00	40.29	73.60	90 (P.N.16 ESP.)	0.30
11	0.390	1,00	22.27	73.60	90 (P.N.16 ESP.)	0.09
12	0.000	1,00	---	73.60	90 (P.N.16 ESP.)	0.00
13	2.018	1,00	50.69	73.60	90 (P.N.16 ESP.)	0.47
14	1.416	1,00	42.47	73.60	90 (P.N.16 ESP.)	0.33
15	2.302	1,00	54.14	73.60	90 (P.N.16 ESP.)	0.54
16	2.302	1,00	54.14	73.60	90 (P.N.16 ESP.)	0.54

Once these values have been obtained, the iteration process, explained in the guided workshop, will be carried out. For this, as mentioned, an Excel spreadsheet will be used as support, due to the large number of operations and iterations (minimum 5 per mesh).

The result of the iteration process is the following:



As in the guided workshop, it would be necessary to determine the pressure losses (to guarantee that the pressure in each node is adequate) as well as the circulation velocities.

Section	D_{ext} (mm)	D_{int} (mm)	L (m)	Rough.	Q (l/s)	v (m/s)	H (m)	Δz (m)	P (mwc)
1	140	114.6	47.6	150	8.04	0.78	0.24	22	29.76
2	90	73.6	146.3	150	2.22	0.52	0.58	22	29.42
3	90	73.6	81	150	1.33	0.31	0.13	49	56.87
4	90	73.6	94.7	150	1.12	0.26	0.11	47	54.89
5	90	73.6	109.6	150	0.24	0.06	0.01	61	68.99
6	90	73.6	101.9	150	0.68	0.16	0.04	61	68.96
7	90	73.6	95.4	150	1.37	0.32	0.16	61	68.84
8	90	73.6	141.2	150	2.42	0.57	0.66	46	53.34
9	90	73.6	77	150	2.52	0.59	0.39	20	27.61

Section	D_{ext} (mm)	D_{int} (mm)	L (m)	Rough.	Q (l/s)	v (m/s)	H (m)	Δz (m)	P (mwc)
10	90	73.6	103.7	150	1.65	0.39	0.24	42	49.76
11	90	73.6	73.6	150	0.51	0.12	0.02	46	53.98
12	90	73.6	117.8	150	0.72	0.17	0.06	47	54.94
13	90	73.6	120.3	150	0.16	0.04	0.00	32	40.00
14	90	73.6	92.2	150	1.05	0.25	0.09	32	39.91
15	90	73.6	42.8	150	1.93	0.45	0.13	27	34.87
16	90	73.6	93.4	150	0.25	0.06	0.01	42	49.99
17	90	73.6	84.2	150	1.68	0.39	0.20	32	39.80
18	90	73.6	41.2	150	1.69	0.40	0.10	10	17.90
19	90	73.6	60	150	0.87	0.21	0.04	15	22.96
20	90	73.6	70	150	1.69	0.40	0.17	2	9.83
21	90	73.6	75.8	150	2.58	0.61	0.40	5	12.60

Discussion for Task 1. Once dimensioning has been done, students were requested to analyze and discuss the technical results obtained.

One of the first remarkable aspects is the existence of certain pipe sections (i.e. sections 9, 18, 19, 20, and 21, corresponding to the net 1) in which water pressure is not between the values cited above (i.e., between 30 and 60 mwc). These design values serve to ensure network pressures in the case of several height buildings without the need for additional installations. Regarding Collique's current urbanization and proposed distribution system of water sources, lower pressures are admitted, as water distribution is made at ground level.

As the network has been dimensioned to support a future distribution to household premises, it must be taken into account that, in those dwellings located at the top of the neighborhood, the pressure is less than 30 mwc. If the upper buildings in the area have more than two floors, it is likely that water pumps will be needed to supply upper floors. Currently, the highest areas of Collique are the ones with most precarious constructions, with only a ground floor (see *Figure 4*). For this reason, the calculated pressures guarantee water service at these heights.

Some sections, which correspond to lower heights, have pressures greater than 60 mwc. It is recommended that these pressures are lower than this value, in order to have a margin of safety for the different elements of the network (such as for joints, pipes, valves, etc.). In those sections in which desired pressure is exceeded, values between 10% and 15% are reached. Although the different material components that make up the network are usually designed to withstand pressures of 100 mwc, it is important to consider these high pressures to foresee the possible installation of regulators throughout the network.

The different mechanical components of a distribution network have not been addressed in this case study; therefore, the problem is limited to the flow and mesh balance calculations, rather than to the constructive procedures of the network itself. In spite of this, other technical considerations must be taken into account that are complementary to those set out above (e.g. other aspects dealt with in the subject).

However, the network is far from the maximum operating values. Water circulation velocities do not reach the value of 1 m/s, which is considered to be the optimum value when dimensioning for a given pipe diameter. Therefore, the resulting network could absorb an increase in demand. To corroborate this statement, the students are recommended to perform an exercise in which the inflow is doubled and the meshes are readjusted (if necessary). In the event that the neighborhood has grown in size and population, not only the increased consumption but also the entrance pressure to the proposed distribution network must be reviewed.

Finally, it can be observed that practically all the pipes used (except for section 1, due to a higher inflow rate) have the same commercial size (90 mm exterior diameter). Notably, using same pipe diameters is useful for both construction and maintenance reasons.

Discussion for Task 2. For the management scheme that is requested, it should be noted that it is an open response with no single “correct” solution. Therefore, no specific example is provided for this.

However, as mentioned previously, students are expected to reflect from two different points of view: I) in those aspects related to the service management itself (organization among residents, relationship with SEDAPAL, control of water supply, etc.); and II) considering professional activity from an ethical point of view. In this sense, and starting from the proposed solution, students are expected to establish links with environmental, social, and economic aspects with the ethical code they have used.

Discussion for Task 3. There may be several reasons why a project is not executed to provide households with water connections on-premise. In this light, and as for the previous question, this response is open; nonetheless, some possible lines of reflection are detailed here: I) a project of this nature has an associated greater complexity of execution and a greater economic cost. Specifically, in the dimensioned network, 1,822 m of pipe were used to distribute water to the public water sources (see *Annex VI*); II) the clear economic savings could be used to build a similar system elsewhere in the city with a situation similar to that of Collique. The objective would be to calculate the number of people who access the service in order to provide an optimal service to a smaller subset; III) the proposed solution pursues citizen participation in the service management. In this sense, the service provider's duties would be facilitated, and an increased awareness for all parties related to this service would be favored. However, this possible strategy would not be exempt from the appearance of possible conflicts between both parties.

Discussion for Task 4. If another ethical code of the profession has been used, students will be requested to identify those main aspects in which it coincides with and/or differs from the codes provided here as the example (*Annexes III and IV*). If the provided codes were used, answering this question is no longer relevant. The main objective of the question is for the students to know about, and to reflect on, the deontological code of the profession.

Discussion for Task 5. The quantitative results of the multidimensional index ($Index_{HRtW}$) are presented below. Specifically, results refer to those cases in which Collique's population access to water through public water sources ("pilón") or directly on-premise. To define the values associated with HRtW dimensions, the conceptual framework proposed in *Table 7* of this document is used. The weights associated with each dimension are kept constant according to the research carried out in Collique.

For the results obtained, a clear difference between the two possible solutions can be seen. Taking into account that the current value is 0.37 (see *Section 2.5*), this valuation would increase 30% (0.52) by building public water sources, and by 60% (0.89) by providing access to water on household premises.

"PILÓN"	Quality (QUA)	Accessibility (ACC)	Availability (AVA)	Acceptability (ACP)	Affordability (AFF)
Value	0.5	0.25	0.75	0.5	0.75
Weight	w_1	w_2	w_3	w_4	w_5
	0.45	0.26	0.16	0.09	0.04
$Index_{HRtW}$	**0.52**				

ON PREMISES	Quality (QUA)	Accessibility (ACC)	Availability (AVA)	Acceptability (ACP)	Affordability (AFF)
Value	1	0.75	1	0.75	0.75
Weight	w_1	w_2	w_3	w_4	w_5
	0.45	0.26	0.16	0.09	0.04
Index$_{HRtW}$	**0.89**				

Discussion for Task 6. Although this question is also open to the opinions of the students, there are some aspects that should be considered. Positive aspects include the use of a common monitoring framework, such as the one proposed, as this would offer a closer view of reality, in line with the recognition of this service as a Human Right. Additionally, it would facilitate the comparison between different areas/regions, objectively supporting the prioritization around what to do and where to invest, and thereby making those sectors of the most vulnerable population more visible. Additionally, transparency would be promoted by the service provider. Negative include potential conflicts that could arise within the population if the assessment is low aspects (this depend on the students' results from this index). Moreover, obtaining and updating the information about the HRtW dimensions would mean an extra cost for the service provider, especially in the first years of implementation. Furthermore, this cost would be greater if the objective is to face the impacts described in the class activity as well. However, it must be said that this last aspect should not be the exclusive responsibility of the service provider.

Finally, the alignment with target 6.1 of SDG 6 is remarkable. Although there are certain differences with the indicators proposed at the international level, which do not include aspects of affordability and acceptability, this multidimensional index could represent a starting point to integrate all HRtW dimensions. However, it should be deepened in a more general proposal that could be used in different realities.

Evaluation criteria

In order to evaluate this activity, a written report will be submitted (including the annex with the relevant calculations), solving all questions formulated in the activity.

For the evaluation of the report, the use of the previously mentioned rubric is recommended (see *Annex VII*). This instrument specifically identifies which aspects of the homework activity will be considered and how they will be assessed.

However, as mentioned above, the professor is free to choose an alternative evaluation method if she/he considers it more appropriate.

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ANNEXES

I. Parameters to be considered for the water network dimensioning
< A.I_Network_dimensioning_parameters.pdf >

II. Meshed network scheme calculations < A.II_Meshed_network_calculations.pdf >

III. Engineering code of ethics example (in Spanish)
< A.III_Ethics_code_industrial_engineering.pdf >

IV. Industrial engineering code of ethics example
< A.IV_Ethics_code_ASCE.pdf >

V. Class activity calculations < A.V_Class_activity_calculations.xlsx >

VI. Homework activity calculations < A.VI_ Homework_activity_calculations.xlsx >

VII. Evaluation rubric < A.VII_Evaluation_rubric.pdf >

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