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Research Paper

Optimization of Hydraulic Designfor Integrated Water Supply Managementin Nigeria

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ABSTRACT:*Integrated water supply management is important in developing nations such as Nigeria for optimization of hydraulic structures.This study presents a method for optimizing the design of a water distribution network using pipe diameter as a decision variable under the required demand loading and hydraulic conditions. Data were collected from field studies and an optimization model was formulated from the obtained information using pipe diameter as decision variable. The results of the study revealed that an increase in minimum pressure will lead to reduction in the required pipe diameter. The predominant pipe sizes in the optimum solution of the model were 100 mm and 150mm. However, at higher values of minimum pressure, pipes of larger diameters were not required to obtain the optimal solution to the water distribution system. The optimization model developed will be very useful for determination of economical pipe sizes in a water supply system for newly planned layout and for evaluating existing distribution system for upgrading and strengthening.*
KEY WORDS:*Integrated, Water Supply, Management, Optimization, Distribution Network*

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I. INTRODUCTION

A hydraulic structure is any structure submerged or partially submerged in any body of water, which disrupts the natural flow of water. Hydraulic structures are anything that can be used to divert, restrict, stop and manage the natural flow of water. Hydraulic design is done mainly by hydraulic engineers which sub-discipline of civil engineering is concerned with the flow and conveyance of fluids, principally water and sewage. Hydraulic engineering is the application of fluid mechanics principles to problems dealing with the collection, storage, control, transport, regulation, measurement, and use of water. One feature of these systems is the extensive use of gravity as the motive force to cause the movement of the fluids. Before beginning a hydraulic engineering project, one must figure out how much water is involved, the sources and the destination, purpose of the water supply, etc. The hydraulic engineer is concerned with the transport of sediment by the river, the interaction of the water with its alluvial boundary, and the occurrence of scour and deposition. The hydraulic engineer actually develops conceptual designs for the various features which interact with water such as spillways and outlet works for dams, culverts for highways, canals and related structures for irrigation projects, and cooling-water facilities for thermal power plants.

Integrated Water Resources Management (IWRM) approach for water resources development is effective and efficient if genuine cooperation is established amongst the water sector stakeholders. This can only be achieved through comprehensive water education at all levels of programs and projects activities. The National Water Resources Institute (NWRI), Kaduna, Nigeria has initiated capacity building projects/programs at different levels of human resources development for knowledge and skills acquisition in the sector thereby fostering cooperation amongst various stakeholders. Integrated urban water management (IUWM) is a philosophy of varying definitions and interpretations. According to the authors of the book entitled, "Integrated Urban Water Management:

Humid Tropics", IUWM is described as the practice of managing freshwater, wastewater, and storm water as components of a basin-wide management plan. It builds on existing water supply and sanitation considerations within an urban settlement by incorporating urban water management within the scope of the entire river basin.

Activities under the IUWM include the following:

- Improve water supply and consumption efficiency
- Upgrade drinking water quality and wastewater treatment
- Increase economic efficiency of services to sustain operations and investments for water, wastewater, and storm water management
- Utilize alternative water sources, including rainwater, and reclaimed and treated water
- Engage communities to reflect their needs and knowledge for water management
- Establish and implement policies and strategies to facilitate the above activities
- Support capacity development of personnel and institutions that are engaged in IUWM.

1.1 **Challenges**

One of the most significant challenges for IUWM could be securing a consensus on the definition of IUWM and the implementation of stated objectives at operational stages of projects. In the developing world there is still a significant fraction of the population that has no access to proper water supply and sanitation. At the same time, population growth, urbanization and industrialization continue to cause pollution and depletion of water sources. In the developed world, pollution of water sources is threatening the sustainability of urban water systems. Climate change is likely to affect all urban centers, either with increasingly heavy storms or with prolonged droughts, or perhaps both. To address the challenges facing IUWM it is crucial to develop good approaches, so that policy development and planning are directed towards addressing these global change pressures, and to achieving truly sustainable urban water systems. Figure 1a and 1b shows Hydraulic Design Installations.

Figure: Hydraulic Design Installations

II. LITERATURE REVIEW

Optimization of structural designs aims to reduce construction costs, improve construction methodologies and find an optimum balance between costs, time, risk and maintenance. Thorough understanding of the environmental conditions, design factors and design formulae form the basis of the optimization process. Important aspect in the design of Hydraulic Structures is the combination of a theoretical correct design and practical design in reality. Any constraints of material and/or equipment should be investigated before design and consideration. As construction costs form a large part of the total costs, highly practical construction is important in the design process where collaboration with the Contractor is very important.

A water distribution system connects consumers to sources of water, through hydraulic components, such as pipes, valves, and reservoirs. Once pipelines are in place, land use planners rightly press for the lowest cost of expansion, which is along the pipeline route. As a result, even though these utilities initially respond to growth, the latter are impetus for urban and rural expansion (Ashton and Bayer 1983).

A distribution network is an essential part of all water supply systems and its cost, in any sizable water supply scheme, amounts to more than 60% of the entire cost of the project (Abdel-Gawad, 2001). Also, the energy consumed in a distribution network is more than 80% of the total energy consumption of the system. The high investment and maintenance costs associated with both new water distribution networks and the expansion of existing ones have led hydraulic researchers to take great interest in mathematical methods to find their optimal design, that is, the minimum cost network.

Vamvakeridou-Lyroudia, et al. (2007) proposed storage optimization technique aiming to bridge the gap between traditional engineering practice and mathematical considerations needed for genetic algorithms (GAs). The major variable used for the optimization was only limited to tank simulation whereas there are other essential variables and components that constitute water distribution systems. Sumer and Lansey (2009) studied the effect of uncertainty on water distribution system model design decisions. However, this work did not incorporate the entire components of water distribution network systems. The work looked beyond the individual network solution strategies currently available that are meant for obtaining flows/pressure given a minimum number of measurements.

The operational control of water networks has posed difficulties in the past to the human operator that had to take the right decisions, such as pumping more water or closing a valve, within a short period of time and quite frequently in the absence of reliable measurement information such as pressure and flow value. This is because the water networks are large scale and non-linear systems. To tackle these challenging difficulties, Arsene, et al. (2005) worked on modelling and simulation scheme for water distribution systems based on loop equations. The purpose of the work was to investigate the implications of the loop equations formulation of simulator algorithm, state estimation procedure and confidence limit analysis for the implementation of decision support systems in operational control of water networks. Coulbeck and Orr (1984) opined that water distribution networks are generally the least well defined of the three major utilities (i.e. gas, water and electricity). There are a number of reasons for this which probably includes: measurement difficulties, high cost of telemetry, complex and interactive networks, empirical network relationships, and undetected leakage.

However, it was concluded that more research is required, notably in respect of the extension of the method to more realistic systems and the handling of multiple demand patterns.

Developing methodologies for the minimum cost design of water supply networks, optimizing coverage with satisfaction has been under investigation for the last four decades and with the advent of computers a radical change is taking place in the planning and design of water distribution pipe network (Letha and Sheeja, 2003). Liong and Atiquzzaman (2004) used EPANET, a widely used water distribution network simulation model, to deal with both the steady state and extended period simulation which were linked with a powerful optimization algorithm, Shuffled Complex Evolution (SCE). It has been shown that SCE is a potential alternative optimization algorithm to solve water distribution network problems.

III. METHODOLOGY

3.1 Optimization Model

3.1.1Objective Function

The objective function is minimizing the total cost of installation.

Where; The length of link in m and is the diameter of link in mm.

There are several Constraints that needs to be considered.There are four constraints to be satisfied by the objective function

a) Node flow continuity Constraints;Where;

Qxis the flow in link x to the node j;

Qjis the demand at node j and;

N is the total number of nodes in the network.

b) Loop head constraints, Where;

Is the constant depending on link material, and units of different terms; and are exponents equal 2 and 5 respectively for Darcy-Weisbach formula; 1.85 and 4.87 respectively in Hazen-William formula.

c) Path head loss constraints, Where:

Is the minimum residual pressure allowed at node j, Where:

Is the minimum residual pressure allowed at node j

d) Non-negativity constraints

Where;

Dmin and Qminare respectively the minimum link diameter and flow allowed in the network.

In solving the formulated optimization model for the water distribution network and to estimate other associated parameters, a software (LINGO 13.0 Version) was used. The model formulated had 64 variables and 129 constraints (45 non-linear). For all the analysis performed, the number of iterations ranged between 260 and 421. The minimum pipe diameter considered was 75 mm and the minimum residual pressure was varied so that the effect of the pressure can been seen on the optimum cost.

IV. RESULTS AND DISCUSSION

4.1 Pipe Diameters

Since the size of pipe also determine the cost of installation, it has been shown that as the residual pressure is increased, the required pipe diameter will be reduced. Figure 4 shows the number of pipes within the ranges of pipe diameter at various minimum residual pressure. It can be seen that with the highest minimum pressure considered (30 m), the smallest pipe size, i.e. 75 mm is predominant which will definitely generate the minimum cost. Hence, as the minimum pressure is increased, the pipe diameter needed decreases to meet up with the loading condition of the network.

The number of pipes whose sizes are between 100 mm and 150 mm are the next highest to the smallest pipe size considered. This can be seen in Figure 5 more clearly where the curves peaks at (100 mm to 150 mm) diameter range at minimum pressure of 8 m and 10 m. The curves have indicated clearly that increase in pipe diameter result in the use of fewer number of pipes in the network. At higher values of minimum pressure, pipes of larger diameters were no longer required to obtained the optimal solution to the water distribution system.

Figure 2shows a statistics of pipe diameter and pressure.

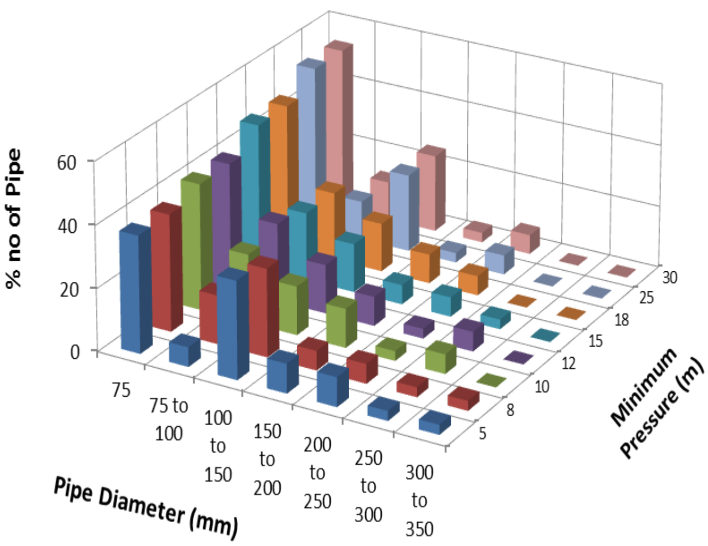

Figure 2:Statistics of Pipe Diameter and Pressure

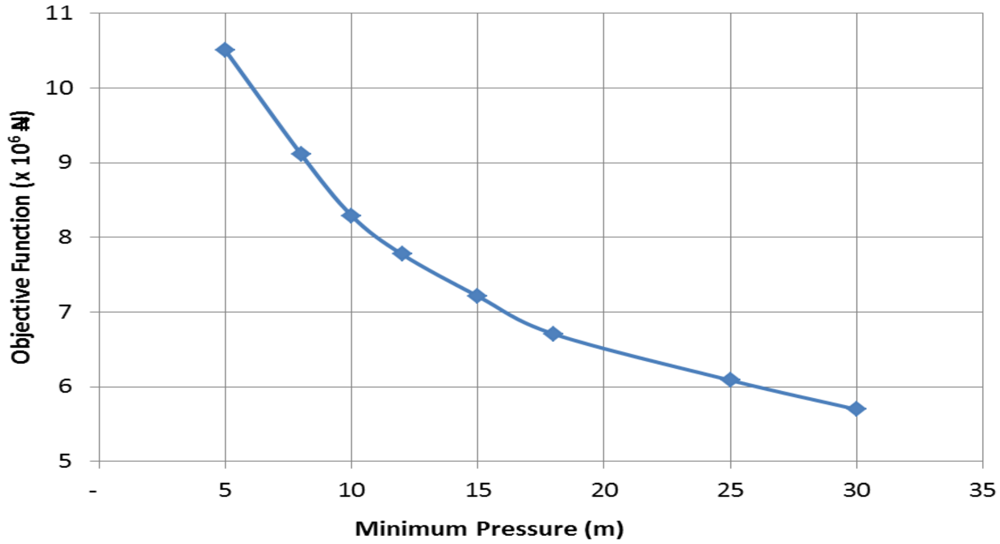

Figure 3:**Objective function model with pressure**

4.2 Pipe Flows

In Table 4, pipe AR has the highest value of flow for all cases of minimum pressure considered. This is because the total volume of water that will serve the whole areas will flow through the pipe. Pipes KO and LP at 8 m pressure and pipe DH at 10 m pressure were found to be redundant because they had zero flow. Such redundant pipes will only be useful when there is problem along the other pipes serving the same area. Pipe RS had the minimum flow at 5 m, 12 m and 15 m pressure. At 18 m pressure, pipe HL had the minimum flow while at 25 m and 30 m pressure, pipe PT was found to have the minimum value of flow. Table 4 results imply that minimum pressure of 12 m is needed to avoid pipes with zero flows.

Figure 6 shows the number of pipes within various flow ranges at stipulated minimum pressure. The pipes flow less than 0.2 l/s were decreasing in number with increase in minimum pressure. But in the case of flow ranges between 0.2 l/s and 0.5 l/s, the numbers of pipe increased with increase in minimum pressure. The number of pipes within these ranges of flow (0.2 l/s and 0.5 l/s) were also predominant in the network as shown in Figure 4. At higher values of minimum pressure, pipes with high values of flow were very limited in number in the optimal solution of the network design case (Figure 4.2).

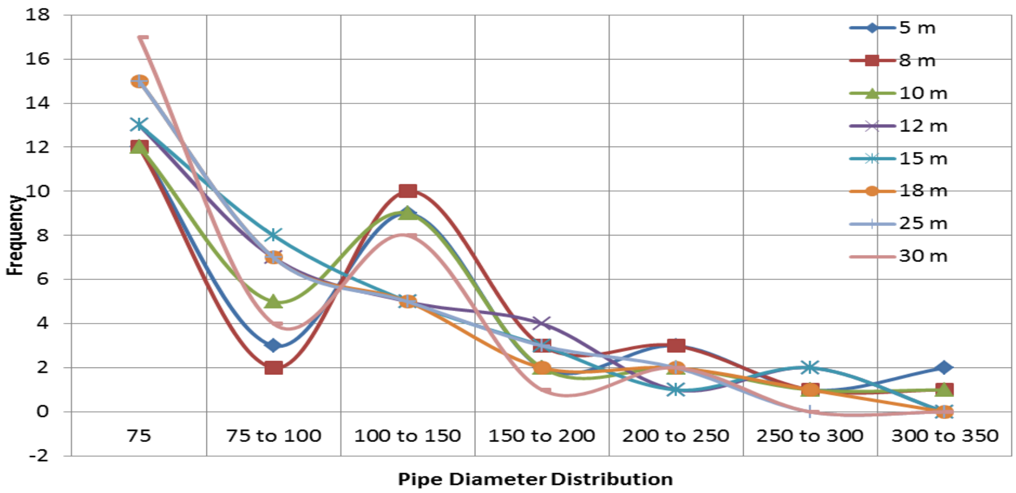

Figure 4: Shows pipe diameter relations with frequency

Table 4.2 shows Summary of Optimum

o Minimum Pressure (m)	5	8	10	12	15	18	25	30
Minimum Flows Pipe	RS	KO, LP	DH	RS	RS	HL	PT	PT
Value (l/s)	0.0074	0.0000	0.0000	0.0257	0.0575	0.0757	0.1014	0.0760
Maximum Flow		Pipe			AR			
Value (l/s)			8.3800 (for all minimum pressure considered)					
Average Flow (l/s)			1.1513 (for all minimum pressure considered)					
Pipes with Negative flow			Nil					

4.3 Pressure Distribution

The pressure obtained at various nodes depends on the topography of the area under consideration. Pipe Flows at Various Minimum Pressures**.** The pressure increases with increase in depth, hence the lower the elevation of a node, the higher its pressure. The minimum pressure was 5 m at Node A while the maximum pressure was 16 m at Nodes P and T. The average pressure in the entire network was 11 m. The values of minimum residual pressure is very adequate for a residential area low rise (bungalow type) buildings. However, where higher head is required, the elevation of the reservoir can be increased accordingly. Figure 9 shows the pipe network distribution contour map. The areas served through nodes C, D, H, L, K and G show a pressure between 8 m – 14 m; while nodes F, J, N and M have between 10 m – 12 m. Both ranges are sufficient to serve the households adequately.

V. CONCLUSION

A Water distribution system connects consumers to sources of water, using hydraulic components, such as pipes, valves, and reservoirs. The engineer faced with the design of such a system, or of additions to an existing system, has to select the sizes of its components. He has to consider the way in which the operational components, pumps and valves, will be used to supply the required demands with adequate pressures. The network has to perform adequately under varying demand loads, hydraulic and operational conditions. Operational decisions for these loads are essentially part of the design process, since one cannot separate the so-called design decisions, i.e. the sizing of components, from the operational decisions; they are two inseparable parts of one problem. This work has presented a method for optimizing the design of a water distribution network system using pipe diameter as decision variable under the required demand loading and hydraulic conditions. It has been established that increasing the minimum pressure will lead to the reduction in the required pipe diameter which will in turn reduce the cost of installation.

The model of linear optimization could be applied to any looped or tree–shaped network, either when piezo metric heads at pressure devices (pump stations or tanks) must be determined or when these heads are given. It permits the determination of an optimal distribution of commercial diameters along the length of each pipe of the network and the length of pipe sectors corresponding to these diameters.

Hydraulic structures should be well designed and constructed by the hydraulic engineers so as to achieve their basic requirement and functions to individuals.

Conduct regular self-inspections of hydraulic structures directed toward identifying potentially damaging conditions. Include in the inspections a review of site inspection, maintenance andinstrumentation records. These records identify changes in conditions and highlight areas of potential distress. Loss Prevention Surveys at the site will require visual examination of the existing condition and review of data from instrumentation monitoring to identify changes in conditions and signs of distress.

RECOMMENDATION

The construction of hydraulic structures should be awarded to expertise (i.e. professional Civil, Environmental and hydraulic engineers) for proper design and construction.Optimization of hydraulic design for integrated water supply management must be holistically embraced by researchers and industries in Nigeria.

Regular maintenance should be done on hydraulic structures after construction to avoid collapse and failure of the structures.Hydraulic structures should be constructed in areas with floods and high-water level.

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