CASE STUDIES

Water supply system in Kojani island (Zanzibar, Tanzania)

Marco Bezzi, Gabriella Trombino and Guido Zolezzi

PHOTO: Kojani island water provision system. Marco Bezzi

GDEE | GLOBAL DIMENSION IN ENGINEERING EDUCATION

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WATER SUPPLY SYSTEM IN KOJANI ISLAND (ZANZIBAR, TANZANIA)

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1. Introduction

The Global Dimension in Engineering Education (GDEE) is a European Union funded initiative involving the collaboration of development NGOs and universities, with an aim to integrate sustainable human development as a regular part of all technical university courses. Part of the initiative is the development of a set of case studies based on real field experiences of development projects. The case studies cover a broad range of topics directly related those studied in engineering, science and other technology, environment or development-related courses.

This case study looks at the design and installation of the transmission main pipe in a drinking water supply system in a developing community located in a small island.

The transmission main is a key component of every piped water supply system: it usually conveys water from the main source to a storage tank that feeds the water distribution system. The correct design of a transmission main can make a dramatic difference in the functioning of a drinking water supply system and ultimately in people's livelihoods. The case study is based on work coordinated by the Italian developmental organization Fondazione Ivo de Carneri ONLUS in the Kojani island, a small island located in the Zanzibar archipelago.

The case study allows students at any level to: learn the basic hydraulic design criteria for a transmission main and, in general, for a pipe connecting two tanks; analyse the hydraulic suitability of existing piping systems; consider the challenges of operationally placing the pipe within a real context of a developing community; appreciate the relative importance of technical, environmental, cultural and socioeconomic factors in the design and implementation of one component of a water supply system; and consider the implications of local stakeholder involvement a water project that interacts with the local territory.

1.1. Disciplines covered

Hydraulics, fluid mechanics, hydraulic constructions, which are especially - though not exclusively - taught within BSc level courses of Civil, Environmental and Architectural Engineering. Other aspects include: health and safety; development; stakeholder participation; urban development.

1.2. LEARNING OUTCOMES

The case study will present how to assess if the pipeline of a water scheme is technically appropriate in terms of flow-rate capacity and how to estimate the power of a pumping station of the aqueduct.
As results of this case study, students are expected to be able to:

- understand some of the challenges related to the provision of water supply in a formerly not served area;
- learn how to calculate the diameter of a pipeline required in a pumping transmission system;
- understand the non-technical factors that play a relevant role in the design and implementation of a new water supply project in a developing community.

1.3. ACTIVITIES

Class Activity: analysis and verification of hydraulic parameters of the new water-scheme of Kojani.

Homework Activity: group reading followed by short essay writing and final classroom discussion about non-technical factors and conflict management in the design and construction of water supply projects.

2. DESCRIPTION OF THE CONTEXT

2.1. KOJANI ISLAND AND ITS ENVIRONMENTAL CONTEXT

Kojani Island is about 7 square kilometers in area and is located in the District of Wete of the Pemba island (Tanzania: see figures 1 and 2). The population is about 15,000 inhabitants, concentrated in the main town called Kojani.
Kojani Island suffers a series of criticalities in terms of water supply, sanitation and hygiene (WASH) typical of small islands in developing countries, and further difficulties arise from its peculiar environmental setting including its connections with the main island of Pemba.
The town of Kojani essentially consists of two main parts: the historical village located on the seafront made of a sandy beach and the new Kojani urban expansion area that is located on the nearby hilly sites. The houses in the historical center are very close to one another and they are subject to frequent inundations from high-water due to tidal oscillations. This peculiar environmental setting creates highly critical conditions for the expanding urban settlement, because it makes hard to design and implement sustainable solid waste management and sanitation systems, particularly with sewage system. Almost half of the population still lives in the old town.

In consideration of the most suitable characteristics of the hilly site for urban development, the Government of Zanzibar is fostering, through multiple actions, the migration of Kojani population from the old town to the new expansion area.
The supply of water and of other important goods and services for the growing urban area of Kojani are strongly dependent on Pemba main island. Kojani suffers from shortage of raw materials, which is exacerbated due to difficulties in sea transportations across the narrow and shallow tidal channel that separates Kojani from Pemba.

To transport people and goods, fragile wooden boats are the only available means of transportation able to cross the shallow and narrow tidal channel. In relation to water supply, drinking water is pumped in Pemba and sent to Kojani through a piped system that has a 2-inches diameter transmission main and also serves other connections located in Pemba main island, located in the community of Chawale. The transmission main also serves other villages in the area beyond Kojani. Water supply is overall extremely inadequate and incomplete and there are many non-functional water collection points (public taps).

The closest village to Kojani located on Pemba island is the community of Chawale, which is found on the other side of the tidal channel separating the islands of Pemba and of Chawale. Until 2013, drinking water was provided to Chawale by means of the same piped system with a 2-inches transmission mail that also supplied Kojani. After 2013, Kojani has been served by a new transmission main (see Section 2.3) thus making the two water supply system independent from each other.

For the above reasons, many environmental and socioeconomic factors make the living conditions in Kojani extremely precarious and vulnerable, exposing people to risks related to poor hygiene. Following recent repeated health emergencies, particularly to recurrent outbreaks of cholera and typhoid infections, the Government of Zanzibar has focused its attention on Kojani Island and has required technical and economic aid to improve the water supply system. The Government has also decided to mobilize the community of Kojani, though with limited and insufficient resources.

Figure 1. *Maps of Tanzania (inserted snapshot) and of the Zanzibar archipelago*.

Figure 2. *Kojani water scheme.*

2.2. Water supply in Kojani

Water supply on Kojani Island is particularly critical due to the inadequacy and insecurity of the water supply system. The following elements provide a general picture of the situation:

- Drinking water is pumped from a 60 feet-deep aquifer through a pumping station located in the nearby Pemba Island to Kojani Island, where it is not technically and economically convenient to dig boreholes because of its hard rock aquifer and of freshwater contamination due to seawater intrusion.

- The existing pumping station in Pemba Island provides drinking water for several villages in the area, including Kojani Island, so that the amount of drinking water available for Kojani is greatly reduced.
- The existing piping scheme, which connects Kojani Island to Pemba's pumping station, is considered too small (a two-inch diameter transmission main) to provide enough water for the 15,000 inhabitants of the Kojani island.

Furthermore, although the water distribution network in Kojani is technically well structured and able to adequately cover most of the urban settlement, including about 220 public taps in the town of Kojani, the functional water supply points are actually very few, due to the low amount of water with insufficient pressure that reaches Kojani island through the 2-inches transmission main. For these reasons, the population of Kojani is forced to seek for alternative water sources on a daily basis. As typical in many developing regions of the world, this situation makes the local community much more vulnerable to poverty and limits its opportunities to improve its livelihoods.

A first alternative water source is collecting water in Pemba on a daily basis, and transporting it back to Kojani. People use non hygienic plastic buckets to collect water and then they bring filled buckets to Kojani Island by wooden boats (Figure 3). This transport implies costs, health risks and disproportionate time consumption, hampering the possibility to carry on more profitable activities.

Figure 3. *Buckets transportation on wooden boats (Author: M. Bezzi, 2009).*

A second alternative water source is represented by shallow open wells (Figures 4 and 5). There are five shallow traditional wells Kojani island, and two of them are out of use. Water in these traditional wells is dirty and polluted, due to environmental contamination and saltwater intrusion. Kojani population uses buckets to collect water from shallow wells (Figure 4).

Figure 4. *Women and children providing water from shallow well in Kojani island (Author: M. Bezzi, 2009).*

Figure 5. *Alternative water source in Kojani: shallow wells (Author: M. Bezzi, 2009).*

The third alternative water source is represented by collection of water from surface ponds (Figure 6). There is a big artificial pond very close to Kojani village (20-50 cm deep). The pond water is used for animals beverage and for domestic purposes. Children also use to play in the pond and to drink the water.

Figure 6. *Alternative water source in Kojani: the pond near the village (Author: M. Bezzi, 2009).*

2.3. Sanitary conditions in Kojani

The sanitary condition in Kojani is dramatic due to lack of adequate latrines, solid waste management and to the diffuse practice of open field defecation.
Sanitation facilities are almost absent, because of the unfortunate location of the historical center of Kojani. No latrines can be safely built in this part of the city and the future construction of new latrines is neither possible, because of regular inundation of the area associated with tidal oscillations. The situation on the hilly site of Kojani is better. The houses are not located so close apart and latrines can work effectively; few of them are already in place. The hilly site of Kojani is indeed safe in terms of high-tide inundation and presents suitable environmental conditions for the construction of new latrines and also of a sewage water system.

Unmanaged garbage landfill areas are widespread in Kojani and children are often playing with solid waste. The garbage sites are often located close to human settlements (Figure 7), often at a distance less than 100 to the nearest houses and are used also as open-defecation sites.

The local community's health situation is further worsened by the lack of sanitation and medical devices (in the island there are only 10 public toilets, while private ones are absent),

Figure 7. *Garbage uncontrolled-area (Author: M. Bezzi, 2009).*

2.4. Coping with WASH challenges in Kojani: past and present interventions

Several interventions have been put in place since 2000 with the aim to improve the water supply conditions of the town of Kojani.

In 2003, a project funded by international donors supported for the laying of 5-inch diameter pipes, in order to connect Kojani and Pemba with a larger transmission main, under the assumption that this could ensure better water supply conditions. The pipeline starts from Pemba Island and then crosses three quarters of the channel from Kojani to Pemba, but at present it has not been completed. The available project documentation and surveys with local stakeholders report that the project was stopped before its conclusion for unspecified reasons.

In 2013, the “Safe Water Project in Kojani Island” was started by the developmental organization Fondazione Ivo de Carneri ONLUS with the following aims:

- to complete the laying of the Pemba-Kojani pipe;
- to provide the anchorage of the pipe on the seabed;
- to connect the piping system to the pumping station that is planned to be built on Pemba Island (on one side) and to the tanks that will be installed on Kojani Island (on the other side), for a total distance of 4.500 meters;
- to connect four 15.000-litre tanks to the existing Kojani distribution network, by means of a 3-inch main pipe, in this way reaching 220 public taps presently located among the houses in Kojani Island’s old town;
- to develop a new water distribution network for the expansion area of Kojani.

To determine the maximum pullout flow from the well, several pumping tests have been performed showing the flow-rate of 8,3 l/s as the maximum sustainable for the aquifer. Moreover, in Pemba Island, the new pipeline was digged also through the administrative territory of the Chawale community located just in front of Kojani town. The community of Chawale is not a direct beneficiary of this new water supply system, and its water supply system is completely independent from the water supply system of Kojani. For this reason the construction of the new water scheme for Kojani is not negatively affecting the existing Chawale Water System neither in terms of water quantity nor of quality.

The “Safe Water Project in Kojani Island” has involved a series of stakeholders, which are recalled in the following. The project has been coordinated by Ivo de Carneri Foundation - Zanzibar Branch (IdCF-ZB), the local branch of Fondazione Ivo de Carneri ONLUS, which is based in Italy. The project direct beneficiaries are the citizens of the Community of Kojani. The local community of Chawale was not beneficiary of the project and its independent water supply system was not going to be affected by the construction of the new Kojani transmission main, which however was going to partially cross its administrative territory.

Local technical and implementing partners have been the Zanzibar Water Authority (ZAWA), responsible for the executive planning and the direction of the renovation and rehabilitation works, and the Public Health Laboratory - Ivo de carneri Foundation (PhL-IdCF), the reference centre for the development and implementation of protocols for systematic microbiological water analysis. Institutional support has been provided by the Italian Embassy in Tanzania. Technical support and advice has been provided by Ingegneria senza Frontiere - Trento (ISF-Trento), by staff of the UNESCO Chair in Engineering for Human and Sustainable Development of the University of Trento (Italy) and by the Azienda Sanitaria Locale - Torino (ASL-Torino), which provided laboratory activities supervision and external audit.

For a variety of reasons, the community of Chawale, including its leaders, have not been informed about the ongoing “Safe Water Project in Kojani Island”. Conversely, the government of Zanzibar, formally also an external actor of the project, and in agreement with the Zanzibar Water Authority, has required to align the project goals with the governmental strategy on the urban development of Kojani town, in consideration of its dramatic sanitary situation. This strategy consists of several urbanistic measures to facilitate the inhabitants migration from the old town to the safer new expansion area located on the hills. These measures are among the attempts put in place by the Zanzibar government to overcome the reluctance of the Old Kojani inhabitants to leave their homes in the old part of Kojani in favour of the new settlements located on the hills.

The design of the new water scheme for Kojani island has therefore foreseen the following three requirements, aimed at creating conditions that could support such migration process:

- the new water tank located in the new urbanization area needs to provide water giving priority to the new urbanization area;
- in the new urbanization area a new HDPE distribution pipeline was foreseen to provide water to private taps;
- in the old Kojani town the old pipeline was not to be replaced, also because of the technical problems posed by digging in such a crowded area, and only public taps could be served with the new water scheme. No private taps could be served in the old Kojani town through the new water supply scheme.

During the construction of the pipeline a sabotage action was performed. The sabotage regards the introduction of material in the main pipeline obstructing the normal water flow e causing a significant pressure reduction. The causes of the sabotage are presently under investigation.

3. Class activity

The activity is an exercise focusing on the hydraulic testing of the transmission main in the Kojani water supply scheme. The activity is introduced by a short summary of the methods to perform hydraulic design and testing of a transmission main.

3.1. Background: design of trasmission main in piped water supply

Water transmission for community water supply purposes is often achieved by means of pressurized pipelines. Technical options have to be careful considered and compared with the involvement of community groups that will support and manage the system. Local knowledge has to be strongly taken into account to enhance cultural acceptability of the project.

Design flow

The estimation of water demand in a distribution area has to consider the typical daily-fluctuation and thus a reservoir is the best solution for a proper water management of the water during the 24 hours. The reservoir localization has to be chosen by local people, based on technical advice and their own socio-cultural criteria. The reservoir is supplied from the transmission main. The transmission main has to be designed for the carrying capacity needed to supply water demand on the maximum consumption day at constant rate. The service reservoir will manage the hourly variations on the water demand during the day of maximum consumption. Depending on the pumping system (diesel or electric motor-drive pump) the daily pumping could be limited to 12-16 hours or less and the reservoir volume has to be adjusted accordingly.

The capital water demand represents the starting point for each kind of designing activity of a new water system and has to be determined taking into account many factors influencing the used amount of water such as:

- cultural habits;
- socio-economic status and standard of living;
- hygiene awareness;
- productive uses;
- the charges for water.

In case of lack of information and when it is not possible to perform a survey, the use of bibliographic data can be useful to determine the flow-rate. Table 1 represents typical domestic water usage data for different types of water supply systems.

Table 1. *Typical domestic water usage data for different types of water supply systems (Nozaic, D., 2002. Water quality and quantity in Smet, J., van Wijk, C., 2002. Small Community Water Supplies. Technology, People and Partnership. Technical paper Series 40, IRC Delft, The Netherlands).*

Type of water supply **Typical water consumption**	**(litres/capita/day)**	**Range** **(litres/capita/day)**
Communal water point (e.g. village well, public standpipe)		
At considerable distance		
(> 1000 m)	7	5 - 10
At medium distance		
(500 - 1000 m)	12	10 - 15
Village well		
Walking distance < 250 mn	20	15 - 25
Communal standpipe		
Walking distance < 250 m	30	20 - 50
Yard connection		
Tap placed in house-yard	40	20 - 80
House connection		
Single tap	50	30 - 60
Multiple tap	150	70 - 250

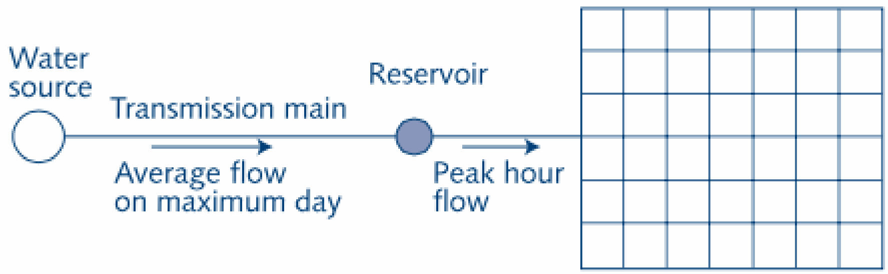

Figure 8. *Transmission main and service reservoir (Trifunovic, N., 2002. Water quality and quantity in Smet, J., van Wijk, C., 2002. Small Community Water Supplies. Technology, People and Partnership. Technical paper Series 40, IRC Delft, The Netherlands).*

DESIGN PRESSURE

In a pressurized pipeline, a minimum pressure of 4-5 mwc (meters water column) is necessary to prevent intrusion of pollution through damaged parts of the pipe or faulty joins. In gravity system the maximum pressure occurs in the most depressed distribution areas during static conditions while, in pressurized systems the maximum pressure will occur in the proximity of the pumping station during operating conditions. To avoid high pressures in the transmission main a multistage pumping system along the pipes can be realized. To avoid critical pressures due to water hammer, air vessels, surge tanks or water-towers as well of suitable pipe materials can be selected as prevention measures.

DESIGN VELOCITY

A minimum velocity is required to prevent sanitary problem in the conducts such as sedimentation and bacteriological growth in the conduits. The maximum velocity has to be respected to control head losses and to reduce the effects of water hammer. Common values of the velocity range in pressurized pipes is between 1 and 2 m/s.

To minimize the energy consumption in the transmission main the head losses has to be minimized. Common values of the hydraulics gradients are around 0,005 (5 mwc of head loss per km of the pipe length).

HYDRAULIC DESIGN

Flow Q (m^3/s) through a cross-section A (m^2) is determined as Q = vA, where v (m/s) is the mean velocity of the cross-section.

“Steady flow”: if the mean velocity of one cross-section remains constant within a certain period of time.

“Uniform flow”: If the mean velocity between the two cross-sections is constant at a certain moment.

Assumptions of ‘steady’ and ‘uniform’ flow are applied in basic hydraulic calculations for the design of water transmission systems.

The more appropriate formulas for computing the head loss of water flowing through a pressurized pipeline are Darcy-Weisbach and Hazen-Williams formula.

The Darcy-Weisbach formula states:

$$\Delta H = \lambda \frac{Lv^2}{D2g} = \frac{8\lambda L}{\pi^2 g D^5} Q^2 = \frac{\lambda L}{12.1 D^5} Q^2$$

where:

- ΔH = head loss (mwc)
- L = pipe length (m)
- D = pipe diameter (m)
- λ = friction factor (-)
- v = the mean velocity in the pipe (m/s)
- g = gravity (9.81 m/s^2)
- Q = flow rate (m^3/s)

introducing the hydraulic gradient $S = \Delta H / L$ the formula can be written as:

$$v = \sqrt{\frac{2gDS}{\lambda}}$$

The factor $\lambda$is the friction coefficient that can be estimated by the Colebrook-White formula:

$$\frac{1}{\sqrt{\lambda}} = -2log\left[\frac{2.51}{Re\sqrt{\lambda}} + \frac{k}{3.7D}\right]$$

where:

- Re= the Reynolds number (-)
- k= absolute roughness of the inner pipe wall (mm)
- D= pipe diameter (mm)

The Reynolds number indicates the flow regime:

$$Re = \frac{vD}{\nu}$$

where:

- v = the mean velocity in the pipe (m/s)
- D = pipe diameter (m)
- ν= kinematic viscosity (m^2/s)

The kinematic viscosity is dependent on water temperature. For T in °C:

$$\nu = \frac{497*10^4}{(T+42.5)^{1.5}}$$

The Colebrook-White formula is developed for a turbulent regime (Re-values above 4000). Normal Re-values are in order of 10^4or 10^5. In case of laminar flow (Re-values <2000), the friction factor can be approximated as:

$$\lambda = \frac{64}{Re}$$

The common range of k-values can also be estimated using tables/charts, produced for certain temperatures. The common range of k-values are listed in Table 1 for various pipe materials. Depending on the age of the pipe and these values can be increased.

Table 2. *Absolute roughness (Bhave, 1991).*

Pipe material	C_{hw} D=75 mm	C_{hw} D=150 mm	C_{hw} D=300 mm	C_{hw} D=600 mm	C_{hw} D=1200 mm
Uncoated cast iron	121	125	130	132	134
Coated cast iron	129	133	138	140	141
Uncoated steel	142	145	147	150	150
Coated stee	137	142	145	148	148
Wrought iron	137	143			
Galvanised iron	129	133			
Uncoated asbestos cement	142	145	147	150	
Coated asbestos cement	147	149	150	152	
Concrete, minimum values	69	79	84	90	95
Concrete, maximum values	129	133	138	140	141
Prestressed concrete	147	149	147	150	150
PVC, brass, cooper, lead	142	145	150	152	153
Wavy PVC	147	149	147	150	150
Bitumen/cement lined			150	152	153

To simplify the calculation a simpler formula can be used although less accurate than the Darcy-Weisbach.

The Hazen-Williams formula states that:

$$v = 0.355ChwD^{0.63}S^{0.54}$$

The values of Hazen-William factor, Chw, are listed in table 2:

Table 3. *The Hazen-Williams factors (Bhave, 1991).*

Pipe material	k (mm)
Asbestos cement	0.015 - 0.03
Bitumen/Cement lined	0.03
Wrought iron	0.03 - 0.15
Galvanised/Coated cast iron	0.06 - 0.3
Uncoated cast iron	0.15 - 0.6
Ductile iron	0.03 - 0.06
Uncoated steel	0.015 - 0.06
Coated steel	0.03 - 0.15
Concrete	0.06 - 1.5
Plastic, PVC, PE	0.02 - 0.05
Glass fibre	0.06
Brass, cooper, lead	0.003

The Hazen-Williams formula is applicable for a common range of flows and diameters. Ita accuracy becomes reduced at lower values if Chw (much below 100), and(or velocities appreciably lower or higher than 1 m/s. The Hazen-Williams formula, due to its simplicity is widely used in the USA and in many, predominantly Anglophone, developing countries. The formula is not dimensionally uniform and if other units are used than SI, it has to be readjusted.

Water transmission by pumping

When the water has to be transported over large distances and/or higher elevation the water scheme needs a pumping system. The total head of a pumping system comprises the static head plus the friction head loss for the design flow rate.

Once calculated the head loss corresponding to design flow rate for several pipe material and diameter the water scheme can be defined as a combination of pumping head and selected pipes capable to supply the required flow rate to the reservoir.

Smaller pipe diameters: require higher pumping head.

Higher pipe diameters: require smaller pumping head.

The selected pipe diameter should represent the most convenient choice taking into account the initial costs (capital investment), maintenance costs and energy cost for pumping.

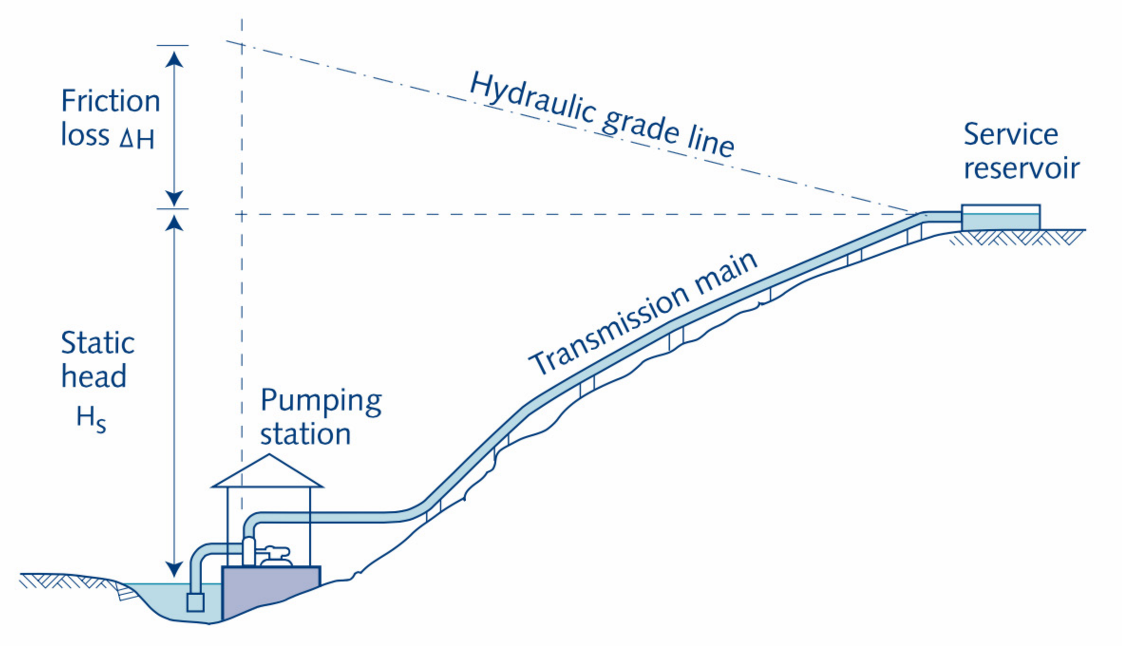

Figure 9. *Water pumping transmission scheme (Trifunovic, N., 2002. Water quality and quantity in Smet, J., van Wijk, C., 2002. Small Community Water Supplies. Technology, People and Partnership. Technical paper Series 40, IRC Delft, The Netherlands).*

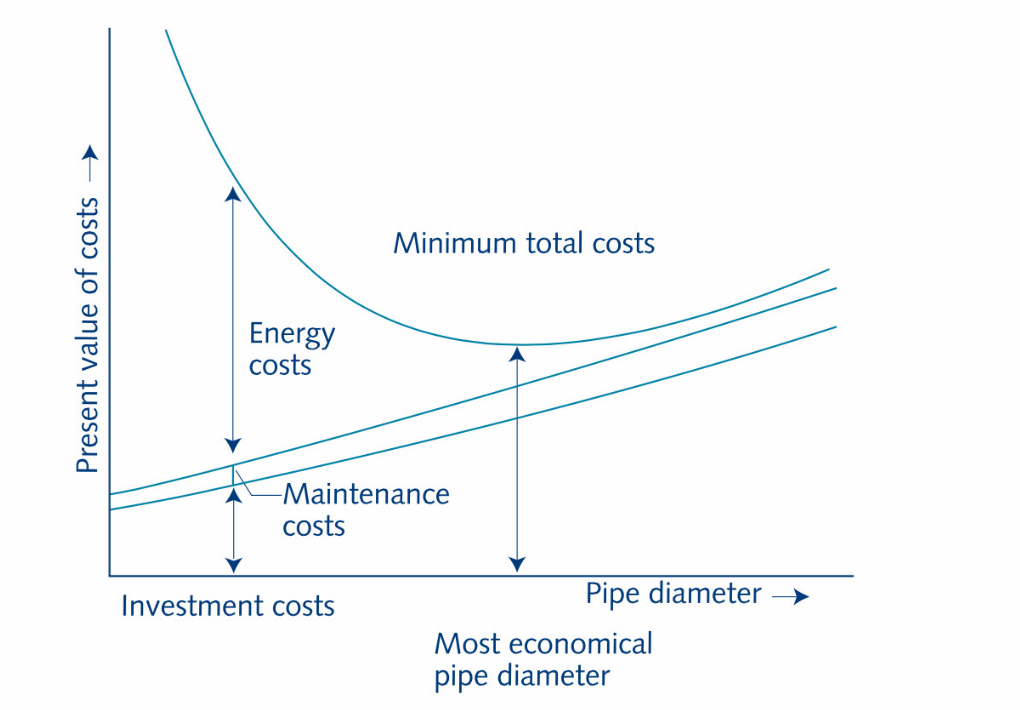

Figure 10. *Analysis of costs for different pipe sizes (Trifunovic, N., 2002. Water quality and quantity in Smet, J., van Wijk, C., 2002. Small Community Water Supplies. Technology, People and Partnership. Technical paper Series 40, IRC Delft, The Netherlands).*

The most economical pipe diameter has to be chosen taking into account the energy costs (a), the unit cost of pipe (b) and the capital interest rates (c). The diameter tend to be large when (a) in high and (b) and © are low. It is important to guarantee enough velocity in the pipeline to avoid potential water quality problems. The velocity of 1 m/s can be the base for the selection of possible most economic diameters.

PUMP SELECTION

Generally drinking water pumps are designed to run almost continuously during the day and thus it is very important the selection of pumps with a higher efficiency to save running costs over a long period of time. Reliability of the pumping system is another aspects to be taken into account especially in rural water supply systems.

The power requirements for a pumping transmission system can be computed following this formula:

$$N = \frac{\rho g Q(Hs+SL)}{\eta}$$

where:

N = power required for pumping (Watts)
Q = maximum pumping capacity (m^3/s)
ρ= specific weight of water (kg/m^3)
η= pumping efficiency (-)
H_s = static head (m)
S = hydraulic gradient (m/km) L = pipe length (m)

Assuming $\rho = 1Kg/dm^3$, $g = 10\, m/s^2$, and $\eta$for small-capacity pumps estimated at 50% the formula can be simplified as a:

$$N = 20Q(Hs + SL)$$

N is expressed in Watts for Q expressed in l/s.

3.2. ASSIGNMENT

The assignment is to verify the new water system constructed for Kojani in terms of pipelines characteristics and in terms of power installation island based on these data:

- Number of Kojani village inhabitants: 15.000
- Distance from the new borehole to the new water tank in Kojani: 4.500 m
- Borehole deepness (from the pump to the borehole head): 70 m
- Difference in elevation from the pump head to the ground level of the new water tank: 10 m
- Difference in elevation from the old Kojani village to the ground level of the new water tank: 15 m
- Maximum productivity of the borehole: about 30 mc/h

Aim of the assignment is to answer to these questions:

Is the HDPE pipe DE=125 mm, used for the connection from the new borehole to the new water tank, appropriate to transport water from the borehole to the new water tank?

What is the power of the pump that has to be installed for the Kojani Water System?

3.3. Solution and evaluation criteria:

Pipe diameter verification

Taking into account the maximum productivity of the aquifer about 30 mc/h (8,3 l/s) the pipe-line used in the project is a HDPE pipe D=125 mm PN10.. The pipeline transport water from the borehole head to the new tank at 4500 m distance. The pressure difference between the borehole head and the tank water surface is 25,0 m. The absolute roughness of the pipe wall is k=0,25 mm and the water temperature can be considered equal to 20°C.
Follow these steps to verify what will be the flow in the HDPE 125 mm pipe-line and to verify if it is enough to transport the aquifer maximum flow-rate.

The difference between the pressure at the borehole head and the tank water-surface indicates the available head loss.
Hence:

$AH = 25,0\ mwc$ and $S = 25,0/4500 = 0,0055$

For water temperature of 10°C, the kinematic viscosity is:

$$\upsilon = ((497 \times 10^6)/(T + 42,5)^{1,5} = 1,31 \times 10^{-6} m^2/s$$

The calculation has to be iterative due to the fact that the velocity (flow) is not known and it influences the Reynolds number. A common assumption is $v = 1,0\ m/s$
Further:

$$Re = (1,0 \times 0,125)/(1,31 \times 10^{-6}) = 9,54\ \times 10^4$$

$$1/\lambda = -2log\left[\frac{5.1289}{(9,54\times10^4)^{0,89}} + \frac{0,25}{3,7\times125}\right] = 6,273 \qquad \lambda = 0,025$$

$$v = \sqrt{\frac{2gDS}{\lambda}} = \sqrt{\frac{2\times9,81\times0,125\times0,0055}{0,025}} = 0,73\ m/s$$

The calculated velocity is different from the assumed one of 1 m/s. Thus the procedure has to be repeated starting with this new value. For $v = 0,73\ m/s$we obtain:

$$Re = (0,73 \times 0,125)/(1,31 \times 10^{-6}) = 6,965\ \times 10^4$$

$$1/\lambda = -2log\left[\frac{5.1289}{(6,96\times10^4)^{0,89}} + \frac{0,25}{3,7\times125}\right] = 6,202 \qquad \lambda = 0,026$$

$$v = \sqrt{\frac{2gDS}{\lambda}} = \sqrt{\frac{2 \times 9{,}81 \times 0{,}125 \times 0{,}0055}{0{,}026}} = 0{,}72\ m/s$$

For $v = 0{,}73\ m/s$, $Re = 6{,}96 \times 10^4$and $\lambda = 0{,}0026$ which yields $v = 0{,}72\ m/s$. The difference of 0,01 m/s is considered as acceptable and hence:

$$Q = 0{,}72 \times \frac{0{,}125^2 \times \pi}{4} = 0{,}00883\ m^3/s = \mathbf{8{,}83\ l/s}$$

Thus the pipeline is enough to transport the maximum productivity of the aquifer. The calculation could be improved considering instead of the commercial diameter of the HDPE pipe (125 mm) the internal diameter, that is depending on the nominal pressure characteristics of the pipe.

PUMP POWER-REQUIREMENTS

Taking into account the estimation of capital water demand for the Kojani Water System and the borehole productivity, for the water supply of Kojani, pumping is required at a rate of 358.560,00 liters per 12 hours. The static head is 95 m and the length of the pipeline is 4500 m. Follow these steps to determine the power requirement for pumping station, if a HDPE pipe D = 125 mm is used.

$$Q = 358.560{,}00 \div (12 * 3600) = 8{,}3\ l/s$$

$$v = 0{,}0083 \div (0{,}110^2 \times \pi)/4 \ = \ 0{,}87 \ \ l/s$$

From Table 1, C_{hw} for HDPE of D = 125 mm can be assumed at 149. Further:

$$v = 0{,}355 \times Chw \times D^{0{,}63} \times S^{0{,}54};$$

$$S = \left(v \div (0{,}355 \times Chw \times D^{0{,}63})\frac{1}{0{,}54}\right) = \left(0{,}87 \div (0{,}355 \times 149 \times 0{,}125^{0{,}63})\frac{1}{0{,}54}\right) = 0{,}0035$$

$$N = 20 \times Q\ (l/s) \times (Hs + S \times L) = 20 \div\times 8{,}3 \times (95 + 0{,}0035 \times 4500) = 18.399{,}00\ W \equiv \mathbf{18{,}4\ kW}$$

Thus the pump has to be installed need a power minimum of 18,4 kW plus the efficiency factor of the pump. In the case of Kojani Water System the installed pump is 4” a submersible pump.

4. HOMEWORK ACTIVITY

The assignment is for students working in small groups (2-3 students maximum). The activity consists of the following steps:

a. Each group is required to read 2 preliminary documents (De Marchi and Ruffato, 2014; Trifunovic, 2002), cited in the Reference List and provided as additional material to this case study

b. After individual reading and discussion of the above two documents, each group is asked to prepare a short essay (max 10,000 characters, approx. 2 – 3 pages), focusing on the management of water supply projects in small communities of developing countries, starting from the case study of the water supply system in Kojani. The essay should reflect the debate that each group jointly develops to the following issues:

   1) Which aspects have to be considered by a project team for the long – term sustainability of a water supply project, especially in relation to the transmission main of a piped water supply scheme? Focus primarily on non-conventional engineering aspects, as social, economical, cultural, environmental and hygienical ones.

   2) Develop one possible hypothesis that may explain the reasons behind the sabotage of the newly installed transmission main after the project “Safe Water Supply in Kojani Island” was completed. Develop arguments to support the hypothesis in relation to the case study. As leaders of the project team, which alternative management options for the project would you recommend to consider to positively overcome the problem (once the sabotage had occurred)?

   3) The sabotage can be viewed as an indicator of a latent conflict on water resources within the area (De Marchi and Ruffato, 2014).

c. Once the essays have been prepared, the teacher organizes a classroom session during which the groups concisely present their work to the entire classroom (half of the time) and the teacher stimulates a debate about the three main issues on which the essay is focused.

4.1. Solution and evaluation criteria

There are no unique / blueprint solutions to the proposed homework activities, though some general guidelines can be reported for the teacher to stimulate and facilitate the debate in the classroom on the three issues (1, 2, 3 under item b. above) on which the group essay are focused.

ISSUE N. 1

A concept that can be used to develop and focus a discussion on this issue is related on how to define sustainability for a water supply system. The following ideas are summarized in Visscher (2006).
Sustainability has initially been developed in relation to environmental issues, and the World Commission for Environment and Development in 1987 initially stated that “developments to meet the needs of the present generation should not compromise the resources, or the environmental conditions of future generations”. The Development Assistance Committee of the OECD (OECD/DAC), indicated in 1988 that it considers a development programme to be sustainable when it can provide an appropriate level of benefits over an extensive period of time after the financial, administrative or technical support of an external agency has ended. However, some care is required to translate this latter definition to the sustainability of a water supply system, because of its clear donor perspective and of the failure in encompassing the environmental element.

An interesting definition has been proposed by CINARA – IRC is as follows (Visscher, 2006):
“A water supply or sanitation system is sustainable when it:

- continuously provides an efficient and reliable service at a level which is desired;
- can be financed or co-financed by the users with limited but feasible external support and technical assistance;
- and is used in an efficient way, without negatively affecting the environment.”

The concept of sustainability here integrates three main dimensions: the community (social and economic dimensions); the environment; and the technology. Such viewpoint is helpful in guiding a discussion related to issue n. 1 in this homework.

Visscher further states: “the community comprises different people usually with common and conflicting interests and ideas and different socio-economic and cultural backgrounds. The water supply system may be one such common interest, but at the same time can be a major source of conflict. The identity of people in communities is shaped by their history and their socio-economic and environmental conditions. Some of them, often the economically better off, may be better informed, may know more of the world, but on the other hand, may have certain interests in keeping the status quo and therefore may not be willing to solve certain problems. Women may have interests different from those of men and may not have been heard in the past, or their position may make it difficult to achieve changes on their own.

The environment is the boundary that shapes the community and dictates the risks it faces and the local resources it can draw from to meet its needs. In water supply, these risks often relate to issues such as: available water resources; their pattern over the year; their level of pollution; sanitation practices of the community; and land and water use. These aspects may be affected directly by users of the catchment area as well as by the broader issue of climate change. The environmental dimension also includes the possible effect a water supply system may have on the environment, for example, by producing wastewater and chemical sludge.

The interface between environment and community represents the risk the community has to overcome in relation to, for example, its water supply. The risk-analysis helps to establish and prioritize actions to reduce the risks that will depend on the level of deterioration of the local environment. The action may focus on the reduction of the pollution level by water source protection or by introducing treatment.

Technology is the combination of hardware and the knowledge to develop and sustain it. This dimension represents the possibilities and tools actors can use to reduce the environmental risks the community is facing. This risk reduction however, can only be sustainable if the community adopts the solution and gains ownership of it by making it its own.

The interface between environment and technology represents the availability of knowledge and practical options to reduce the risk, either through technical matters or change in behaviour. It deals with the viability, effectiveness and efficiency of solutions and their effect on the environment. The interface between technology and community deals with the type of solutions the community is expecting, is willing and able to manage and sustain, and that are in line with the technical, socio-economic and environmental conditions and capacities of the community".

Issues n. 2 and 3

In the real case two hypotheses have been developed to explain the sabotage of the transmission main, the former being the most likely to approach the reality:

a. Lack of involvement of the community of Chawale in the Kojani water supply project: some community members of Chawale may therefore be responsible for the sabotage, because of the lack of proper involvement in the construction of the new water supply system.
b. The project strategy has not been well not understood by the local old Kojani inhabitants, who are reluctant to move to the new urban expansion area. They

A main conclusion concerning the rehabilitation of Kojani water system after the project completion has been as follows: "Religious representatives involvement is also necessary to avoid sabotage of the new water-system. During the debriefing meeting it was decided that Juma (ZAWA) will be responsible for the organization of a meeting with sheias and religious representatives. The meeting will involve Religious representatives, sheias, teachers. Aim of the meeting is to decide a shared strategy to convince the people of avoiding sabotage activities. The meeting will be organized in a school of Chwale before 15th April. Moreover in the specific recommendation is mentioned the following aspect: ‘Involvement of the 2 Sheias of Kojani and the 3 Sheias of Chwale is necessary for the good maintenance of the completed work and to avoid sabotage risk for the constructed aqueduct.”

Socio-environmental conflicts arise from those who claim inclusion in decision-making (De Marchi and Ruffato, 2014). They are generated mostly because of resource scarcity, by a quantitative decrease, hence, less arable land, less fishery resources, less forest area; or because of the loss of it, for instance, by the aggravation of the air and water quality following pollution.

The following questions, if not or partially answered in the students group presentations, can be used by the teacher to stimulate the discussion:

- Who are the relevant stakeholders of the case study and what has been done in terms of stakeholders involvement throughout the process?
- Which approaches you would have used to diagnose latent conflicts and to turn them into inclusive development opportunities if you had been the project team leader?

Evaluation criteria

- Capacity to analyze a case-study and identify the relevance of non-technical factors in engineering-based water supply projects
- Understanding of the basic drivers of environmental conflicts that may help in interpreting critical issues in water supply project, like the example presented in the case study
- Capacity to identify alternative management strategies to improve the long-term project sustainability

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