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Corso di Laurea in INGEGNERIA CIVILE

TESI DI LAUREA

The sewage system of Qetaifan island in Qatar

Il sistema fognario dell'isola di Qetaifan in Qatar

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INDEX

1 INTRODUCTION

Qetaifan Island North is located off Lusail City, Qatar. Designed to be Qatar's future iconic destination; the project spans approximately 1.3 million square meters, with 129,296 square meters of waterpark alone. The island also features exciting entertainment attractions that families can enjoy, in addition to diversified waterfronts, distinct neighborhoods, luxurious hotels, pedestrian friendly streets, living gardens, and world class facilities that make it a modern, globally competitive community with a unique design that is inspired by the rich culture and nature of the region.

The island has the highest Ride in the world (90m) named as ICONIC TOWER.

The island which links all zones together is the Linear Park. An artificial Salt Lake linked to the sea, allowing visitors to enjoy fishing, boating and plenty of other family-friendly fun activities. Spread over the lakeside are community facilities, such as snack stalls, prayer rooms, seating, as well as meeting rooms, game rooms, and a kids club.

Qetaifan Island has seven private beaches, featuring a clubhouse that offers an assemblage of activities to be enjoyed by the whole family. The Island's Sales Center and Qetaifan Projects offices are also present in the same building.

Some pictures of the island and water park are shown in the following figures (Figures 1 to 4)

Figure 1 cinematic view of the park

Figure 2 green area, hotel, and water park

Figure 3 top view of the water park

Figure 4 side view of the water park

1.1 Missions of the project

The target is to size the pipe network, which carries the sanitary load that comes from each building until the final destination, which could be one of the following:

1-Authority connection point (figure 5)

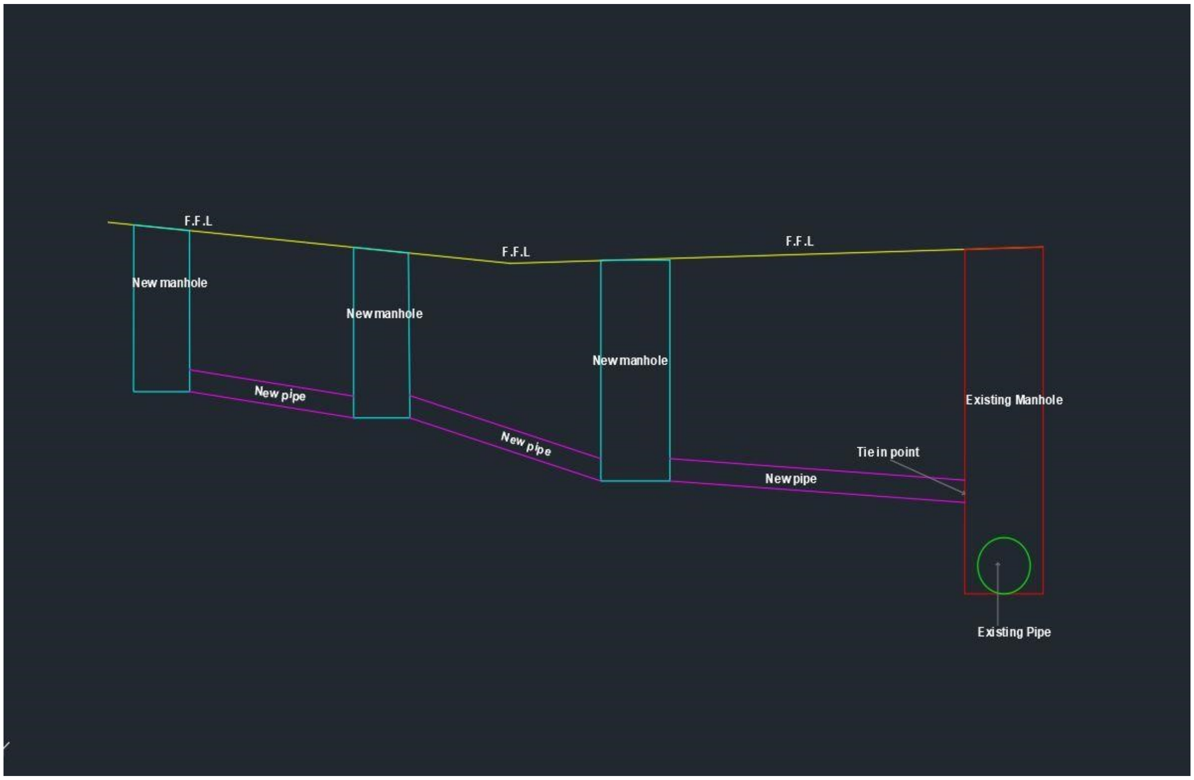

Figure 5 authority connection point

This connection (which works by gravity) could be established only for the buildings whose level of connections and networks from the first point until the last point is higher by gravity/slope than the final/existing network connection. This type of connection is common in city centers, residential areas and areas that are close to them because in these situations, there is usually a pre-established sewage pipe system.

2-Septic tank (figure 6)

A septic tank is an underwater sedimentation tank used for waste water treatment through the process of biological decomposition and drainage. It is an underground watertight container (mostly rectangular or round) made of fiber glass, plastic or concrete. Septic tanks are installed underground normally 50 meters away from the household. They are usually made up of two chambers or compartments and one tank that receives wastewater from an inlet pipe. For those that live in cities and towns septic tanks are not needed as waste water will be transported and dealt with their sewage system. How Does A Septic Tank Work?

A septic tank (figure 6) will digest organic matter and separate float able matter (e.g., oils and grease) and solids from the wastewater, it's connected with two pipes (for inlet and outlet). The inlet pipe is used to transport the waste water and collect it in the tank. It is kept there long enough so that the solid and liquid waste is separated from each other. The second pipe is the outlet pipe, this pipe moves out the pre-processed wastewater from the septic tank and spreads it evenly in the soil and watercourses. When waste water has been collected after a while it will begin to, separate into 3 layers. (as shown in the image below)

The top layer is oils and grease and floats above all the waste. This commonly referred to as "scum". The middle layer contains wastewater along with waste particles. The third and bottom layer consists of particles that are heavier than water and form a layer of sludge.

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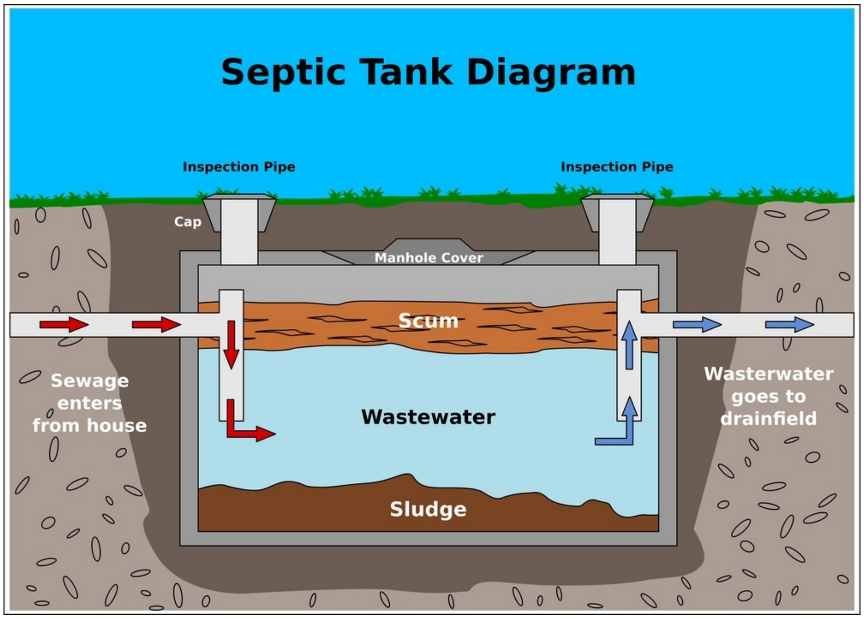

Figure 6 septic tank diagram

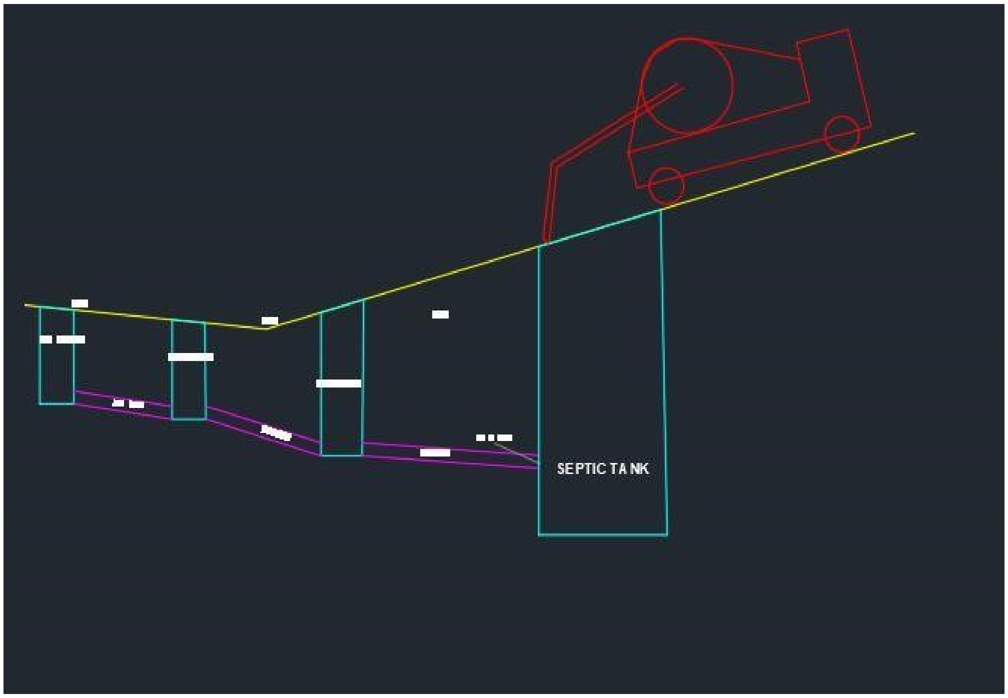

Figure 7 septic tank connection

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The previous photo (figure7) illustrates that the sewerage connection which works by gravity/slope to the last point in the network which is lower that the tie in point (Authority Point) for this reason, a septic tank is used to collect all the sanitary load, and a mobile suction tank is used to remove the water once it reaches the maximum level.

3-Lifting station

A wastewater lift station is a pumping station that moves wastewater from a lower elevation to a higher elevation. The benefit of using a lift station in a sewage collection system is that it saves a substantial amount of money in excavation costs, which involves digging for sewer pipes. Sewer pipes live underground, and digging trenches is expensive. Installing a wastewater lift station at certain points in a gravity pipeline system saves on front-end construction costs without sacrificing efficiency or functionality. They play an integral role in moving waste water to a wastewater treatment plant. Waste water makes its journey underground in sloped pipelines that take advantage of gravity to minimize costs. This type of pipe system is commonly referred to as a gravity pipeline. In some situations, it’s necessary for wastewater to enter the pipe system from a lower elevation. In order for the raw sewage to continue the journey towards a wastewater treatment plant, it needs to be efficiently transported to a higher elevation. Eventually, waste water reaches a storage container referred to as a wet well, which is essentially a holding cell that empties out once it reaches a predetermined level. Coarse (solid) materials are removed at this stage. Once the wet well is full, a lift station pump will “lift” the sewage upwards using a pressurized sewer force main. A sewer force main is a system that consists of pumps and compressors. Its purpose is to elevate the wastewater to a higher elevation so that it can continue its inevitable journey towards treatment and recirculation. Municipalities in charge of collecting and treating wastewater commonly use two types of lift stations. The submersible pump, which is more modern, and the dry well/wet well pump, which is more traditional. In dry-well lift stations (figure8), the system is housed in a separate location (usually underground or in a separate chamber). Due to this physical separation, maintenance on a dry well is more hazardous and poses increased safety risks.

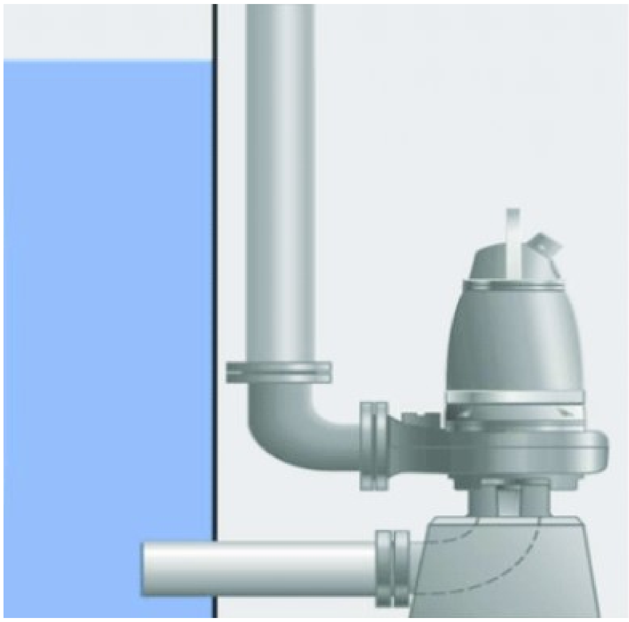

Figure 8 dry pump

Submersible pumps (figure 9), as the name suggests, are submerged in the wastewater they pump. It is mounted inside the wet well and uses a motor to pump the wastewater. This method is more modern due to the reduced health and safety concerns they offer.

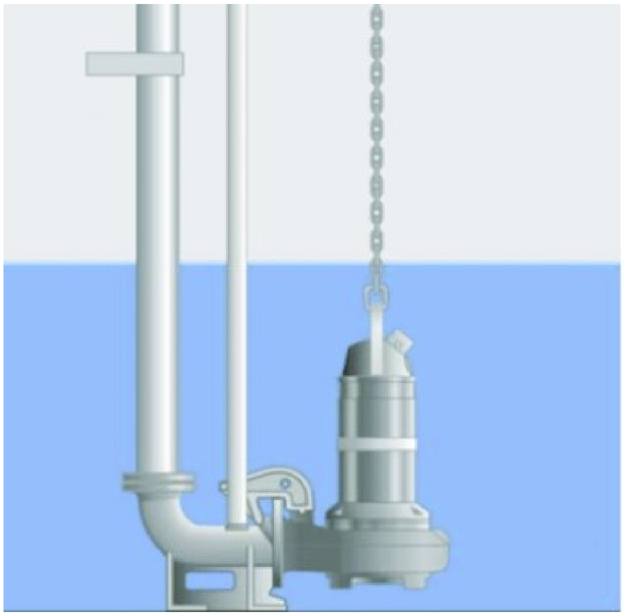

Figure 9 submersible pump

Submersible pumps are used to transfer the sanitary load from the last chamber (which could be big like the septic tank, or smaller). The pumps inside start pumping once they take a signal from the float level device.

The sanitary load gets transferred from the collection manhole to the existing network (existing manhole) as shown in figure 10.

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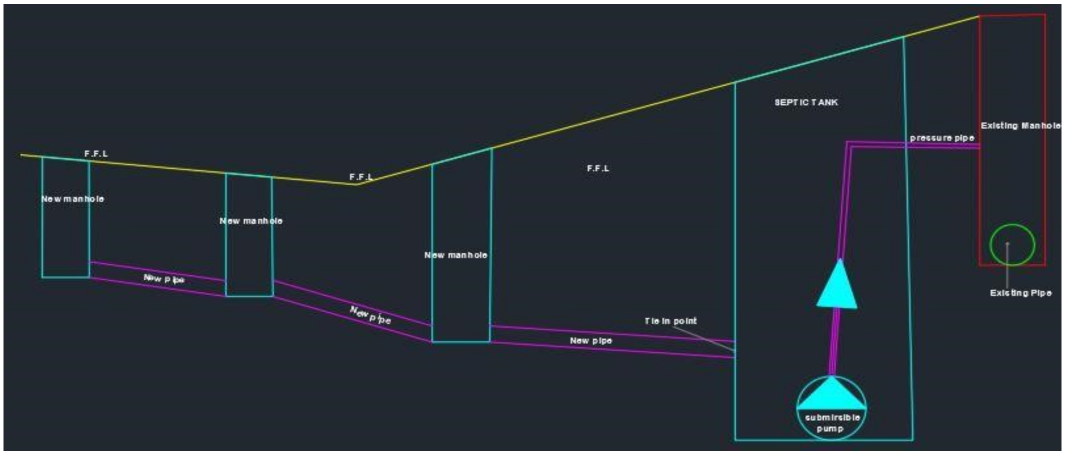

Figure 10 lifting station

4-Multi lifting stations (figure 11)

This method is used for cost saving, actually it is the same as the previous one (lifting station), but this method is famous in rock areas and hard stone fields. It reduces the excavation quantity amount, saves a lot of time and money to avoid deep excavations, and keeps the pipeline at a high level.

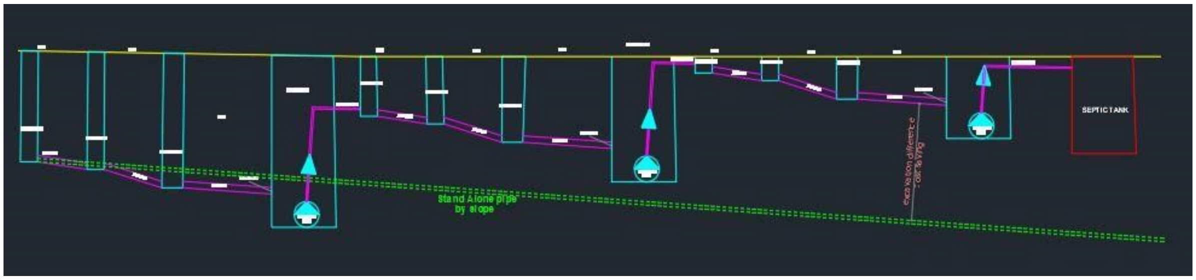

Figure 11 multi lifting stations

2 DATA COLLECTION

2.1 Water loads

For each building, the sanitary load is calculated, depending on the function of the building (the function will follow the Government authority's standards).

for example, the Urban class category is to be followed if the area belongs to classes (A, B, C, D).

** Class A is considered as the highest quality in the city such as embassies, Richest/high class people, government members, Hospitals....etc. this Class considers per person around 500 Liters per day.

** Class B considers agricultural and farming areas. This class considers per person 350 Liters per day.

** Class C considers commercial areas such as banks, offices, movie theaters, malls…etc. This class considers per person 150 Liters per day.

** Class D considers industrial areas and labor camps. This class considers per person 100 Liters per day.

Sanitary Load calculation

the national standard sanitary load calculation considers 80% of the water load consumption, the other 20% is wasted due to many reasons, such as:

1- Filtration.
2- leakage in the network from pipes
3- leakage in the network from the manholes.

4− Evaporation of the sanitary liquid mostly due to the elevated difference of the temperature.

2.2 Digital terrain model

The data is collected by a surveying team sent to the site by using land surveying equipment,

the surveying team provides a text file containing all points, each point will have its own coordinate (East, North), Level, description, and other special characters that can be decided by the team.
The data is used as an input to create a virtual ground surface using advanced programs such as Civil 3D, Archicad, Openflows waterCAD…etc.

This surface is shown in the following figure (figure 12).

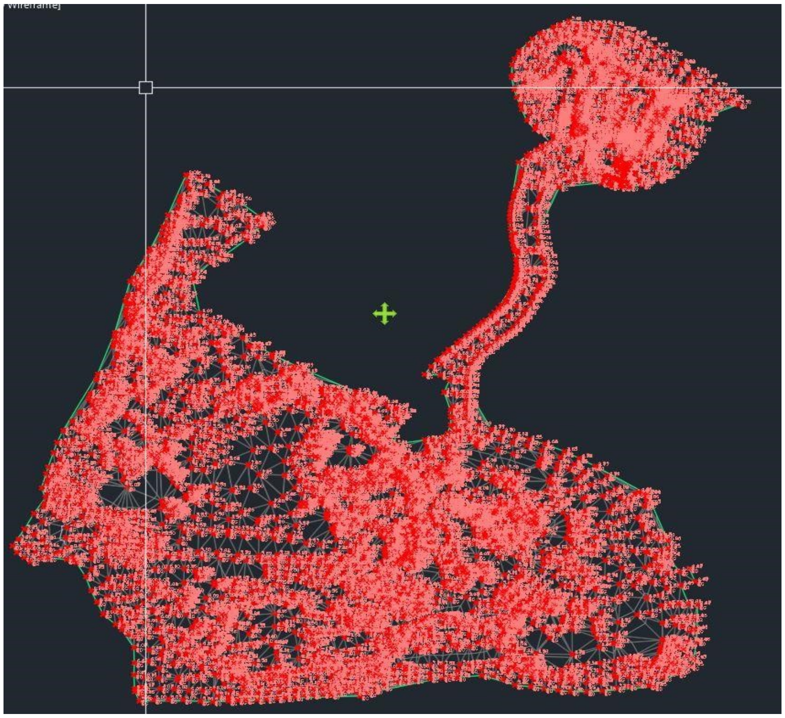

Figure 12 virtual surface

At this point, the sewer system could be drawn on the virtual surface.

A sewer system is a system which collects the sanitary load (black water) from each building, pool, and landscape one by one to transport it to a precise destination.

Manholes need to be inserted at a specific distance from each pipe according to the national standards of the project.

Pipe diameters should not exceed a maximum dimension according to the national standards of the project.

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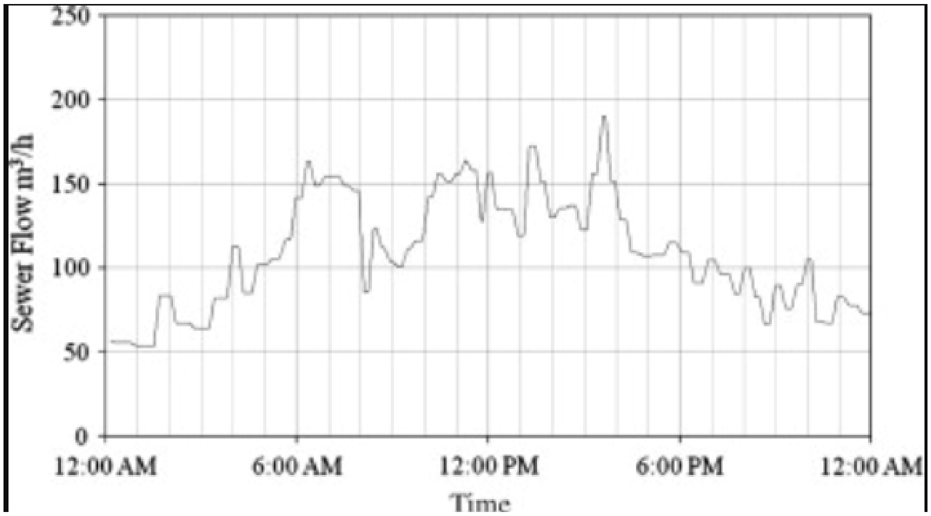
3 THE SEWAGE NETWORK

3.1 Design criteria and material selection

3.1.1 Design criteria of pipes

Waste water flow varies according to the season (monthly variations), weather conditions, week of the month, day of the week, and time of the day. Graph 1 shows how sewage flow varies within 24 hours of a full day for a small town. It can be seen that the peak flow is almost 50% more than the average daily flow, so the pipes should be always designed to withstand the most critical conditions, which in this case is the peak daily flow.



Graph 1

Designing the size of the drainage network depends on many parameters, which are listed below:

<u>Maximum and minimum velocities</u>: A sewer should be so designed that the solid matter present in the sewage is not deposited at the bottom of the sewer and thus clogging of the sewer is prevented. The deposition of the solid matter and the resulting clogging of the sewer can be prevented if the solid matter is held in suspension in the flowing sewage. In order to keep the solid matter in suspension certain minimum velocity of flow of sewage is required. Such a minimum velocity of flow is known as self-cleansing velocity which is usually around 0.6 m/s.

Just as it is necessary to provide minimum velocity of flow of sewage or self-cleansing velocity in a sewer to prevent its clogging, it is also necessary that velocity of flow of sewage in a sewer should not be excessive to cause scouring or erosion of its inner surface. At higher velocities of flow beyond certain limit scouring or erosion will be caused due to abrasive action of harder materials like sand, grit, gravel, etc., present in the sewage and this will damage the inner surface of the sewer. Such velocity is usually around 3 m/s

Minimum diameter of pipes:

The minimum size is intended to make sure that even running at full capacity, the pipe that the drain leads to will never be more than half full. This leaves room for air in the other portion of the pipe, which helps to vent it and keeps water flowing through it quickly and evenly, smaller pipes equal more pressure. Usually, this minimum diameter varies from 150 to 300 mm

Depth of excavation:

Minimum cover on the top of sewers Depth of excavation depends on:

Water table, topography, lowest point to be served, and other factors. In cold places, pipes should be placed deeper in the ground to prevent water from freezing.

Slope parameters:

Proper slope of gravity drainage and sewer pipes is important so that liquids flow smoothly, which helps transport solids away without clogging. A pipe that is too flat will prevent waste from flowing away. It is also commonly thought that pipes that are too steep will allow liquids to flow so quickly that solids will not be carried away. The slope of all the pipes in the project’s network follow the following international code (table 3), which shows the minimum and maximum slopes:

Pipe material	Pipe diameter (mm)	Minimum slope to achieve velocity of 0.75 m/s (Partial flow) (m/km)	Minimum slope to achieve velocity of 0.9 m/s (Full flow) (m/km)	Maximum slope to achieve velocity of 4 m/s (m/km)
UPVC, HDPE, GRP (n=0.012)	200	4.40	6.33	125.08
	300	2.56	3.69	72.85
	400	1.75	2.51	49.64
	500	1.30	1.87	36.86
	600	1.02	1.46	28.91
	700	0.83	1.19	23.54
	800	0.69	1.00	19.70
	900	0.59	0.85	16.84
DIP Mortar lined (n=0.013)	200	5.16	7.43	146.80
	300	3.83	5.52	109.02
	400	3.01	4.33	85.49
	500	2.05	2.95	58.26
	600	1.52	2.19	43.26
	700	0.97	1.40	27.62
	800	0.81	1.17	23.12
	900	0.69	1.00	19.76
Concrete (n=.0.015)	200	6.87	9.89	195.44
	300	4.00	5.76	113.82
	400	2.73	3.93	77.56
	500	2.03	2.92	57.60
	600	1.59	2.29	45.17
	700	1.29	1.86	36.78
	800	1.08	1.56	30.78
	900	0.92	1.33	26.31

Table 1 minimum and maximum slopes

3.1.2 Design criteria of manholes

Manholes have a standard, written by client Authority, one can choose between precast or cast in place manholes. They should be installed at all of the following locations:

- grade breaks

- changes in horizontal alignments.
- changes in sewer diameters.
- at street intersections.
- at sewer pipe intersections.
- at the beginning of sewer runs.

The cover of the manhole should be strong enough to withstand the loads of traffic. It is usually made of cast iron to carry a minimum concentrated load of 25 ton. The manhole should be supplied with steps to allow for maintenance access.

Moreover, there are certain limits to be respected when placing manholes in a sewage system, such as maximum distances between individual manholes which are shown in table 2.

Pipe Diameter (mm)	Distance (m)
200	60
300	70
400	70
500	80
600	100
700 - 1200	120
over 1200 and designed as "man-entry manhole"	up to 200m

Table 2 **Maximum Distance between Manholes**

From the table above, the distance between the manholes can be determined based on the pipe diameter, which can be sized by knowing the capacity of the sanitary load of the project. At every change of alignment gradient or diameter, there should be a manhole or an inspection chamber.

3.1.3 Material selection

In this project, 2 major items will be used, i.e., Pipes and manholes.

The pipe selection needs to follow the national standards, and the budget of the project. So, in Qatar the authority gives the contractor the liberty to choose between two materials for the pipes. These are High Density Polyethylene (HDPE pipes) and Ductile Iron pipes (DI Pipe).

The HDPE pipe (figure 13 left panel) is flexible and ductile, not rigid. It has outstanding resistance to fatigue. Unlike other plastic pipes, it is designed, and pressure rated to handle the kind of occasional and recurring surge events that are common in water distribution systems.

Ductile iron (figure 13 right panel), also referred to as spheroidal or nodular iron is a group of irons that exhibit high strength, flexibility, durability, and elasticity due to their unique microstructure. Cast ductile iron normally contains over 3 percent carbon; it can be bent, twisted, or deformed without fracturing. Its mechanical properties are similar to steel, and far exceed those of standard cast irons.

Figure 13 HDPE pipes (left) and DI pipe (right)

The parameters that control the decisions are i) the price, in fact, project’s cost is a major constraint in deciding the materials and diameters of the pipes, contractors cannot exceed a certain amount of a pre-established budget given by the clients; ii) Availability, that is connected to the project’s execution time and availability of the materials, in this project HDPE pipes will be chosen since they are more available and locally produced; and iii) installation technique: lighter pipes are easier to install, less working hand and equipment are required.

HDPE pipes are light and fast to install, moreover they are also cheap.

Manholes can be divided into 3 main categories. Plastic manholes, precast concrete manholes, and fiberglass manholes

Plastic manholes (figure 14) are manufactured by using the polyethylene material. This is manufactured with durable one-piece construction. This construction does not employ any seams or seals as they cause several maintenance issues.

Figure 14 Plastic manhole

Plastic manholes are environmentally friendly and sustainable. They do not contaminate or cause any adverse effect on the soil or the ground where they are is placed. They are extremely resistant to corrosion. These do not degrade with time and do not demand frequent rehabilitation and maintenance with time. These manholes are manufactured with additional accessories like ladders and manhole covers.

Construction of manholes by precast concrete (figure 15) is a traditional method. These manhole frames are engineered in the segment in a factory located offsite, this method hence ensures quality and also facilitates quick installation. These precast manholes are assembled on site, they have a long lifespan of 100 years, and thus they are widely spread and used.

Figure 15 precast manhole

Fiberglass manholes (figure 16) are engineered such that they include a manhole barrel and a cover. This basic structure also incorporates additional features like grinder channels, weirs, flumes, separation units for storm water …etc.

Figure 16 Fiberglass manhole

Fiberglass manholes are easy to handle, they weigh one-tenth of the weight of the concrete manhole. As the unit is lightweight, the manhole is easy to install, they are environmentally friendly, and are highly durable.

3.2 **Pipe network design**

3.2.1 Manning formula

The Manning equation is a widely used and very versatile formula in water resources. It can be used to compute the flow in an open channel, compute the friction losses in a channel, derive the capacity of a pipe, check the performance of an area-velocity flow meter, and has many more applications.

Open-channel flow occurs when liquid flows in a conduit or channel with a free surface. Rivers, streams, canals, and irrigation ditches provide examples of open channel flow. The flow of liquids in partially filled pipes, when not under pressure, is also considered open-channel flow. For example, water flowing through a culvert running underneath a street is considered open-channel flow. Likewise, flows in sewers and tunnels are classified as open-channel flows, along with other closed channels that flow partly filled. Other examples of open-channel flow include flow in water treatment plants, storm and sanitary sewer systems, industrial waste applications, sewage treatment plants, and irrigation systems. Although not as accurate as a hydraulic structure, the formula can provide a sufficient level of accuracy in some applications.

For best results when applying the Manning formula:

- The channel should be straight for at least 70 m (and preferably 300 m).
- The channel should be uniform in cross-section, slope, and roughness.
- There should be no rapids, dips, sudden contractions / expansions, or tributary flows.
- The flow should not backup or be submerged.

The Gauckler–Manning equation (equation 1) states:

$$Q = \frac{K\,A\,R^{2/3}S^{1/2}}{n}$$

Q = flow rate
A = cross-sectional area of flow
R = hydraulic radius (cross-section area divided by wetted perimeter)
S = slope of the channel at the point of measurement
n = surface roughness (based upon channel material and condition)
K = constant dependent upon units

Equation 1 Gauckler-Manning equation

The cross-section area (A) and the hydraulic radius (Rh) are calculated for a given depth of the liquid in the channel. The slope (S) often has to be estimated based upon previous installation drawings of the channel or pipe, but true site measurements will provide a more accurate flow rate. The roughness coefficient (n) is selected from standard reference roughness values based upon the channel / pipe material and its condition. Rougher conduits with higher friction have a higher value, and smoother conduits with lower friction have a lower value. Numerous n-values have been calculated for a variety of streams, channels, and pipes. Usually, the values are given as a range (minimum - normal - maximum) for a particular channel type or material. There are numerous factors that affect n-values, including cross sectional geometry, boundary surface roughness, vegetation on channel, channel irregularity, and channel alignment. Under ideal conditions, the Manning formula can achieve accuracies of +/- 10-20%. However, variances in the above measurement conditions means that accuracies of +/- 25-30% are more likely, with errors of 50% or more if care is not taken.

3.3 Velocity in pipes

The Minimum Velocity

A minimum velocity enables the sewage flow to self-cleanse the nominal amount of silt carried through the sewers and helps to minimize sewer blockage as a result of siltation and grease accumulation. Subsequent maintenance costs and environmental nuisance are reduced. It is not easy to determine the particle sizes of silt in the sewage system because both the range of sizes and the variation of sizes are great. According to BS EN 752: 2008, self-cleansing for small diameter sewers of diameter less than 300mm can generally be achieved by ensuring that a velocity of at least 0.7m/s occurs daily.

For larger diameter sewers, higher minimum velocities should be used, particularly if relatively coarse sediment is expected to be present. Sewers of diameter up to 900mm, should be designed to achieve a self-cleansing velocity of 1.0m/s in full pipe condition.

General Notes:

(a) Very fast flow is not stable and will give rise to cavitation especially when the pipe surface is not smooth, and if the sewer contains junctions, bends, manholes, the usual hydraulic equations for flow prediction may also not be applicable.

(b) Very fast flow occurs when the sewer is laid at steep gradient and the flow becomes supercritical. When the gradient eventually flattens, the flow may become subcritical and a hydraulic jump will occur, and the potential damage associated with the uncontrolled energy dissipation is substantial.

(c) Inspection and maintenance of sewers with fast flowing sewage are unsafe, usually difficult and sometimes impossible. The maximum velocity at peak flow shall be limited to 3 m/s but this can be relaxed to 6 m/s provided that: (a) a continuous, smooth, durable, and abrasion resistant pipe (e.g. ductile iron) or internal lining is chosen; and (b) all junctions, bends, manholes or other appurtenances are designed with appropriate erosion protection measures. Sometimes, sewers with steep gradient are unavoidable due to the topography of the area. Measures to reduce the maximum velocity generally include: (a) laying the sewer at flatter gradient with the installation of backdrop manholes in the system to dissipate excessive static head in a controlled manner; (b) providing steps at manholes to dissipate energy; and (c) using special designed energy dissipaters. For the sewage flow conditions commonly encountered in Hong Kong, a combination of measures (a) and (b) is adequate. The application of measure (c) is more common in storm water drainage systems where the flow rate is much higher.

The relationship between flow and velocity is the following: $\mathbf{Q\ (m^3/s) = V\ (m/s) \times A\ (m^2)}$

Example of sizing pipes

The total number of labors is given as 120 rooms x 4 labors = 480 labors. Considering 300 Liters/day for each labor (consideration may vary according to the authorities of the country) we find a mean flow rate Q=144 m^3/d, that is Q=0.0017 m^3/s.

Then we consider 80% of the calculated amount as the sanitary load, because of the following reasons:

1-Infiltration inside the network. Due to evaporation.

2-Leakage in the whole drainage network.

3-Dispersing of water over the floor before going inside the drainage network.

So, the sanitary load (80% of 144,000 Liter) =115,200 Liters=0.00136 m^3/s

Then from the formula Q=VA, area can be calculated. The recommended velocity is around 0.7 m/s,

$A = (0.00136\ m^3/s) / (0.7\ m/s) = 0.00194\ m^2$, the diameter of the pipe should be 5 cm

Hydraulic Height (height of the sanitary load inside the pipe) can be calculated using the following table (table 3):

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Diameter (mm)	Max d/D	Corresponding Max q/Q_{full}	Design Capacity
200	0.50	0.50	$0.50*Q_{full}$
250	0.50	0.50	$0.50*Q_{full}$
300	0.67	0.79	$0.79*Q_{full}$
400	0.67	0.79	$0.79*Q_{full}$
500 and larger	0.75	0.93	$0.93*Q_{full}$

Table 3

Most of the countries in the world as per their own code suggest that any starting pipe outside the building that pours inside the main network and then goes to the final city outlet, should start from at least 150 mm or 200 mm. Starting from this point, each individual building that gets added to the network, should be counted and the sum of the sanitary load increases. Pipe size should also be increased to maintain equilibrium. This size depends on the volume of the capacity of the accumulative sanitary load building by building until the end of the sanitary network.

The fluid flow velocities in potable water systems should not exceed certain limits to avoid noise and damaging wear and tear of pipes and fittings. The table below (table 4) can be used as a guide to maximum velocities:

Application	**Maximum Velocity**	
	(m/s)	***(ft/s)***
	General Water Service	0.9 - 2.4
Tap water (low noise)	0.5 - 0.7	1.6 - 2.3
Tap water	1.0 - 2.5	3.3 - 8.2
Cooling water	1.5 - 2.5	4.9 - 8.2
Suction boiler feed water	0.5 - 1.0	1.6 - 3.3
Discharge boiler feed water	1.5 - 2.5	4.9 - 8.2
Condensate	1.0 - 2.0	3.3 - 6.5
Process water	1.5 - 3	5 - 10
Pump discharge	1.5 - 3	5 - 10
Pump suction	0.9 - 2.4	3 - 8
Heating circulation	1.0 - 3.0	3.3 - 9.8

Table 4

The velocity in potable water networks could be increased because the network doesn’t rely on gravity, instead it uses discharge and pressure methods.

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4 AIRFLOW IN SEWER SYSTEMS

The field of sewer ventilation modeling is an important area within the sewer modeling field. Sewer ventilation models are generally used as part of an analysis to determine odor emissions from a proposed or existing sewer system. Ideally, sewer ventilation models can predict places in a sewer system where the venting of sewer gases is likely to occur. Potential computed ventilation rates are combined with measured or estimated concentrations of odor producing substances to generate mass emission rates. The most common substance analyzed is hydrogen sulfide. Additionally, these models should be able to estimate the air flow rates so that mass flow rates exiting the system can be calculated. These can then be used as input for air quality dispersion models to determine if there will be odor problems. Air flow rates are also required for the design of air treatment facilities (ATF) to control odors. This chapter describes the major factors that affect the flow of air in sewer systems, and reviews the existing ventilation models.

4.1 Water drag

The most important factor in determining sewer airflow is typically the drag between the water surface and the air in the headspace, as shown in Figure 17. It is found that due to this effect, airflow in sewers is always in the direction of the water flow, unless mechanically forced otherwise. The air velocity is typically less than the water velocity, with average air velocities usually in the range of 5% to 30% of average water velocities.

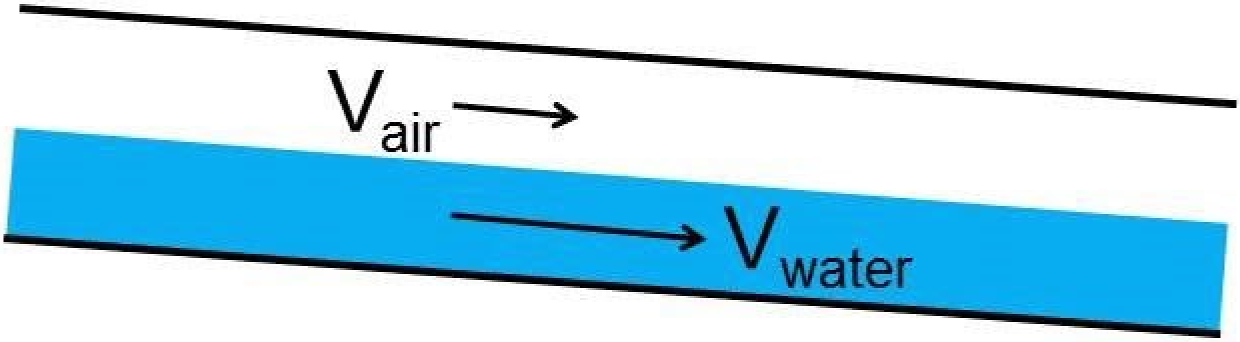

Figure 17 airflow in a sewer

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When airflow at a downstream section is less than at an upstream section due to slope variations, which causes the depth of the water to increase and its velocity to decrease, the airflow difference will vent at the nearest manhole. The combination of these will cause a significant drop in the air flow rate. This is shown in Figure 18.

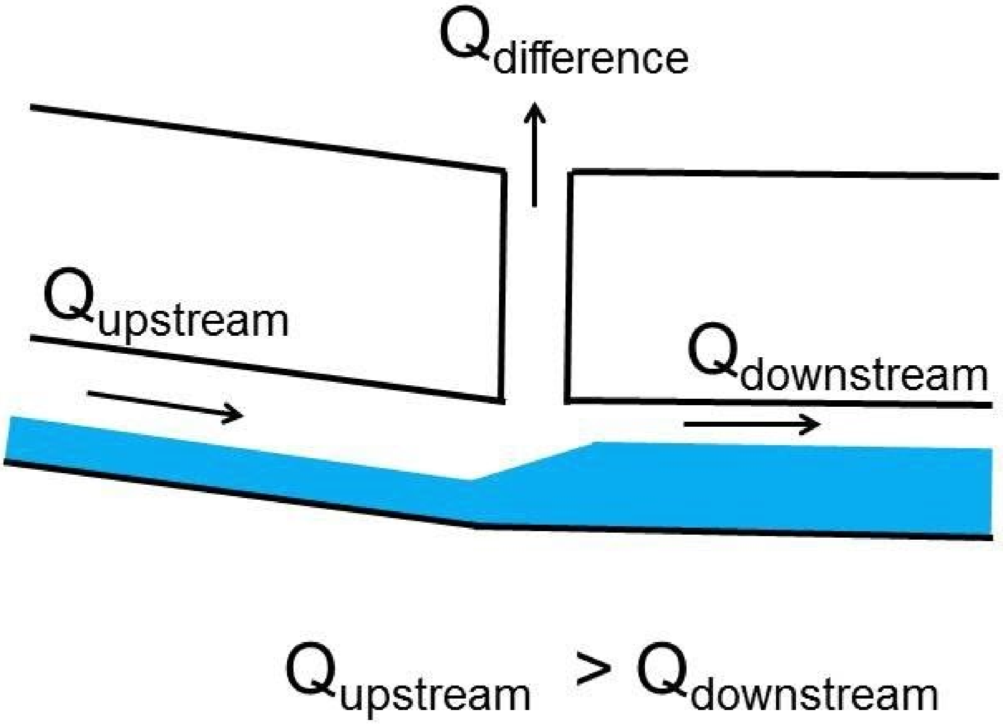

Figure 18 Sewer venting

The converse of this situation is shown in Figure 19, causing air to be drawn into the system.

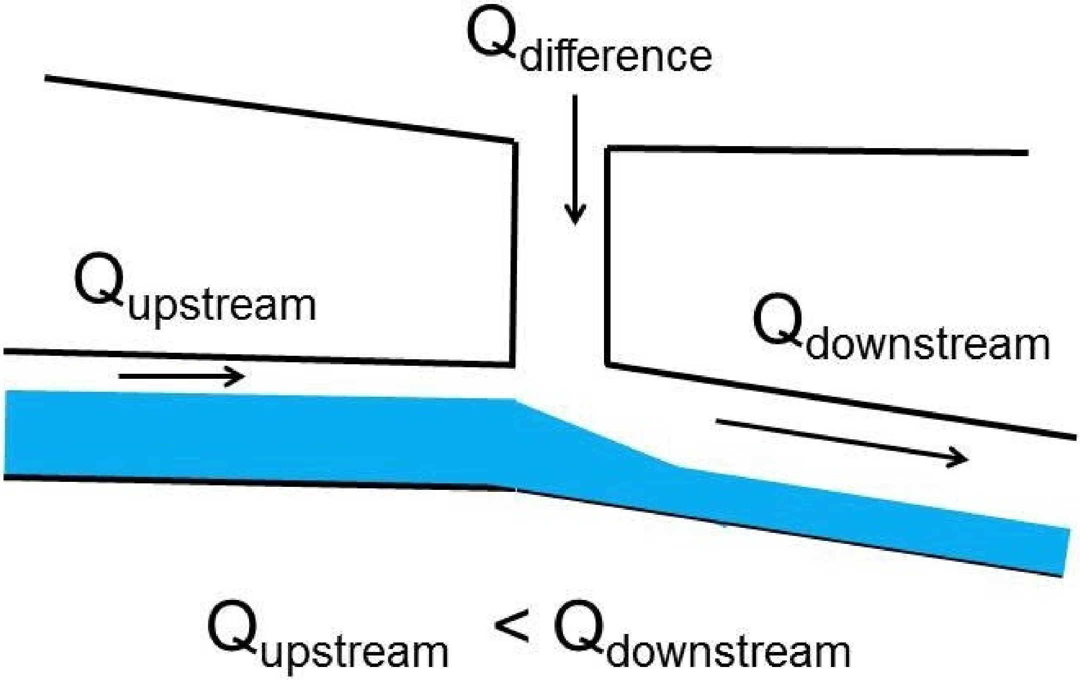

Figure 19 Air drawn through manhole

Ideally it would be possible to reasonably predict the air velocity based on water velocity. This would allow the airflow rates to be calculated. However results of field studies have consistently shown that there is more variation in airflow rates, and thus air velocity, than can be explained by just water velocity alone.

4.2 Air pressure

Air, like all fluids, will flow from high pressure to low pressure. Unlike water, air is a compressible fluid and compressibility effects can be important. If the air pressure in a system could be accurately computed then the resulting air flow could also be calculated with reasonable accuracy. If the system were closed then this might be possible. In a real sewer system there are thousands of openings to the ambient atmosphere such as manholes and drop shafts. These basically present poorly defined boundary conditions in terms of modeling. Experimental studies have shown that there are poor correlations between manhole and pipe pressures, and measured parameters would be thought to influence pressure. These include wind speed, air temperature, sewer headspace temperature, atmospheric humidity, sewer headspace humidity, and atmospheric pressure. The air pressure differences that affect airflow rates are also small. Local atmospheric motion, for example, is typically driven by pressure differences on the order of 4 mbar. Given that the ambient pressure is about 1013 mbar, the driving difference is about 0.4%. A pressure of 4 mbar is the equivalent of ~40 mm of water. Pressure differentials from manhole to manhole measured, found differences on the order of 0.02 mbar, the equivalent of 0.2 mm of water.

4.3 Drop structures

Sewer systems also contain various hydraulic structures besides pipes and manholes. These structures affect the air flow. Drop structures, for example, are common and have complicated water and airflow characteristics. There are two main types of drop shafts: vortex and plunge. Vortex shafts cause the flow to spiral down and cling to the walls of the shaft, thereby minimizing air entrainment and hydraulic shock effects. Plunge shafts allow the water to free fall. Some drop shafts have vents and desecration chambers to reduce the amount of air entering the downstream pipes. Figure 20 shows one scenario where air is drawn into the system. In this case air is also entrained in the flow. The entrained air will usually desecrate further downstream.

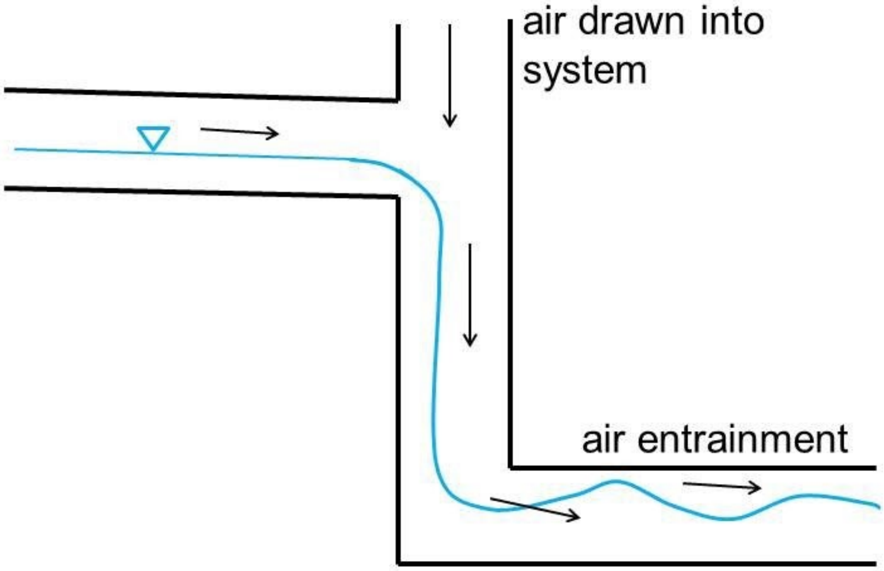

Figure 20 air drawn in

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Another drop structure scenario is shown in Figure 21. In this case the water surface forms a temporary air flow block that causes the upstream airflow to vent at the structure. Drop structures where perpetual venting occurs are often the point of odor problems for sewer systems.

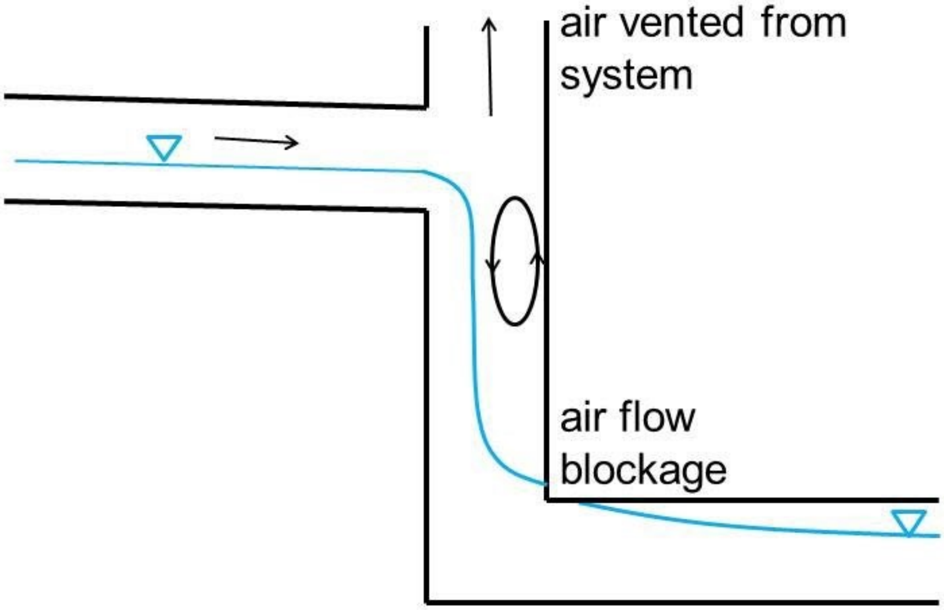

Figure 21 air vented

4.4 Buoyancy effects

The air in sewer systems is often less dense than the ambient air. This is due to two factors: humidity and temperature. Although counterintuitive, more humid air is less dense. This is because water vapor, with a molecular weight of 18 g/mol, is less dense than both nitrogen (N2, 28 g/mol) and oxygen (O2, 32 g/mol). Not surprisingly the air in sewers tends to be more humid than the ambient air. In winter the air in sewers also tends to be warmer, and hence lighter, than the ambient air. So an empty tunnel, for example, will see more dense air enter and displace the lighter air in the tunnel, along with odors. This is an example of buoyancy-driven circulation, also called the stack, or chimney, effect. This is shown in Figure 22.

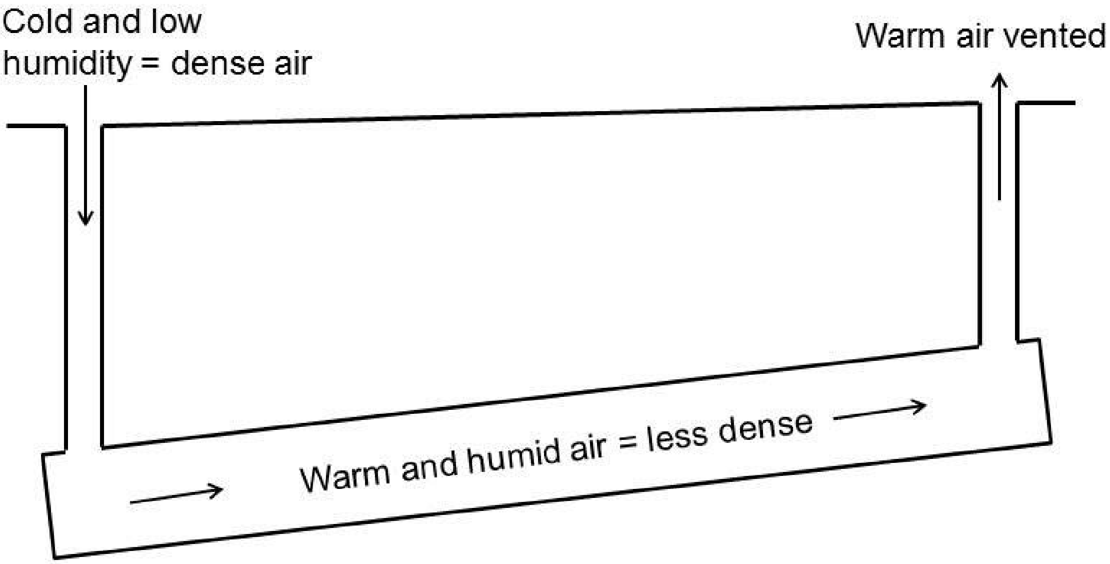

Figure 22 Buoyancy driven venting

4.5 **Siphons**

Siphons produce a complete barrier to airflow as the siphon pipe is completely full. This means that all airflow must vent at the upstream end of the siphon, as shown in Figure 23. This creates the potential for an odor hot spot. One solution sometimes employed is to create an air jumper by using a small pipe connecting the upstream and downstream headspaces. This allows the air to keep flowing downstream.

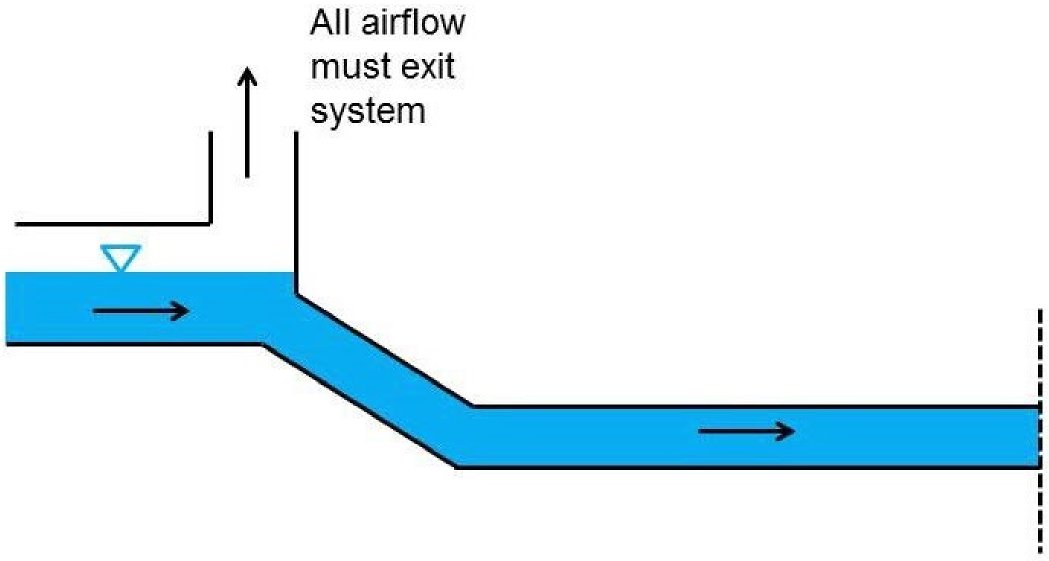

Figure 23 air venting at siphon

4.6 Modeling approaches

In general there are three main approaches to modeling sewer ventilation. Ranked in terms of popularity they are:

Empirical, computational, and thermodynamic

Empirical models tend to correlate measurable, or readily calculable, hydraulic parameters with air velocity. There are many versions of empirical relationships that have been used over the years. Computational models are generally finite element based computational fluid dynamics (CFD) models. These models either compute the air and water flow, or import the hydraulics and limit the numerical model to the air regime. Thermodynamic based models are the least common. These models tend to work best for calculating buoyancy driven airflow.

These models were tested, and it was found that all of them were fairly inaccurate, and tended to over-predict most of the time. The models were most inaccurate at low airflow rates—with order of magnitude over-predictions. At higher flow rates the models performed better, in some cases almost matching the measured flows, and generally being within a factor of 2 to 3. It should be noted that from a design point of view the fact that models tend to overestimate air flows is not necessarily a bad outcome. The fact that models perform well at high airflow rates is also a positive result. All of the approaches discussed above are steady state. Given the difficulty in getting steady state models to produce reasonable results, the development of dynamic models is not a priority at this point. The exception is the calculation of air flows due to the filling of tunnels. In this case dynamic hydraulic modeling results are used directly. The barriers to improved models are not technological but rather the inability to predict the boundary conditions which can greatly influence the system. These mainly concern the pressure variations that exist from manhole to manhole.

5 FINALIZING THE PROJECT

5.1 The network

The mission is to design the pipe size of the network as shown in figure24.

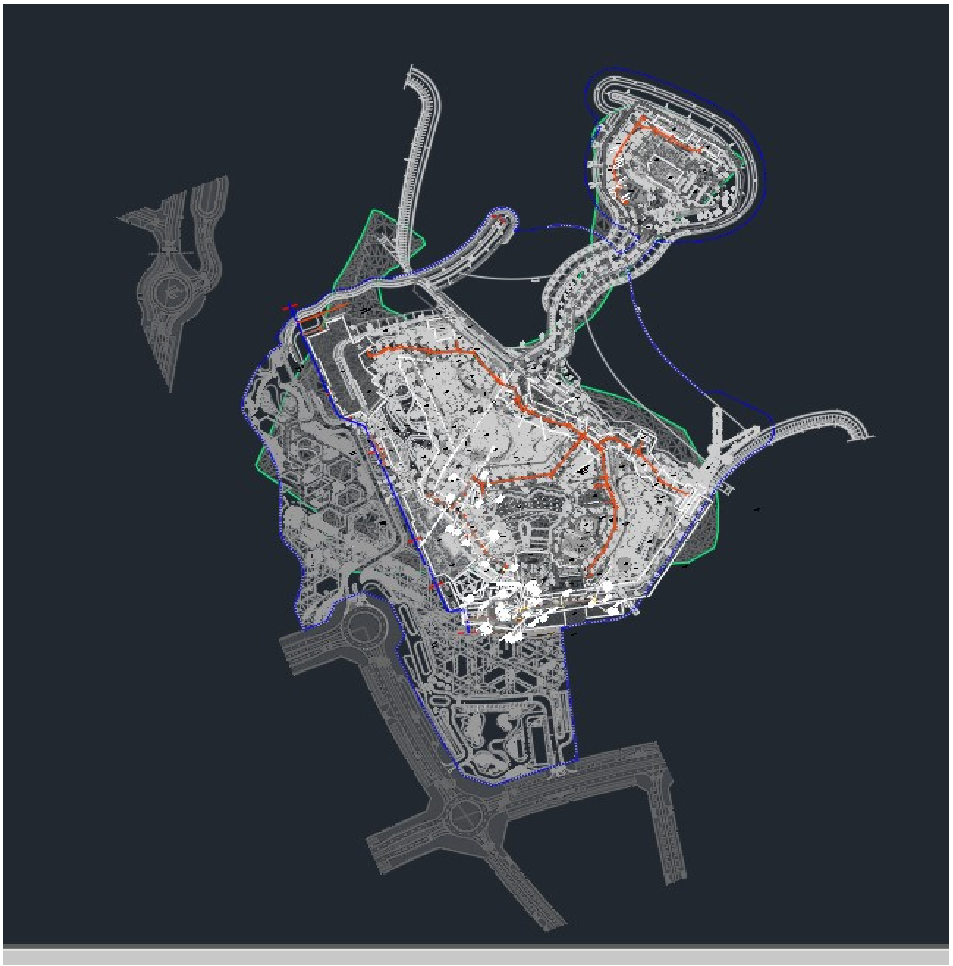

Figure 24

We will consider only a part of the network (figure 25) which has only 3 buildings that act as an output for the waste water as an example in this project. Moreover, the distance between all manholes will be assigned as the minimum distance.

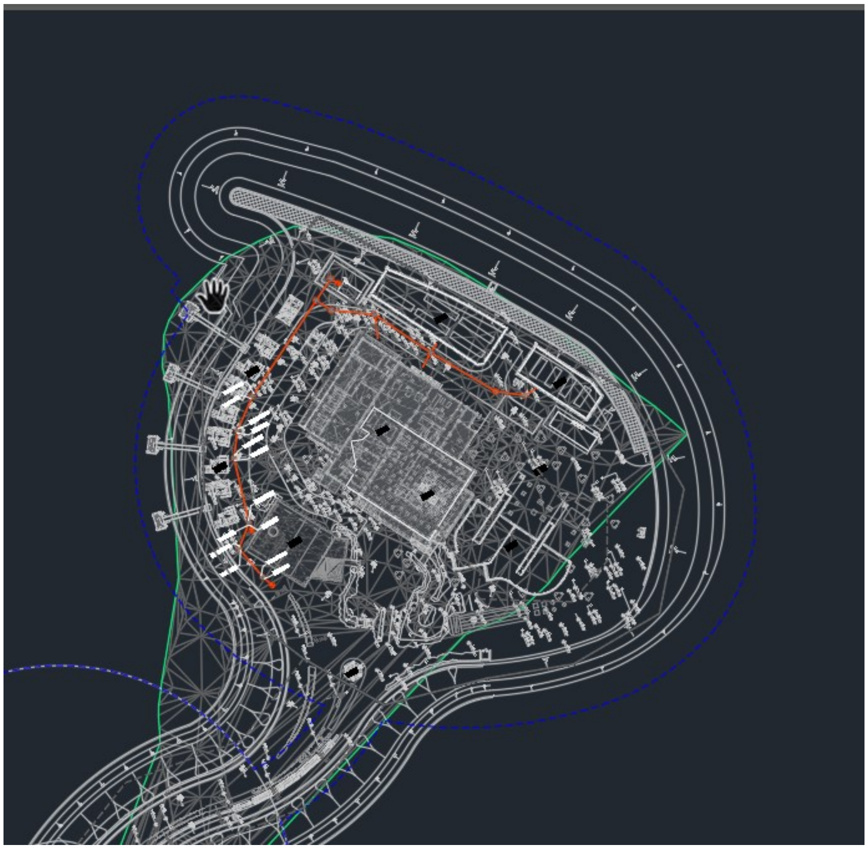

Figure 25

The process consists in calculating the load (depending on staff / people in each building) that is produced by each building which is connected to the network. From the starting manhole, each building will be added to the previous, current, or next manhole through the network. This result could be then modified following the international / national standards. From the previous results, pipe diameters could be sized. The table below (table 5) shows the optimum size to handle the sanitary load which passes through each pipe for each pipe size and its load capacity.

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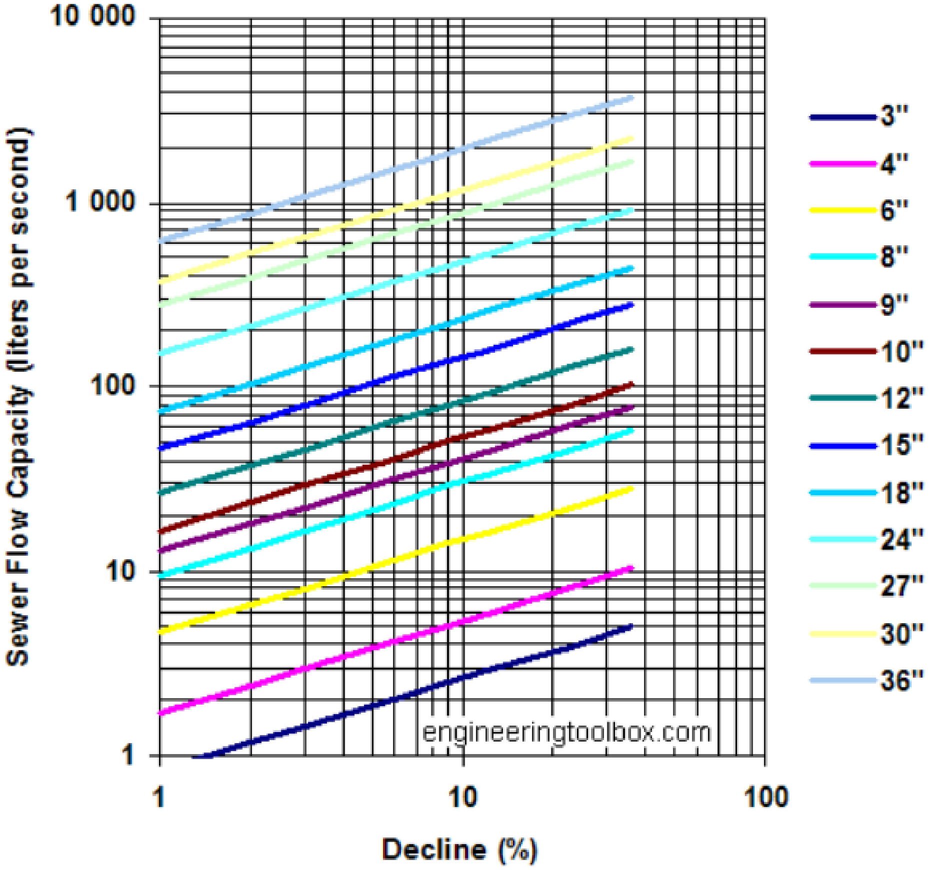


Table 5

As stated before, the pipe network is attached to 3 buildings (B801, B802, and B803). In the following pages, pipe sizes and velocities are going to be calculated for the starting, and ending points of each of these buildings. It is to be noted that this connection considers only waste water and not storm water.

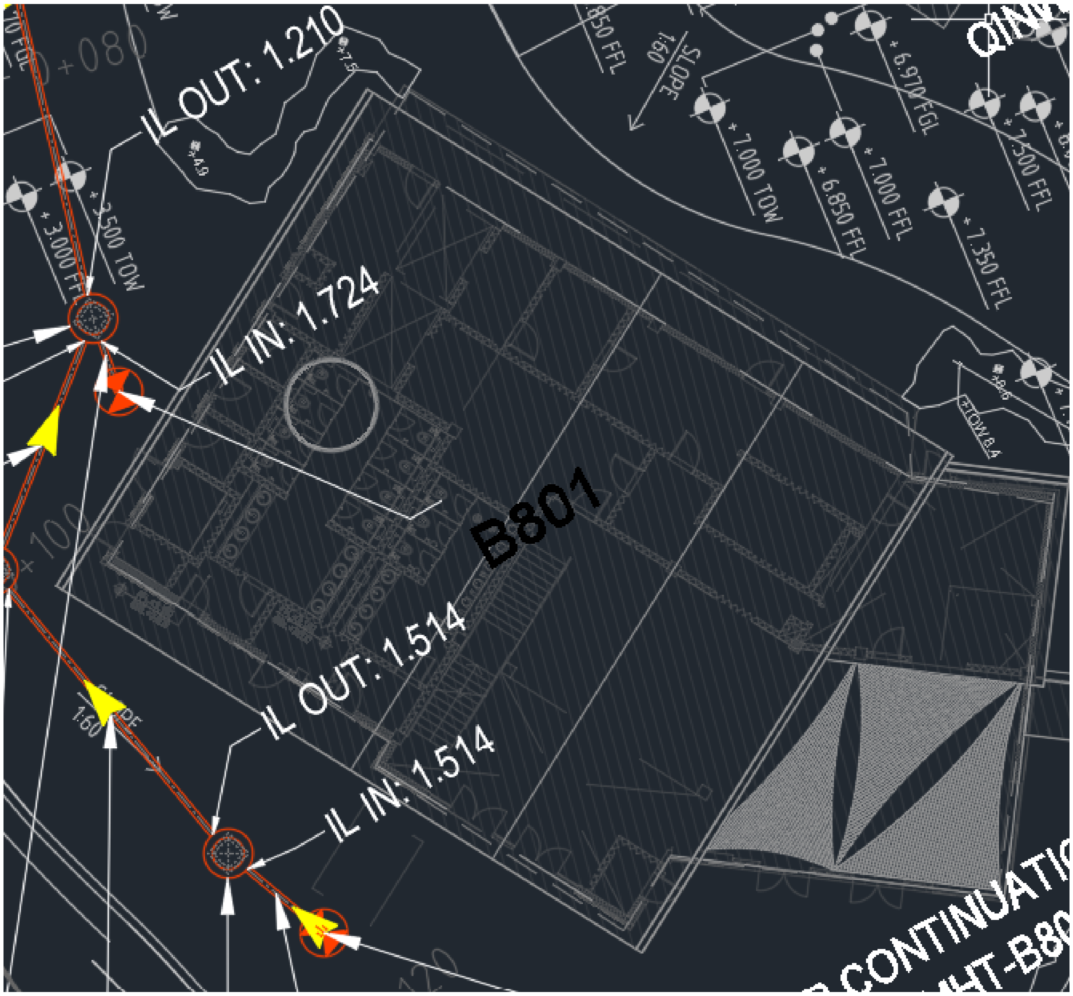


Figure 26

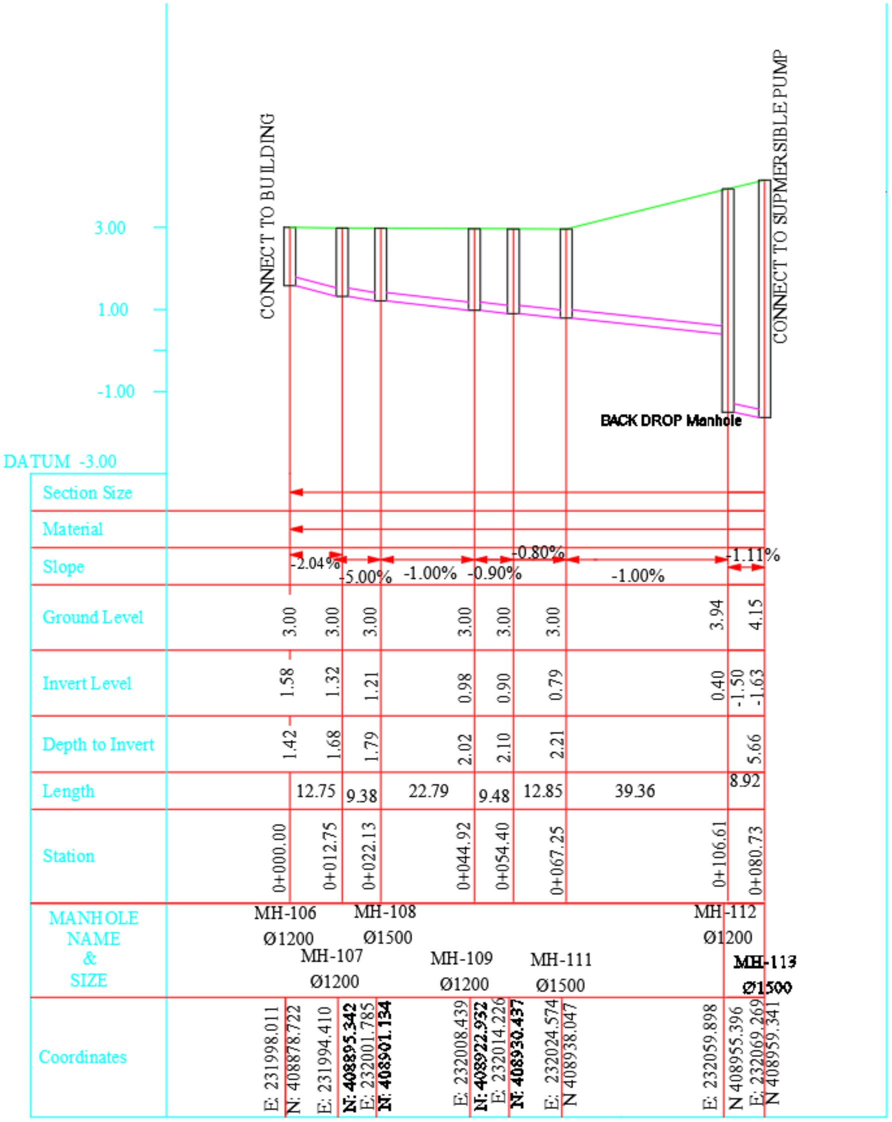
Building B801

This building (figure 26), is considered as a public toilet/shower. As per the data collected by project owners, there are 20 water closets/showers, 20 users for each closet/shower per hour. Moreover, the opening time for this park will be between 9 am till 12 pm, which means 15 hours of daily use.

To find the sanitary load for building B801, the following calculation needs to be made:

20 closet x 20 users x 15 hours = 6000 liters/hour= 144000 liters/day = 0.0017m^3/s. considering 80% of this load for the reasons mentioned in section 2.1 we get 0.0014m^3/s. As per Qatar sewer Authority, minimum diameter for external pipes should be at least 200 mm. The velocity inside the

pipe can be calculated using manning equation by taking into consideration the slope of the pipe which is inserted in the digital terrain model automatically or manually. This load moves through the pipes from MH-106 (upstream) up to MH-112 (downstream). The longitudinal profile of the system is shown in figure 27.



Sewer pipe from MH-106 to MH-113

Figure 27

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The velocity can be calculated for each pipe using manning's equation given the slopes, diameters, and n values which depend on the type of material selected for the pipes. In this project, ductile iron pipes will be used. For example for the first pipe (start station 00 end station 12.75) the slope is 2.04% and the diameter is 200 mm, by applying manning's equation with an n value of 0.012, we get a velocity of 1.73m/s.

Building B802 and B803

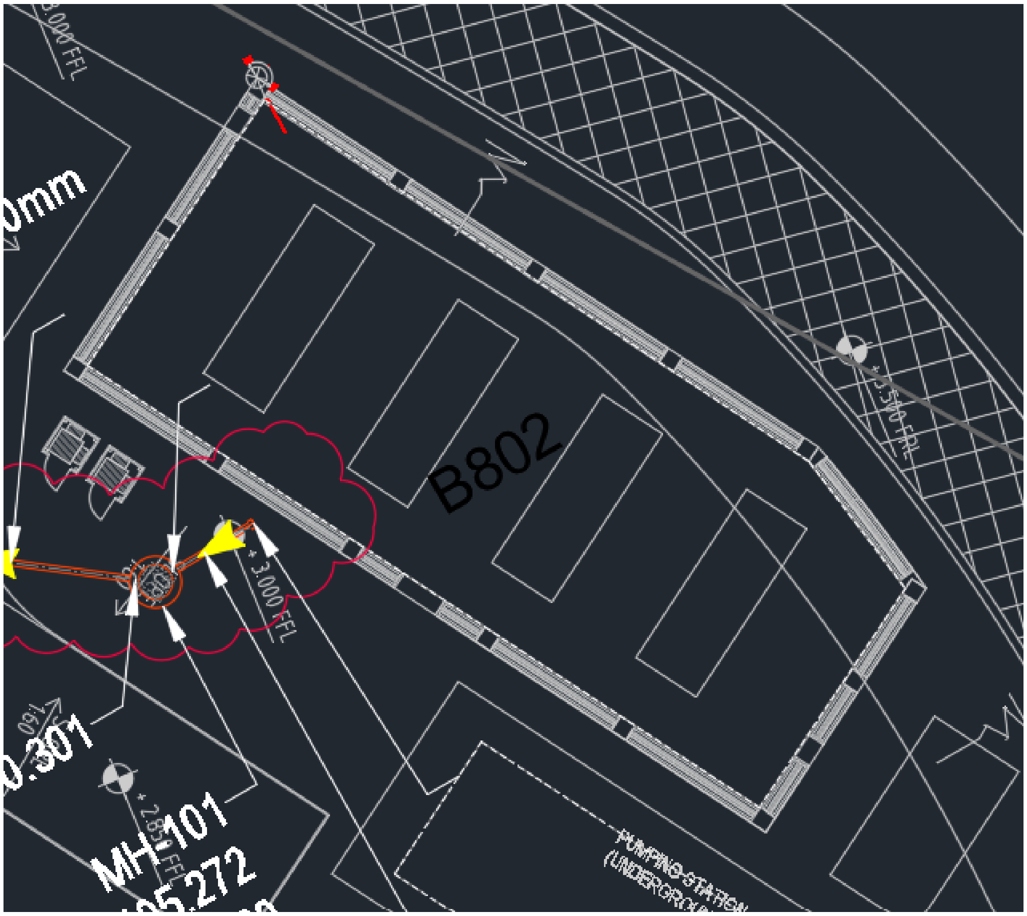


Figure 28

This building (figure 28) is considered as a utility building, maintenance, or service/Working staff building.

From the data obtained from the architect team there are 30 labors, as per country standard we consider 30 liters for each labor. In maintenance buildings, since the labor will work only 8 to 10 hours a day, the consumption of the water for this building is as follows:

30 labor x 30 liter per day as per Qatar code/ Regulation = 900 L/Day =0.0000147 m3/sec.

The sanitary load is considered as 80% of the previous result, so the final amount is 0.0000147x0.8= 0.00001176 m3/sec. A 200mm diameter pipe could also be used in this case.

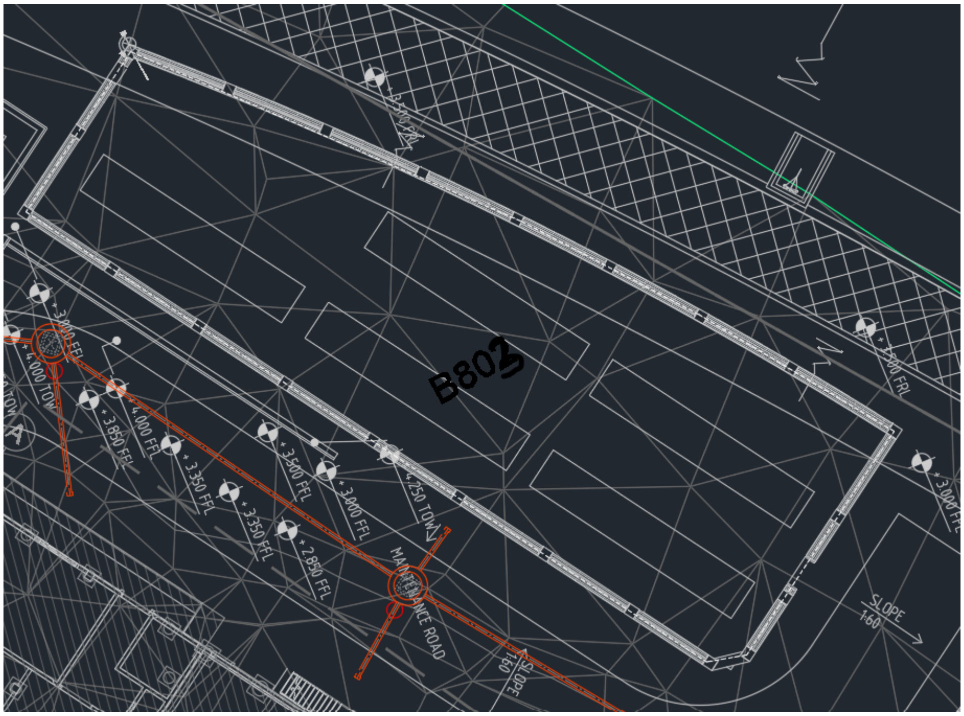


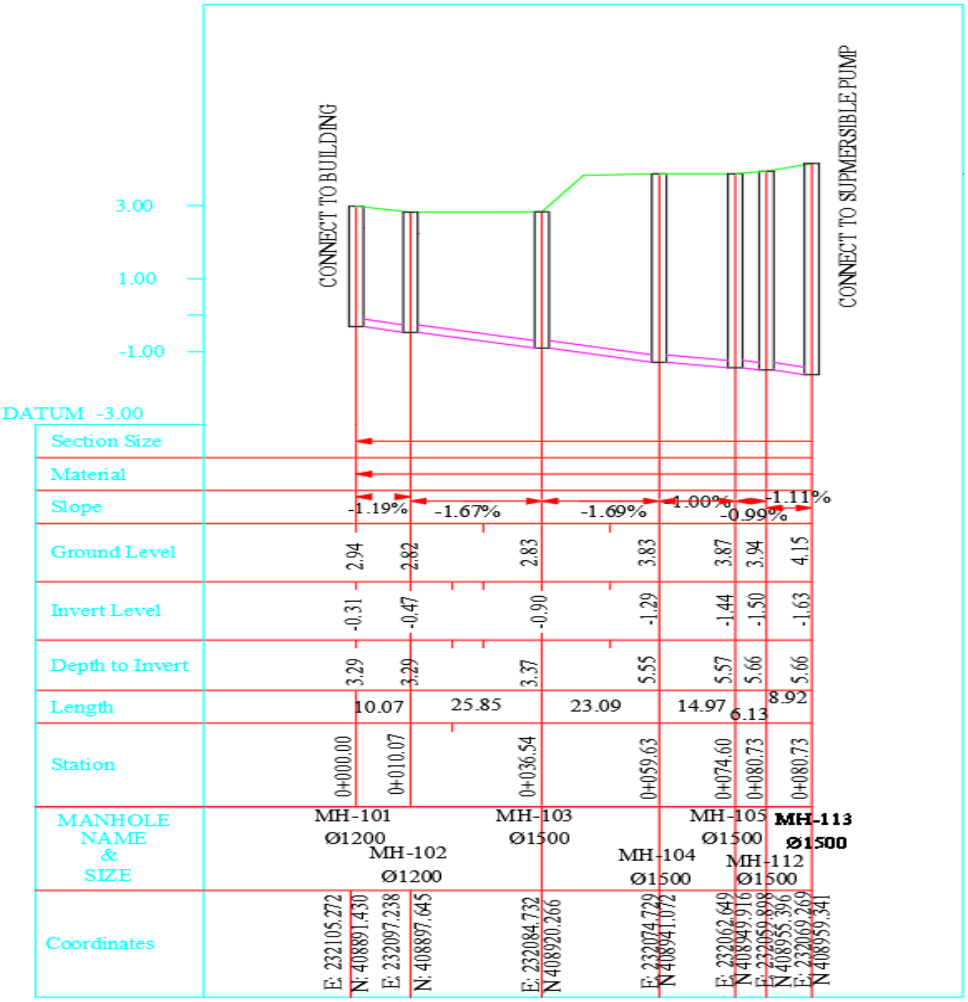
Figure 29

Considering the same assumptions made for building B802, and considering 40 labors in the building, the sanitary load of building B803 (figure 29) could be calculated as follows:

40 labors x 30 liters/day =1200 liters/day considering 80% of the previous result, will result in 432 Liters/day, which results in 0.000014 m3/sec. This calculated load, drops from building B803 to manhole MH-103. MH-103 collects the load which comes from building B802 (0.00001176 m3/sec) and building B803 (0.000014 m3/sec). So the total amount (0.000026 m3/sec), is the sum

of the two loads. In this case, 2 buildings are connected to the same pipeline (building B802 and Building B803). The load from building B802 moves through MH-101 until MH 103 as shown in the longitudinal profile (figure 30), then the loads from both buildings move from MH-103 until the final point as shown in the longitudinal profile.

Figure 30



Sewer pipe from MH-101 to MH-113

We could also apply manning’s equation to find the velocity in any pipe. For example, using a 200mm pipe that goes between MH-101 and MH-102 and given its 1.19% slope, we get 1.32m/s. A description of the connection is shown in figure 31.

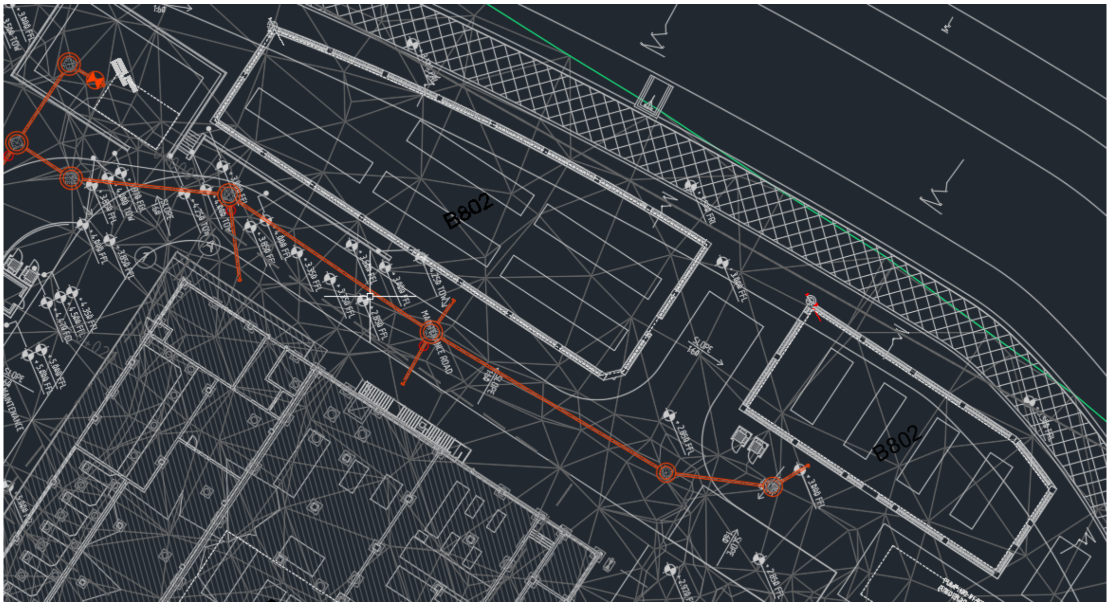
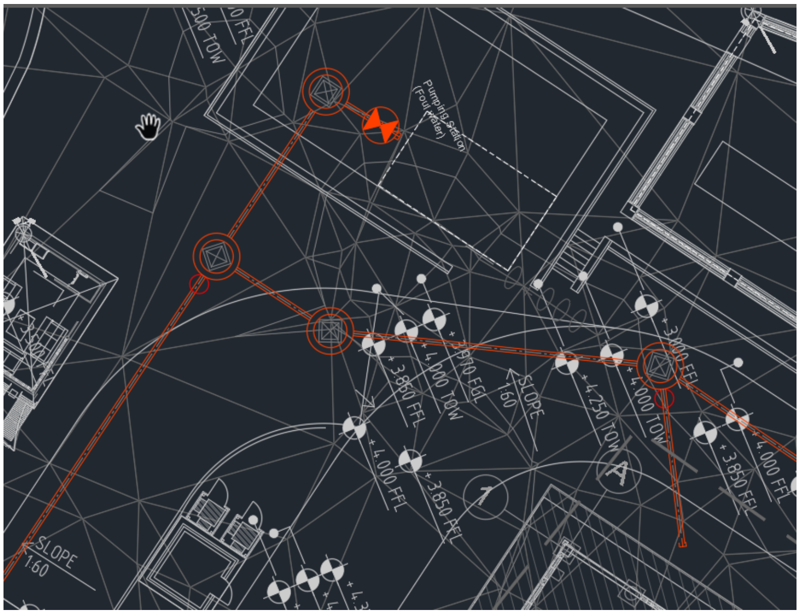


Figure 31

MH-113 is the final manhole before arriving to the end point (figure 32) which collects the sum of the three previous loads (0.00142m3/sec). The end point could be a lifting station, authority connection point, or a septic tank as stated in section 1.1.

Figure 32



Saudi real estate company Dar Al Arkan and Qatar’s government-backed developer Qetaifan Projects have partnered over this project to be developed at Qetaifan Island North, which is set to be ready in 2023 as a part of many other projects in the self-developing, modern country of Qatar which offers lot of opportunities for engineers from all around the world to test their skills and acquire new methods for constructing and maintaining the future.

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