IMPROVING UTILITY OPERATION AND MAINTENANCE THROUGH THE USE OF GIS

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ABSTRACT:

Infrastructure networks are vital to cities, to ensure the well being of citizens and to enable them to achieve their potential for economic development. To guarantee uninterrupted and high quality services, utility companies are focusing on the performance and lifetime of their infrastructure networks. The major difficulties they are faced with in operating and maintaining their networks are caused by the high costs of asset replacement on the one hand and the limitation of income generated to cover all other costs (operation and maintenance costs, organisational costs and re-investment costs, etc.) on the other. For this reason, utility companies are increasingly using GIS to help analyse operational problems and improve the decision making process.

Against this background, this study addresses a number of important aspects in the operation and maintenance of the water supply network in the city of Damanhour, Egypt and discusses how GIS can be sensibly employed. The paper suggests a design of a data model for asset management of the existing water supply network in Damanhour, looks at methods to inventory the status of the water pipeline distribution system and suggests strategies for replacement, while determining the effect of those strategies in terms of costing. Finally replacement costs are compared to income generated by water tariffs in a particular district of the city. The outcome suggests that sustainable cost recovery to cover operation and maintenance tariffs can be achieved.

1. INTRODUCTION

1.1 Beheira Governorate in Egypt

Beheira Governorate is the second largest Governorate in Egypt, with an area of 10000 km², divided into 15 administrative districts, a population of 4.8 million people, and a population growth rate of 2.1 % per annum. The area includes 470 main villages and 5333 small villages. The population density of the populated area is 996 people/km².

The Beheira Company is the sole organization that is responsible for the operation and maintenance of the drinking water facilities in Beheira Governorate. Established in 1981, it has developed its assets from 21 million Egyptian pounds (LE), (= 3.4 million US $) to 516 million LE (= 84.2 million US $). In the year 2002, the company has produced a total of 170 million m³ of water to 400,000 connections and almost 5 million people. The total length of its distribution networks reaches 6000 km. In addition, also facilities like treatment plants, pumping stations, boreholes and small works are among the assets of the company. In the years 2002 – 2007 a further 1000 km of pipeline will be constructed to improve the quality of the network and confront the increase in population over this period (Beheira Government Website, 2004). The Beheira Company has installed a GIS to strengthen its management information system. This system is being utilized in the design of new networks, the rehabilitation and extension of existing waterworks and in monitoring and optimizing the operation of the distribution facilities. Most of the networks of the main cities and the countryside have been included in the GIS. The system has been linked to a hydraulic simulation model for the analysis of pressure and flow in the distribution network.

This paper addresses a number of important aspects in the operation and maintenance of the water supply network in the city of Damanhour, Egypt and discusses how GIS can be sensibly employed. The paper suggests a design of a data model for asset management of the existing water supply network in Damanhour looks at methods to inventory the status of the water pipeline distribution system and suggests strategies for replacement, while determining the effect of those strategies in terms of costing. Finally replacement costs are compared to income generated by water tariffs in a particular district of the city. The outcome suggests that sustainable cost recovery to cover operation and maintenance tariffs can be achieved.

2. DATA PREPARATION AND MODELING

2.1 The Available Digital Data

The digital data for this work has been kindly provided through the Beheira Water Company. Within these data, two types can be distinguished, spatial data and tabular data. The provided spatial data is in CAD format files and contains data about the water network elements (Pipes – Meters – Hydrants – Fittings), the road network and the blocks and parcels. The data used in the paper covers Damanhour City. The provided tabular data was in Oracle format files, these files contain information about consumers and landuse type (Residential – Commercial – Others).

2.2 Data accuracy and validation

The results of any analysis in GIS are very much dependant upon the quality of the input data. In order to assess this quality a procedure was developed to examine and test the data, convert the data from the orginal CAD format into a GIS environment and to remove errors. Common errors found are shown in the figure below. The resulting features were converted into an ArcGIS geodatabase using a data model that has been designed through the use of CASE tools. This set of tools enables the establishment of the geodatabase elements and the definition of their relationships.

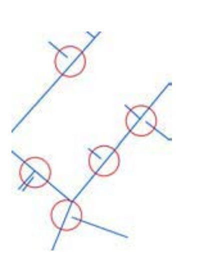
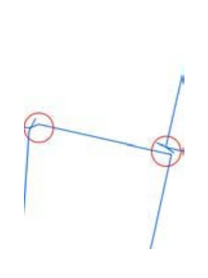
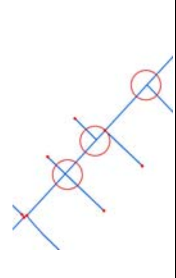
Some Pipes are not connected to the network	Errors in digitising the network, overshoots	No junctions (nodes) in intersections between some pipes
		
Use an appropriate tolerance to connect the pipes to the network	Use a certain dangle to fix the errors	Inserting junctions, using the clean command

Figure 1. Major errors in the available data and data calibration steps carried out.

2.3 The conceptual network data model

In this study five spatial entities have been defined to support the required analysis: Pipes, Meters, Valves, T-Connections, and Hydrants are used to construct the geometric network for the study. Below, the conceptual data model is shown. In this model, the relevant spatial entities are presented with their spatial relation, the cardinality of the relation (one to one or many to many in this case) and whether or not the relation is obligatory (indicated with a dot in the box for which the relation is obligatory, e.g. a water meter has to connect to a pipeline, this relation is obligatory, vice versa it is not necessarily the case). The nature of the spatial relations between the network elements is that of connectivity. This model is used later in the definition of the network and the development of connectivity rules.

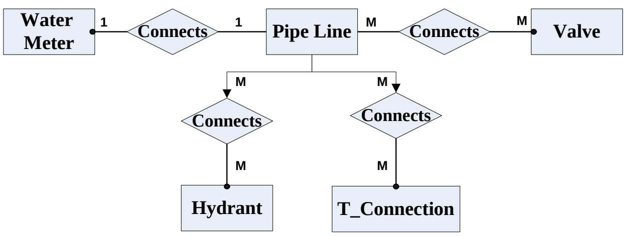


Figure 2. The conceptual network data model

The following process model shows the procedure followed in the development of the Geodatabase. Central to this procedure are the grouping of the relevant network spatial data in one feature dataset. These data are then converted into a so-called geometric network, a network that has topological connectivity established. The establishment of connectivity allows carrying out spatial analysis combining characteristics of different spatial features based on the fact that they are connected. In this procedure a spatial tolerance needs to be specified, to be able to connect those objects in the input data that are not connected. This tolerance is established after examining the quality of the input data. Other important features are the use of so called domains that can be used to define the type and valid values for each network element. In this way, one can specify for example for main lines what are the permissible values for material and diameter. This avoids errors in data processing.

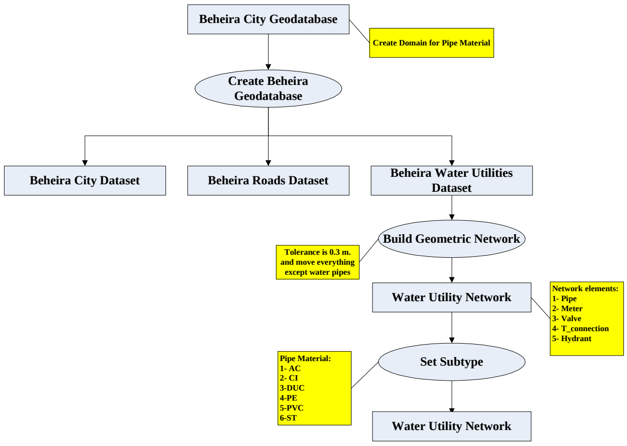


Figure 3. The process model for the network GeoDatabase

2.4 Design of the Geodatabase model for Damanhour City

In the figure below the resulting design of the geodatabase is given. As indicated in figure 2, the main datasets are the water network dataset, the road network dataset and the city dataset. The relevant feature classes in these datasets, their nature and the nature of their linkages is indicated in the figure below.

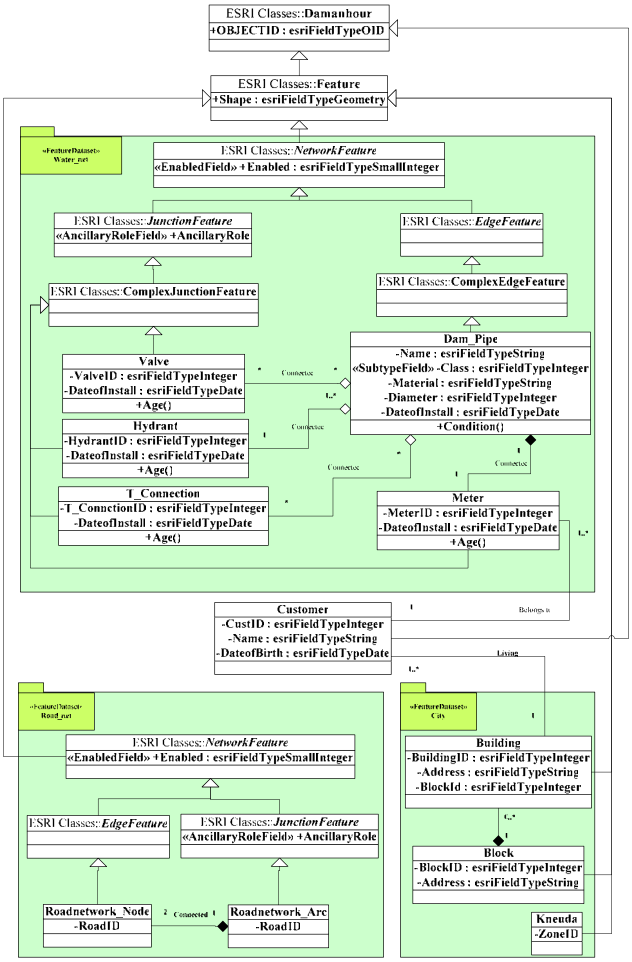


Figure 4. The final design of the geodatabase

2.5 Applications of GIS in water supply O&M in Damanhour City

In order to carry out a proper management of the infrastructure assets, a number of different analysis are being developed in this section through manipulation of the data in the GIS. This analysis takes place at two levels; the city level, focusing on the whole city of Damanhour and the district level, focusing on one particular district within the city, the district of Kneuda. At the city level, first a basic non-spatial overview is generated of the age distribution of the pipeline system as a function of pipe material and pipe length. This is followed by an analysis of replacement activities that would need to be carried out in the future, combined with a calculation of the associated costs. At the district level a similar analysis is done, however also the income generated from tariffs is calculated and compared with the costs of replacement

The most important asset in the water supply system is the piped distribution network. One of the main questions that the management is interested in therefore is to get an overview of the status and need for future replacement of the water supply assets. For the piped distribution network, we will first analyse the age distribution of the pipes in relation to the material and in relation to their length. This information is important to decide on replacements that need to be carried out. In order to do so we can use the spatial data to make graphs indicating for each material of pipe what the age and length distribution is. We will do this for the all materials, to compare and indicate materials history and length distribution.

Outputs:

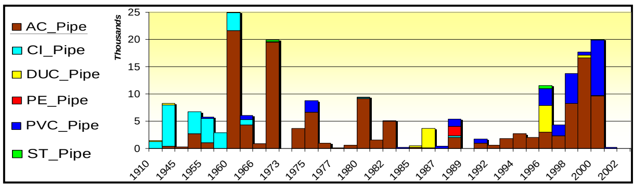


Figure 5. Length of distribution network constructed, by year of construction and material type.

The figure above gives an overview of the important historical aspects that affect the performance of our network. It can be observed that pipe construction over time is quite irregular with respect to both material and length. From the beginning of the last century until 1960 the predominant material of construction was Cast Iron, afterwards most of the network was constructed from Asbestos Cement (AC), unfortunately a material with a limited lifetime of 30 years, which renders a large portion of the network as obsolete. From the 80's mains construction was done in Ductile Iron (DUC) and gradually more PVC is being used, although still AC pipes are also used. The current strategy of Beheira Water Company in replacement activities is that all AC and PVC pipes will be replaced with PVC, and all CI and DUC pipes will be replaced with DUC pipes.

The above figure also leads to the conclusion that maintenance and replacement requirements in the future will most probably also be irregular. This aspect will be analysed further in subsequent paragraphs.

2.6 Water pipe replacement activities

Maintenance or replacement: One of the vital issues in any utility company is to determine a strategy for maintenance and replacement of infrastructure assets and to calculate and sensibly distribute the associated costs in space and time. When pipes reach their anticipated lifetime, they need to be in principle replaced, or will most probably require extensive maintenance, whichever option is economically more attractive. The maintenance activities required depend to a large extent on the quality of the pipe material, the quality (aggressiveness) of the drinking water transported and external factors such as soil and loading. In the case of Asbestos Cement - the material most used in Beheira - the rates of deterioration grow significantly after the lifetime is reached. This may cause the increased release of fibres from the inside of the pipes, which may lead to increased health risks. Options for renovation are limited to the application of epoxy and cement mortar to the inside of pipes to provide enhanced protection. In the absence of information on the above-mentioned water quality factors, we are in this section going to look at replacement only, whereby the replacement strategy is based on the expected lifetime of the pipes – the design lifetime. This is a simple and generalised approach. Other more sophisticated approaches attempt to take into account differences in pipe quality as observed during maintenance activities and through burst and leakage reports, but these require historic data that is absent in this case. While focusing on lifetime, in order to get a good overview of the replacement activities required, we are going to analyse which pipes need to be replaced directly and which pipes in the next 30 years, classified in periods of 10 years. The period of ten years is a sufficiently long period to give a gradual overview of required replacements. This analysis is based on the following aspects (material, date of construction or pipe, lifetime and pipe length). The table below gives an overview of the design life times of the pipes in use in Beheira.

Material	**Design life time**
Asbestos Cement (AC	30 years
Cast Iron(CI)	50 years
Ductile Cast Iron (DUC)	60 years
Poly Ethylene (PE)	30 years
Poly Vinyl Chloride (PVC)	25 years
Steel (ST)	60 years

Output:

As can be seen from the map in figure 6, substantial parts of the pipe network need immediate replacement. These network sections are located all over the city and are relatively unclustered, as compared to the replacement categories 10 – 20 years and more then 20 years. It can be identified that there is a very substantial backlog in replacement activities that will be hard to overcome. The financial aspects of this situation are discussed below in the estimation of costs of replacement.

2.7 Estimation of cost of replacement activities in the city

Application Concept

In this application we will look at the costs involved, not only the total replacement costs but also the costs of each phase. An inventory is made of water pipes that need to be replaced and the cost of replacement is calculated based on the design criteria for each class. The process model below outlines the steps taken in this approach.
In order to be able to calculate replacement costs, data on the construction costs of the two types of materials for different diameters were collected. The table below presents these costs, given per m' length of pipe construction. They include material costs, trenching costs and all personnel costs involved. This data was linked to the data in the pipe table in the geodatabase, after which the costs were calculated.

Diameter "mm"	Cost of 1 m' of PVC pipe (LE) incl. construction
25	10
38	12
50	15
75	20
100	25
125	35
150	45
175	55
200	65
250	100
300	150
350	160
400	175
500	225
600	250

Table 1. PVC pipe cost*

Diameter "mm"	Cost of 1 m' of DUC pipe (LE) incl. construction
75	100
100	150
125	200
150	250
200	300
250	350
300	500
350	600
400	800
450	850
500	950
600	1000
700	1100
1000	1400

Table 2. DUC pipe cost*
(* source: Beheira Company)

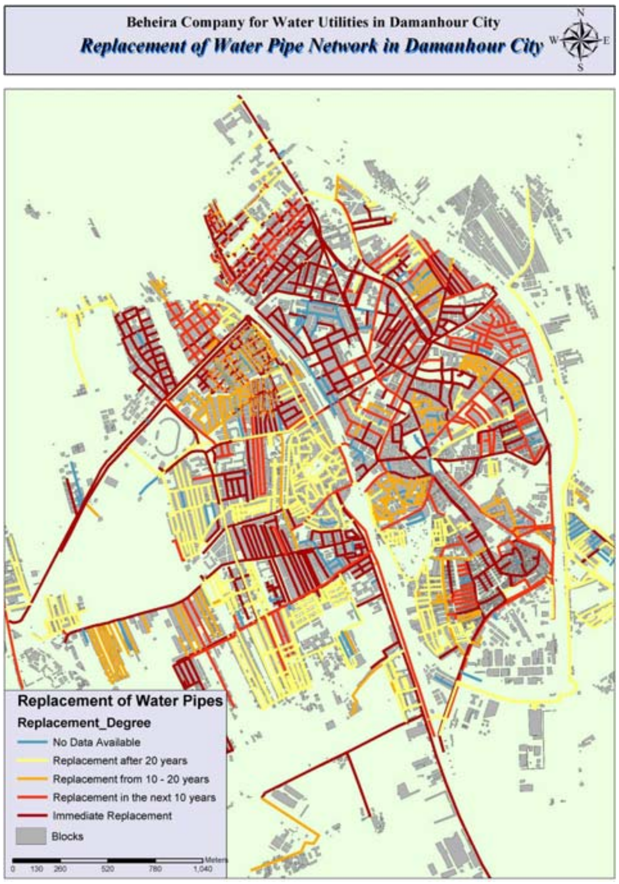


Figure 6. Water pipe replacement activities map for Damanhour

Outputs:

The tables and graphs below summarise the results of the cost calculation for the construction of new PVC and DUC pipes, amounts are in LE of 2004, not corrected for inflation. They show that there is a substantial immediate need for new PVC pipes to replace existing AC pipes. Also in the next 10 years the investment needs are substantial for PVC construction. In DUC, investment needs are actually higher, although the length of the network replaced is much less, this is due to the significantly higher unit rates for the various diameters. Significant replacement of DUC is needed immediately and in the next 10 years. Looking at the combined table, it can be identified that the replacement costs are fluctuating heavily in the different phases, which is not favourable for setting a replacement strategy. Also there is a substantial backlog in maintenance activities. It is proposed that the company develops a strategy for replacement activities that is based on an equal investment per year/decade through an optimisation process. This can also be done in GIS but is not further discussed.

Replacement	PVC_Pipe_ cost (millions of LE)	DUC_Pipe_ cost (millions of LE)	Total repl. Cost (millions of LE)
No data on age available	0.25	0.13	0.4
Immediate Replacement	2.50	3.95	6.5
Replacement in the next 10 years	2.10	3.98	6.1
Replacement from 10 - 20 years	0.63	0.18	0.8
Replacement after 20 years	2.18	7.33	9.5
Total cost	7.7	15.6	23.2

Table 3. Cost of replacement with PVC, DUC (in million LE)

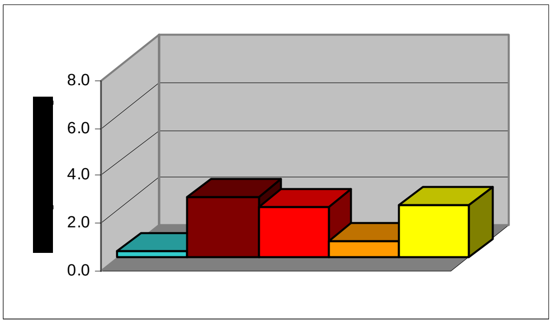


Figure 7. PVC Replacement cost

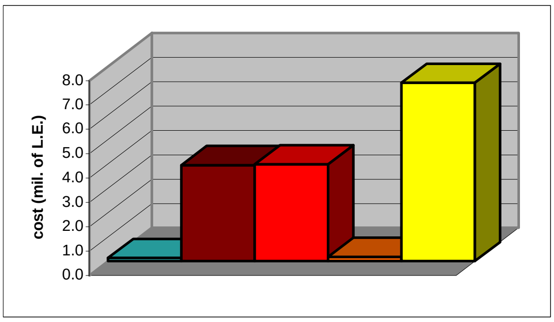
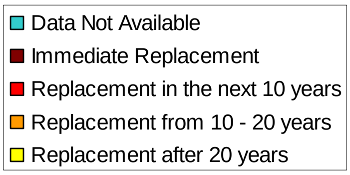


Figure 8. DUC Replacement cost



2.8 Replacement activities in Kneuda District

Application Concept: In this section we are going to look at replacement activities that will need to be carried out in Kneuda district. In addition, we will look at income generated through water tariffs and will discuss whether water tariffs are able to cover the needed replacement activities. In the process model below, the initial steps are given that are needed to develop a map of the Kneuda district only. Subsequently, the costs of replacement have been calculated, using a similar approach as taken for the whole city. The results are discussed below. To be able to calculate the income that is generated in the area, information about tariffs, no. of customers, family size and landuse category are necessary. The process model indicates the analytical steps followed. The different tariffs are indicated in the white box on the right hand side, furthermore, because no water metering takes place in the area, the tariffs are based on a flat rate of 100 litres per person per day counting with 6 residential consumers for each water connection (the average family size in the area is 6) and 3 consumers per commercial/other connection.

In the analysis of replacement activities vs. income, in periods of 10 years the income generated is compared with the required costs for replacement.

Outputs:

The first result presented is a map showing the distribution of pipelines and their required date of replacement. The map shows that a significant part of the Kneuda area is already obsolete. This concerns in particular the older developments nearer the city centre. Going more towards the outskirts of the district, the pipelines are relatively newer and need replacement in the future. Nevertheless, the Kneuda district is a district where most of the pipe infrastructure is in need of immediate renewal. Looking at the distribution over the materials as indicated in figure 9, a slightly higher investment is needed for PVC construction than DUC construction.

2.9 Calculation of Income from Customers

In this section, we are going to compare the required investment costs in the renewal of the pipe network with the total income generated in the district. On the basis of the calculation explained earlier, the basic income generated through tariffs in the year 2004 is estimated at approx. 220000 LE for the Kneuda District. This is based on the delivery of 900 thousand m3 of water to some 20000 people, which is again based on the delivery standard of 100 litres per person per day augmented with commercial and industrial use. A conservative estimate of 50 % unaccounted for water is used. In the absence of complete data, the calculation is indicative only. Of course not all this income is available for the construction of the distribution network. An instrument to be able to give a reasonable estimate of the appropriate cost levels is a so- called benchmark study, in which the financial and operational performance of various water companies are compared. As no such study is known from Egypt, other data based on a benchmark survey in the water sector in the Netherlands are used. Research under 16 water supply companies revealed that, although there are large differences, on average 50 % of the company turnover needed to be used for operational costs. Out of this share, one third on average is used for replacement and maintenance of the distribution networks. A reasonable figure therefore seems to be an overall average of almost 15 % of yearly income used to maintain the distribution network

The following replacement scenarios are developed. In **scenario 1**, during the first 5 years all pipelines are going to be replaced from the category *immediate replacement.* In the five years afterwards, the pipes from the category *replacement in the next ten years*, will be done, followed by the 2 decades afterwards, in which the other pipelines are going to be replaced. In **scenario 2**, investments are made on the basis of a maximum expenditure of 15 % of income for pipe replacement. Scenario 3 is based on an equal share of total income per year to be invested over the whole project period. The following chart shows the result of the investment requirement as a function of time. It is clear that the first scenario requires substantial investments in the first five years, whereas the second and third scenario are almost equal except for a small gap around the year 2020. Of course the downside of scenarios 2 and 3 is that if investments are postponed, the performance of the system will deteriorate, which will lead to reduced water sales.

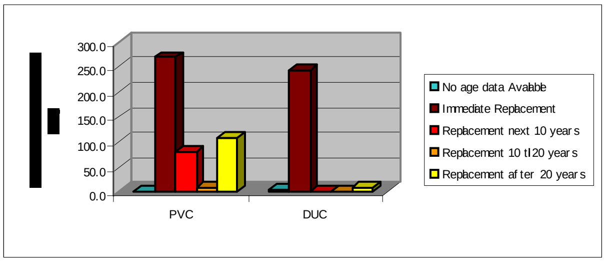


Figure 9. Cost of replacement with PVC and DUC in Kneuda (in thousands of LE)

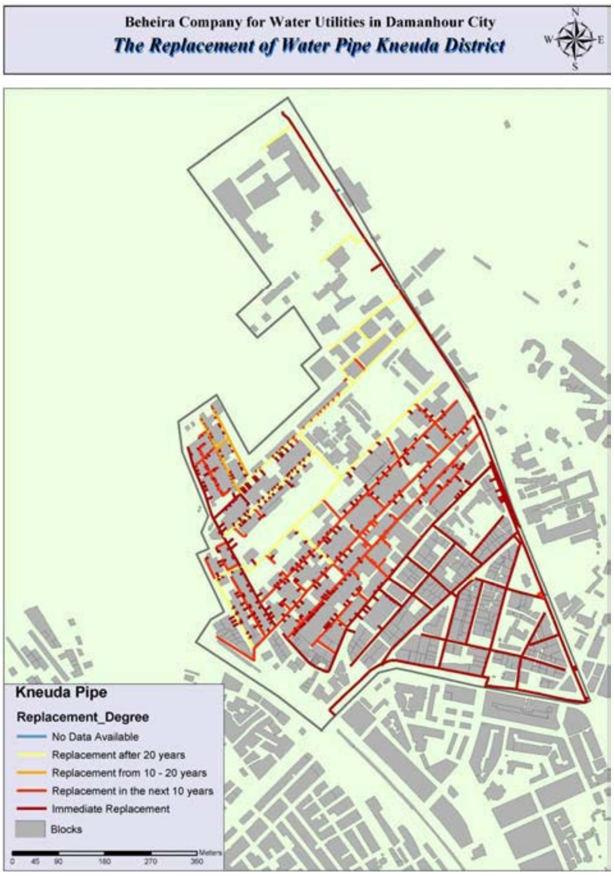


Figure 10. The pipeline system in Kneuda district and need for replacement

Replacement	PVC_Pipe_ cost (thousands of LE)	DUC_Pipe_ cost (thousands of LE)	Total repl. Cost (thousands of LE)
No data on age available	0.3	4.4	4.7
Immediate Replacement	269.3	242.8	512.1
Replacement in the next 10 years	81.0	0	81.0
Replacement from 10 - 20 years	8.7	0	8.7
Replacement after 20 years	109.2	9.8	119.1
Total cost	468.6	257.0	725.6

Table 4. Cost of replacement with PVC, DUC and total costs in Kneuda (in thousands of LE)

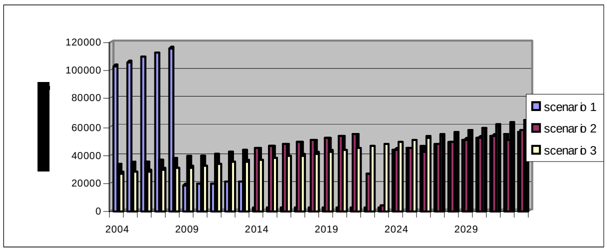


Figure 11. Investment schedule for different scenarios (in LE)

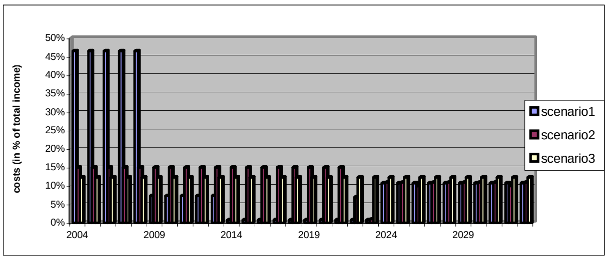


Figure 12. Investment schedule for different scenarios (in % of total income)

3. CONCLUSIONS

A number of different kinds of analysis have been carried out involving the management of the water distribution network in the city of Damanhour, Beheira Governorate. It is demonstrated that it is necessary to carry out a proper design of a system data model before any analytical process is carried out. The designed system must be flexible to carry out the current analytical tasks and be able to adapt to any future requirements. The current existence, common in many utility companies, of non-topological CAD like data, constrains the type and quality of the analysis that are possible. It is recommended that Beheira Company address these aspects in the future, like it has been addressed for the Kneuda district in the study. Completeness and accuracy of data are a prerequisite for correct analysis.

The analysis of the replacement activities to be carried out show that a large portion of the pipe system is ready for replacement in the coming years, but on the other hand that investments required can be covered through tariffs. It is important to have a complete overview on the status of the network, including historical information on performance. Better quality information is the key to improved decision-making and the employment of more elaborate models that focus on the performance of the assets as the key deciding factor on replacement, rather than the age. If performance modelling is taken up seriously, the resulting strategy can be fine-tuned and costs can be saved.

4. REFERENCES

[1] Beheira Government Website, http://www.beheira.gov.eg/en, accessed June 2004