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Analysis and design of Nvene potable water supply scheme

O.E. Ekenta

Department of Civil Engineering, Nnamdi Azikiwe University, Awka

Abstract

The Nvene water supply scheme study is undertaken to highlight the salient features that should be conceived and implemented in the analysis and design of functional, reliable, clean, safe and economic drinking water facilities. Surveys carried out include hydrological/topographical surveys, geotechnical investigation, aquifer characteristics and water quality analysis. This research investigated the benefits realisable from the application of computer programming as an alternative analytical tool for engineering analysis of complex systems. Water production facilities designed include spring water collection works, water treatment units, and pipeline aqueducts. Economy in construction of capital projects could be achieved through comparative analysis and costing of alternative systems, taking into consideration the medium and long term operational and maintenance costs associated with the management of water supply schemes.

1. Introduction

The Nvene water supply scheme was developed to provide potable water for a newly constructed University Teaching Hospital at Ituku Ozalla, near Enugu. Spring water was abstracted from Nvene spring located some 3.5 kilometres away from Udi town centre off the Udi-Ozalla road.

Water from the spring water harnessing works is transported by gravity over a distance of 280 metres to a new pumping station. After treatment the water is pumped to an existing 540m^3 reservoir located 10.0 kilometres away in the hospital complex compound. The treatment processes prescribed for the raw water when implemented would result in the provision of a clean and safe potable water conforming to World Health Organization standards for drinking water. The estimated total cost of the scheme was over N100,000,000.00 (one hundred million Naira). A layout of the facilities in the scheme is presented in Fig. 1 (Ekenta, 1997).

2. Methodology

2.1. Preliminary surveys

2.1.1. Hydrological/topographical surveys

A thorough hydrological survey for the determination of the safe yield of the Nvene spring was carried out. Discharge measurements confirmed that the average abstraction from the spring would exceed 1440m^3 per day.

Topographical surveys were executed for mapping of the spring water collection works site, the pumping station and treatment facilities sites, and the routes for construction of aqueducts.

2.1.2. Water demand

An analysis was carried out for the water requirements of the teaching hospital complex. The initial and ultimate water demands were found to be 472.50m^3 per day and 1,356.0m^3 per day respectively. The hospital is planned to house 1000 hospital beds including 5,000 residents.

2.1.3. Geotechnical investigation

The investigation was carried out to determine the engineering characteristics of the natural soil materials at the spring collection works site and the intake pumping station site, with a view to determining their suitability as a foundation for sub-structures. An analysis of the strength parameters (Table 1) of the parent material was carried out. These are unconfined compressive strength (UCS) test results from which correlation values were derived. It was found that the site is predominantly a uniform deposit of poorly graded silt sand mixtures of varying consistency. Geologically sandstone and siltstones underlie the area. The bearing capacities were found to be fair. Foundation strip widths should not be less than 0.7 metres while isolated column bases must not be less than 1.0 metre square. Meyerhof's bearing capacity Eq. 1 was applied in the computation of bearing capacity values (Cappa et al., 1977; Cappa and Cassie, 1976).

$$q = cN_{c'}S_{c'} + \gamma D_f N_{q'} + \gamma B N_\gamma S_\gamma /2 \quad (1)$$

where c = cohesion component of strength, $N_{c'}$, $N_{q'}$, N_γ = Terzaghi's bearing capacity factors (Terzaghi and Peck, 1967). $S_{c'}$,$S_{q'}$, S_γ = Meyerhof's scale factors.

2.2. Spring water collection works

2.2.1. Aquifer characteristics

The soil investigation carried out at the spring source indicated a soil profile with sandy silt to a depth 0.60 metre from the surface followed by 0.4 metre of silty-sand and a sand-stone leaky aquifer for a depth greater than 1.10 metre. The average hydraulic conductivity of the sandy-silt, and sandstone layers is in the region of 6.0 metre per day (Shaw, 1988).

2.2.2. Collection structure

The existing dilapidated spring water collection structure was re-designed to allow for increased abstraction of spring water to meet with the ultimate water requirements of the hospital. A reinforced concrete box structure was constructed with the seepage face of the formation packed with graded gravel filter material. The enlarged structure was provided with a collector channel, piping and reinforced concrete peripheral drainage channels. The spring water collection works components are shown in Fig. 2.

2.3. Water treatment

2.3.1. Water quality analysis

Raw water samples were collected from Nvene spring for water quality analysis. Physical, chemical and bacteriological tests were carried out for twenty (20) parameters. The results presented in Table 2 indicated a low pH of 4.94, a high Free CO_2 of 0.76 m-mol per litre, and a Faecal Coliform plate count of less than 200/100 ml.

2.3.2. Disinfection

The presence of Faecal Coliform in the raw water dictates that a disinfection unit be installed to provide for safety disinfection through the maintenance of the required chlorine residual in the distribution system. It would also contribute to the elimination of traces of taste and odour producing substances (Tebbutt, 1988; WHO, 1999). Two metering pumps for dosing of Calcium Hypochlorite, solution tanks and piping were specified for installation.

2.3.3. Water conditioning

A lime plant was specified for installation in the water treatment room at the pumping station (Fig. 1). Calcium hydroxide slurry will be applied to the raw water to stabilize the pH to an acceptable range of 6.5 to 8.5 and to reduce the level of Free CO_2, thereby minimizing substantially the occurrence of corrosion in the distribution system. The Free CO_2 level of the product water should attain positive Langelier Index. The installed plant should comprise: two dosing pumps with motors, two slurry tanks, dust extractors, piping and other ancillary equipment.

2.4 Aqueducts

2.4.1. Transmission by gravity

A 280 metre long a, 200mm diameter ductile iron pipeline (Pont-A-Mousson, 1997) was designed to transport raw water by gravity to a new 40 cu.m reinforced concrete collection tank interconnected to an existing $60m^3$ tank at the pumping station. An interesting feature of this aqueduct is the construction of a pipe bridge 50 metre long across an 8.0 metre deep gully.

2.4.2. Pumped transmission

The design of the pumped transmission system took into consideration the need for the provision of functional and durable facilities of optimal sizes at economic cost. Analysis was carried out using pump and system equations including controlling parametric boundary limits in selecting economic pumped transmission system components for the scheme.

The graphs plotted in Fig. 3 show the pipeline characteristics for 150 mm and 200 mm diameter ductile iron pipes. Super-imposed on these curves are the pump-head capacity curves and efficiency curve for two rotodynamic mixed flow motor driven pumps. The duty point for the 150mm diameter pipe indicated a head of 84 meters for a discharge of $58m^3$ per hour at a pump efficiency of 74 percent (pump P_2) while that of the 200mm diameter pipe indicated a head of 42 metres for a flow of $62.5m^3$ per hour at a pump efficiency of 72 percent (pump P_1).

A computer program (Casey, 1992) was also applied in the analysis of the pumped transmission system for different diameters of rising main. The coefficients A_1 and A_2 in the rotodynamic pump Eq. 2 were computed for the selected pumps given three points on the H/Q standard speed curve, including the shut-off value A_0. The values obtained for the duty point discharges, the duty point heads and pump speeds for the 200 mm and 150 mm diameter delivery mains agree substantially with the results obtained from the graphical plots.

$$H = A_0 + A_1 * Q + A_2 * Q^2 \quad (2)$$

where H = pump head and Q = discharge.

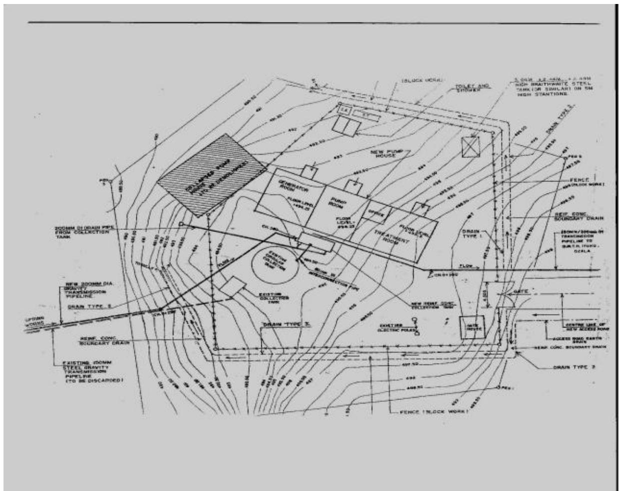

Fig. 1. Layout of facilities for Nvene water scheme.

Table 1
Summary of soil engineering data.

Borehole	O.M.C (%)	Unit Weight (KN/m^3)	Cohesion (KN/m^2)	Friction	Allowable Bearing Pressure(q) (KN/m^2)
$2\text{-}S_2$	12.4	15.4	470	11^O	400.0
$3\text{-}S_2$	11.8	19.5	578	9^O	520.0
$3\text{-}S_3$	13.7	16.5	490	10^O	460.0

3. Economic analysis of rising main

The analysis carried out for the assessment of the optimum diameter of rising main and pump capacity for the pumped transmission system is shown in Table 3.
Table 3 shows that the percentage friction loss of 60 % of the static head for the 200 mm diameter pipe is more economical than 248 % obtained for the 150 mm diameter pipe. With the low value of 9.1 kW power for pump P_1 compared with 19.2 kW power for pump P_2, it is clearly evident that substantial savings would be made on energy consumption if a 200 mm diameter pipe were chosen. The higher capital cost of the 200 mm diameter ductile iron pipe would be compensated by its very low running costs in the medium and long term of operation of the scheme.

Table 4 validates this fact. The total annual running cost for the system with a 200 mm dia. pipe is lower than that for the 150 mm dia. pipe. Similarly the total net present costs for the two systems indicate that the 200mm pipe system has a substantially lower cost than the 150 mm pipe system when discounted over 40 years. The 200 mm pipe combined with a 9.1 kW pump provides for the best and the most economic pumped transmission system for the scheme.

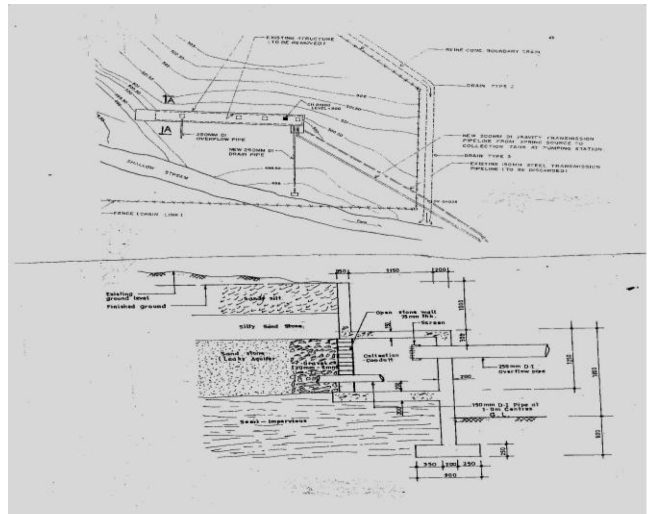

Fig. 2. Spring water collection works: plan and section A-A.

Table 2
Summary of water quality analysis results for Nvene spring

Parameter	Collection Date (10-02-97)	Collection Date (14-04-98)
Temperature (^oC)	27.5	33.6
Colour (Pt C_o)	9.6	2.0
Turbidity (F. T.U)	1.9	1.0
Electrical Conductivity (μS / cm)	0.34	0.05
Total Hardness (mg/l as $CaCo_3$)	4.0	7.0
Manganese (mg/l)	0.01	0.00
Silica as SiO_2 (mg/l)	4.25	0.469
Total Iron (mg/l)	0.45	0.08
Nitrates as NO_3 (mg/l)	1.2	1.60
Total Alkalinity (mg/l as $CaCO_3$)	10.0	2.0
Total Dissolved Solids (mg/l)	170.0	31.9
PH	4.94	6.0
Calcium Hardness (mg/l as $CaCO_3$)	3.0	4.0
Magnesium Hardness (mg/l as $CaCO_3$)	1.0	3.0
Sulphates as SO_4^{2-} (mg/l)	5.0	1.0
Acidity	61.0	-

(mg/l as $CaCO_3$)		
Free CO_2 (m-mol/l)	0.76	-
Suspended Solids (mg/l)	15.0	3.0
Nitrites (mg/l)	0.006	0.006
Sulphide (mg/l)	-	0.000
Faecal Coliform Plate Count	< 200/100 ml	-

4. Results

This study indicates that functional and reliable water supply schemes could be conceived and designed using available spring water sources. The results obtained from preliminary surveys were applied in the design of water production facilities. Designs were carried out for spring water abstraction works, pumping station, gravity and rising mains including treatment units for water disinfection and conditioning. Computer aided analysis facilitated the task of selecting pumps for the scheme. Economic analysis for selection of rising main installed for transportation of potable water was also carried out.

5. Conclusion and recommendation

The design of mini-water supply schemes could be easily realized by harnessing available spring sources that are usually less prone to pollution than surface water sources. Capital costs for developing such schemes are manageable considering the reduced cost of investments on treatment plants and intakes. The design of an economic pumped transmission system should take into consideration the provision of facilities that would minimize running costs during the operational life span of completed schemes. Optimum diameters of pumping mains must be applied in the construction of aqueducts.

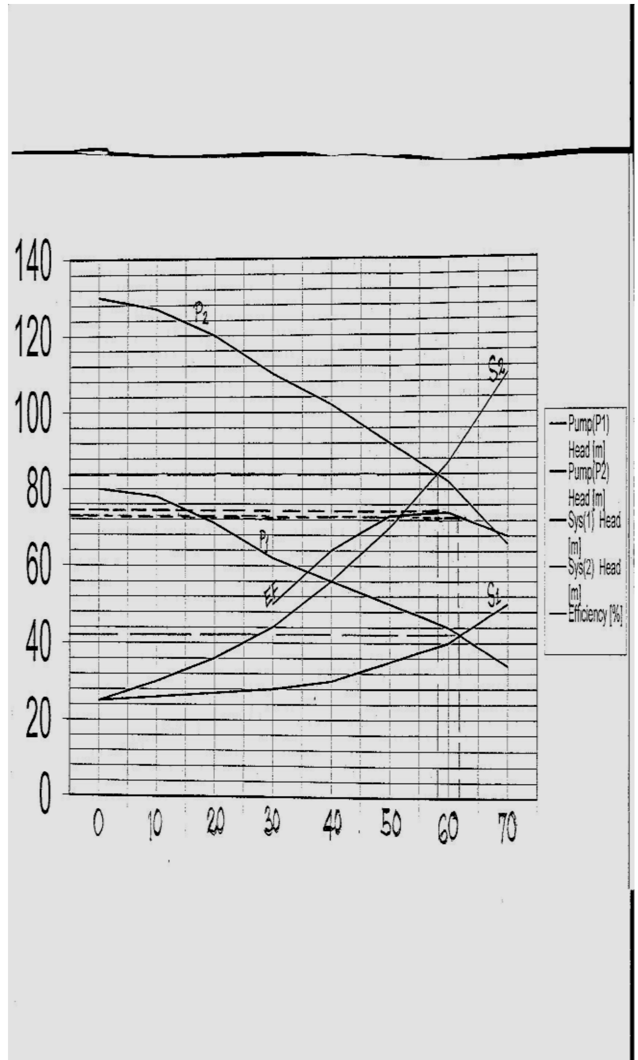

Fig. 3. Pump-head and system-head capacity curves vertical axis – head (m); efficiency (%) horizontal axis – discharge (m^3/hr).

Table 3
Assessment of optimum rising main and pump capacity

Dia (mm)	Friction Coeff. (m/km)	Friction Head (m)	Static Head (m)	Total Dynamic Head (m)	Friction Over Static Head (%)	Velocity (m/s)	Pump Power (kW)
125	15.5	155.0	25.0	180.0	620.0	1.34	39.8
150	6.20	62.0	25.0	87.0	248.0	0.93	19.2
200	1.30	13.0	25.0	40.0	60.0	0.53	9.1

Table 4
Cost comparism of alternative systems

Dia (mm)	Pipe Cost (£)	Pumpset Cost (£)	Total Capital Cost (£)	Annual Charges on Capital @ 10 % Interest (£)	Power Charge @ 9p per kWh (£)	Total Annual Running Cost (£)	Net Present Cost Discounted @ 10% for 40 yrs. (£)
150	193,000	10,665	203,665	20,367	18,062	38,429	381,896
200	261,000	4,905	265,905	26,591	8,278	34,869	347,393

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