

EVOLUTION OF WATER DISTRIBUTION SYSTEM

*NIAZ AHMED SIDDIQUI

Research Scholar, Department of Mechanical Engineering, Sai Nath University, Ranchi, India

*Address for communication: Niaz Ahmed Siddiqui, Research Scholar,
Department of Mechanical Engineering, Sai Nath University, Ranchi, India,
email ID:niazsiddiqui@yahoo.com

ABSTRACT

Water distribution system is an integral part of present society. It includes the features like Collection and Storage, Transportation, Treatment, Distribution. Water distribution systems can be classified according to the source of water that they use, like – Surface Water Distribution Systems, Groundwater Distribution Systems, Regional Rural Water Distribution Systems, and Purchased Water Distribution Systems. There are many piping systems through which water is distributed. Few main piping systems are listed as Transmission Lines, In-plant Piping Systems, Distribution Mains, and Service Lines. There are various types of layouts for water distribution network, suiting to different types of populations, communities and terrains. They can be classified as Serial Network, Branched Network, and Looped Network. The design aspect of water distribution system is an important area to tackle with. The designer decides about a particular type of design depending upon the various controlling factors, the various options are listed as System-Wide Master Planning, Transmission – Main Design, Sub-division Design, Rehabilitation and Strengthening. There are many methods for optimization of water distribution networks. All methods of optimization are not fully successful but have some drawbacks too. The designer must take into notice the various limitations/drawbacks before deciding a particular type of optimization method. There are certain myths about the optimization methods which are listed as Optimization models do not provide solutions to practical problems, Solutions obtained by optimization approaches do not give better solution than those obtained using traditional approaches, Optimization approaches are too difficult to use in practice, Practicing engineers are not comfortable with optimization approaches. Optimization methods are not well suited for strengthening and expansion of existing looped water distribution network. Even though mankind has known transportation of water through rivers, canals, streams etc. for many centuries, the transportation of water through pipelines and its distribution through networks is of recent origin. Even though developed nations have piped water supply, developing nations also have started providing water through pipe networks. Even consumers in remote villages have started getting water, if not in their residences, at least near to it. Thus, water distribution networks have been a part of modern living.

Keywords: Water, Distribution, Network, Optimization, Loop, Method, Solution, Pipe, Series, Link, Rural, Urban, Flow, Reliability, Design, Flexibility, Cost, Performance.

INTRODUCTION

Water distribution system is an integral part of present society and civilization. The system supplies water for different uses such as domestic, public, commercial, industrial and fire fighting purposes. Presently, water distribution system includes the following features –

1. Collection and Storage: Collection and storage include construction of dams, ponds, lakes, reservoirs, wells, *bawlis* etc.

2. Transportation: Transportation means transporting of water from source to consumer centre by some means, like - canals, aqueducts, pumping mains etc.

3. Pumping: Pumping includes pumps and other ancillary units for pumping water.

4. Treatment: Treatment includes screening, filtration, sedimentation, disinfection, softening and aeration.

5. Distribution: Distribution means distribution

pipes, valves, fire hydrants, equalizing reservoirs and other accessories.

HISTORY

The systems for collection, transportation and distribution of water existed in ancient civilization also. Modern distribution systems supplying water to consumers for domestic and other uses are of recent developments. British Parliament passed an act in 1544 ' to provide for clear water for residents' and started issuing directives to public and private water works companies. In USA, the earliest water supply dates back to 1652 for the cities, like Boston and Massachusetts. In 1746, the first piped supply for an entire population was built in Schaeffer city of Pennsylvania, USA.

In both these systems of Britain and USA, water moved from higher elevation by gravity and was stored in wooden tanks from where people filled buckets. Steam operated pumps were first used in 1764 to raise water in the city of Bethlehem, Pennsylvania, USA. Winston-Salem of North Carolina, USA, had the first complete water distribution system by 1776. However, the earlier systems were originally built for 'fire protection' and 'dust suppression' with little consideration for domestic services.

Provision of water distribution system for urban population started in India in the nineteenth century i.e. 1800 onwards. However, it was the latter half of the twentieth century, i.e. 1950 onwards, that water distribution systems became a necessity in urban areas and was also being provided for semi-urban and selected rural areas.

The International Drinking Water Supply and Sanitation Decade, 1981-1990, gave thrust to water distribution systems in the developing countries like India and many more. About 250 crores of people in the developing countries were provided piped water during this decade and an additional 200 crores were provided piped water in the last decade of the twentieth century i.e. 1990-2000.

The water distribution networks in USA used wooden mains even up to 1940s. Even though a cast iron main was laid in Versailles, France in 1664. The first cast iron main was laid in USA in

Philadelphia in 1817. Modern water distribution networks throughout the world now use pipes of iron, steel, asbestos, cement, concrete and plastics.

Of the total expenditure incurred on different facilities of a water distribution system, the expenditure incurred on transportation and distribution of water is quite large and may even exceed 70% of the cost of total water distribution system. It is, therefore, necessary to design new systems as well as expand and strengthen old ones to cut the cost drastically, as far as possible.

TYPES OF WATER DISTRIBUTION SYSTEMS

Water distribution systems can be classified according to the source of water that they use, like-

1. Surface Water Distribution Systems

When water is available in sufficient quantity from a natural stream, river, canal or a reservoir, like pond, lake, dam etc, the system has surface water as source of distribution (Fig. 1) [1].

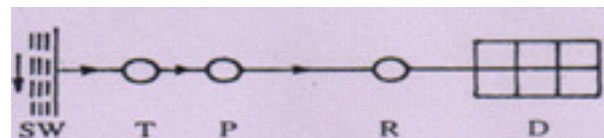


Fig. 1

SW: Surface Water

T: Treatment plant

P: Pump

R: Reservoir

D: Distribution network

The quality of water is average, hence it requires conventional treatment to remove mud and other impurities. The treatment plant is usually located on one end of the distribution network and large transmission mains and several service reservoirs are required if the population is large and spread in wide area. Since, the water tariff is reasonable, the consumers tend to use large quantities of water if the usage is not controlled. Therefore, in almost all areas the timings of water distribution is restricted. It is not a 24 hours supply any more. The surface water distribution system can also meet the needs of industries that require large quantities of

processed water.

2. Ground Water Distribution Systems

Water distribution systems for small population can use ground water as source, if sufficient quantity of ground water of good quality is available (Fig.2).^[1]

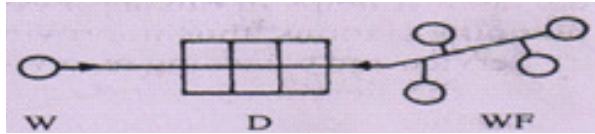


Fig. 2

W: Well
D: Distribution network
WF: Well Field

However, as the population grows and water consumption exceeds, additional source of water becomes a necessity. Sometimes, water can be used directly without any treatment but treatment is necessary to remove hardness and other impurities. If the ground water is available at several locations, wells can be spaced around to avoid the need of large transmission mains. However, if large quantity of water is available in one area, water from all wells in this area, termed as 'well field', is collected and treated at one location. This reduces operating costs and allows a better control on water quality but requires large transmission mains.

2. Regional Rural Water Distribution Systems

When ground water is scarce or of poor quality, several rural communities in a region are grouped together and are served through a system that is termed a 'Regional Rural Water Distribution System' (Fig. 3).^[1]

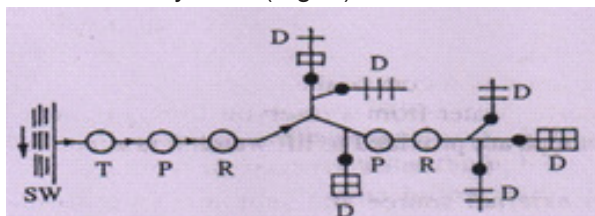


Fig. 3

SW: Surface Water
T: Treatment plant
P: Pump

R: Reservoir
D: Distribution network

If the system is large and the terrain is uneven, the services of booster pumps are, generally, availed to tackle the problem. Although, the consumers within a community are close to one another, the communities themselves are spread wide apart and the source is also far away. It is usually not possible to provide mains of enough capacity to provide fire requirements.

3. Purchased Water Distribution Systems

Sometimes, when a water system finds that its distribution has become inadequate or has become contaminated, it purchases water from another system (Fig. 4).^[1]

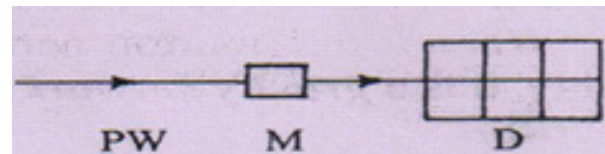


Fig. 4

PW: Purchased Water
M: Meter
D: Distribution network

For such a purchased water distribution system, little or no treatment is required. However, disinfection and re-pumping to boost the pressure up is necessary. Since all water leakages and wastages have to be paid for, strict water accountability is necessary.

TYPES OF PIPING SYSTEMS

Piping systems used in water distribution systems can be classified in four categories-

1. Transmission Lines:

Transmission lines are pipes that carry raw water from source to treatment plants and treated water from treatment plants to pumping stations, service reservoirs and distribution networks as shown in Fig.5.^[1]

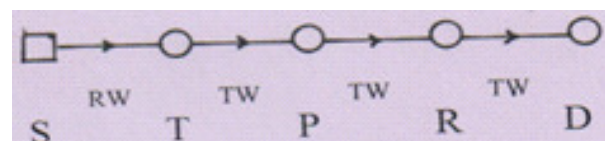


Fig. 5

- S: Source
- T: Treatment plant
- P: Pump
- R: Reservoir
- D: Distribution network
- RW: Raw Water
- TW: Treated Water

They are usually long, large in diameter (>400 mm) and carry large quantities of water. They carry water from one point to another; have few side connections except when they supply water to bulk consumers or service reservoirs.

2. In-plant Piping Systems

In-plant piping systems usually consists of pipes in treatment plants and pumping stations. They are larger in diameter but small in length and contain several outlets, valves, meters and bends.

3. Distributions Mains

Distributions mains are pipes that carry water from transmission mains or service reservoirs and distribute it to the consumers. They are laid along the roads, have several side connections for consumer services. They are 100 or 150 mm and larger in diameter.

4. Service Lines

Service Lines are small diameter pipes and carry water from distribution mains to consumer premises.

TYPES OF WATER DISTRIBUTION NETWORKS

Water distribution networks are classified according to their layout, like-

1. Serial Networks

A serial network has no branches and loops (Fig. 6) [1].

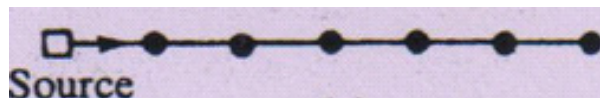


Fig. 6

It is the simplest of all types of water distribution networks. Generally, it has one source node, one sink and one or more intermediate nodes. First link starts at a source

node and the last link ends on a sink. All intermediate nodes are connected by two links, a supply link on the upstream and a distribution link on the downstream. The direction of flow in all links is fixed and is along the direction from the source node to the sink.

2. Branched Networks

A branched or a dead-end network is a tree like network and has no loops (Fig. 7) [1].

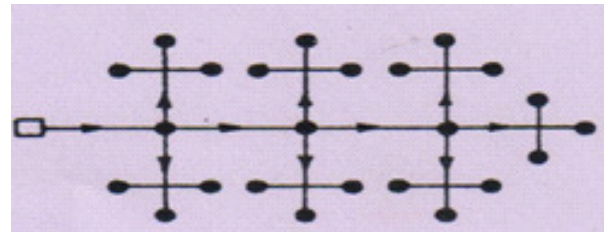


Fig. 7

It consists of several serial networks. Usually it has one source node, one or more intermediate nodes, and has more than one sink. Each intermediate node is connected on the upstream by one supply link and on the downstream by one more distribution links. The direction of flow in all links is fixed and is along the direction from the source node to the sink.

Since serial and branched networks are similar from design purposes. The term branched networks is often used to denote both – serial and branched networks.

3. Looped Networks

A looped network contains loops (Fig. 8) [1].

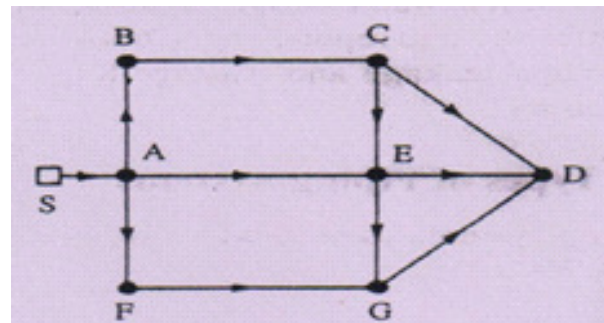


Fig. 8

- S: Source
- A, B, C, E, F: Nodes
- D: Sink
- G: Node/Sink

It has one source node in a single source network, but has several source nodes in a multiple source network. A looped network must have at least one sink. The node that behaves as a sink depends on the nodal demands. For example, node D in Fig. 8 behaves as sink. However, if demand at node G increases, the flow direction in link DG is reversed and node G behaves as a sink.

For a particular demand pattern, the direction of flow in a link is fixed, however, it may change for another demand pattern. Thus, for a node, a link that behaves as a supply link for one demand pattern may behave as a distribution link for another demand pattern. Similarly, when the direction of flow changes in a link, the upstream node becomes a downstream node and vice versa.

Looped water distribution network in practice seldom consist of loops only. In addition to loops, they contain branched and serial networks.

NETWORK COMPONENTS

Water distribution networks contain several components. Each network is unique in source, layout, topography, pipe material, valves, meters and consumer connections.

A small water distribution network^[3] may have a single source node, such as an elevated service reservoir or a pumping arrangement directly supplying water from the treatment plant to the network. A large network, however, may have several nodes, service and balancing reservoirs and pumping stations.

Layout of a distribution network depends on the existing pattern of streets and highways, existing and planned sub-division of the service area, possible sites for ground and elevated service reservoirs and locations and density of demand centers.

Topography of the service area may be even or uneven. In an uneven terrain, booster pumps are necessary for pumping water to high level areas. Similarly, it may be necessary to provide pressure reducing valves for areas with lower elevation to reduce pressure. Check valves may also be necessary to maintain flow in the

selected direction.

Pipes in distribution networks may be of cast iron, steel, concrete, asbestos, cement or PVC. Pipes may be un-lined or lined with cement mortar.

Valves are provided in water distribution networks to –

- (a) Control flow.
- (b) Shut off pipelines during repairs or replacements.
- (c) Drain pipelines during cleaning.
- (d) Reduce pressure for low lying areas.
- (e) Maintain flow in selected direction.
- (f) Suppress water hammer effects.
- (g) Allow air to enter pipelines while emptying.
- (h) Release air from pipelines at higher points.
- (i) During filling.

Meters are provided to measure flow of water from a source, transfer of water between different zones and the supply of water to consumers.

Water distribution to the tapping points of the consumers may be direct or indirect. For direct supply, sufficient pressure is required in the network so that the tapping points at different elevations get water. For highrise buildings, however, the supply is indirect. The distribution system supplies water to sumps at the ground level, while lifting of water from these sumps to the individual tapping points and overhead tanks is left to the consumers.

NETWORK MODEL

A factual water distribution network is extremely complex involving a large number of different components. It is extremely difficult to consider all such Components in the optimal design of a water distribution network. Therefore, a designer prepares a mathematical model of the network and designs it.

The mathematical model of a water distribution network is a network consisting of nodes and links. The network include all services, reservoirs, pumping stations, links in the main

direction of flow and loop forming links. Bulk consumptions are considered individually while small demands such as domestic consumption are put together and are assumed to occur at demand nodes. Depending on the topography, booster pumps and pressure reducing valves are included in the model. Check valves, if necessary, are also included.

While preparing a mathematical model of a water distribution network, it must be seen that the model is neither too elaborate to pose problems working on it, nor too sketchy to distort the behavior to unacceptable limits. The model should rather include important elements so that the results obtained from it can describe the behavior of the real-life water distribution network.

DESIGN REQUIREMENTS

The design of a water distribution system for a small community is rather simple since this primarily involves deciding sizes of different pipes in the system. The design of water distribution system [2, 3] for a large community is rather complex. In addition to the usual pipe sizing, the design involves decision regarding –

- (a) Location of sources of water.
- (b) Division of community in different zones.
- (c) Location and capacity of distribution reservoirs.
- (d) Locations, types, capacity and operating schedule of pumps.
- (e) Locations, types and settings of different valves.

There are many requirements for properly designing a complete water distribution network. The network should be able to:

- (a) Determine optimal pipe layout and sizes.
- (b) Design both – new networks and extension of existing ones.
- (c) Select existing pipes for cleaning and relining as part of an optimal solution.
- (d) Analyse the network under several demand patterns, including fire-flow requirements.
- (e) Handle all types of networks and network complexities.

- (f) Determine the location, size and heights of reservoirs and their operations.
- (g) Assist in the selection of pumps and pump stations.
- (h) Determine the optimal settings of all types of valves in the operation of the network.
- (i) Determine optimal designs and operations of networks containing a large number of pipes, pumps, valves and reservoirs.

DESIGN PROBLEMS

The design of water distribution system is classified into four types of design problems –

1. System – Wide Master Planning

Master planning of system to determine the general layout of water distribution system, like locations, sizing and construction schedule of major elements over a period that may be as long as 10 years. The pipe diameters are large (>400 mm) and are mainly controlled by future demand of domestic and industrial nature. Since the construction will be in stages, modification in pipe sizes is permitted at the time of installation, taking into consideration the latest data regarding water demands.

2. Transmission – Main Design

Using the master plan as a guideline, the design of transmission mains is finalized.

The design has better idea of the temporary demands, routes along which the pipes will be laid, and the field data regarding different lengths and levels. Since the pipe sizes are large, fire flows are usually satisfied. However, the behavior of an element during peak flows must be considered.

3. Sub - division Design

Considering different sub-divisions, such as residential, industrial and commercial and the corresponding demands, the sizes of pipes within the sub-division are decided. The 'transmission main' network should be studied deeply and the pressure obtained at junction points, connecting a sub-division to the 'transmission main' system, should be used in the design of pipes in the sub-division. Pipe sizes are controlled by simultaneous peak flow without any interruption

of an element. Minimum pipe diameter is 100 or 150 mm.

4. Rehabilitation and Strengthening

Loss of carrying capacity because of pipes may need rehabilitation and strengthening of an existing network. Such pipes may be completely replaced by new pipes, cleaned, lined or strengthened by parallel piping. In such a design, calibration of existing network is essential. The design is governed by simultaneous peak and fire flows.

OPTIMIZATION OF WATER DISTRIBUTION NETWORK AND ITS LIMITATIONS

Several methods have been developed, since 1960s, for the optimal design of water distribution networks. However, optimization approaches have not been widely used in practice. Some genuine reasons for not supporting the optimization approaches has already been elaborated.^[5]

The details are discussed below:

1. Optimization models do not provide solutions to practical problems -

It is true that no optimization model neither presently exist nor would be available in near future that would give optimal solution to all the types of design problems discussed in^[2] and also for all the design requirements proposed in.^[4] However, as observed in^[5] optimization models can give reasonably good solutions to practical problems, if the solution is not desired for the water supply system as a whole but for a single type of design problems.

2. Solutions obtained by optimization approaches do not give better solution than those obtained using traditional approaches

This is not quite true. An experienced designer may obtain by traditional method, a design that maybe cheaper in cost to that obtained through optimization techniques. However, as has been observed in practice, Lauria 1993, designs through optimization approaches can result in savings, sometimes as high as 20 to 30%, over traditional designs, for the desired level of performance.

3. Optimization approaches are too difficult to use in practice –

This is true. Optimization approaches are mainly confined to research work, the algorithms are developed and used for research purposes. Computers programs are not easily available for practical applications.

4. Practicing engineers are not comfortable with optimization approaches –

This is true. Unless system analysis, operations research and optimization processes applicable to water distribution networks are introduced in engineering studies, practicing engineers would not be comfortable with optimization approaches and would be reluctant to use them.

5. Optimization methods are not well suited for strengthening and expansion of existing looped water distribution network-

As stated in earlier study^[2], this is to be one of the main reasons for not adopting optimization processes by practicing engineers. This is not wholly true, optimization methods can be successful when used for strengthening and expansion of existing water distribution networks.^[6]

6. Clients do not insist on competitive designs-

This is partly true. In developing countries wherein cost is of primary concern, the planning agencies, mostly the state water supply and sewerage boards have started insisting on competitive designs obtained through optimization approaches.

CONCLUSION

Even though mankind has known transportation of water through rivers, canals, streams etc. for many centuries, the transportation of water through pipelines and its distribution through networks is of recent origin. Even though developed nations have piped water supply, developing nations also have started providing water through pipe networks. Even consumers in remote villages have started getting water, if not in their residences, at least

near to it. Thus, water distribution networks have been a part of modern living.

It is seen that it is matter of time before optimal design of water distribution networks becomes common in practice. It is, therefore, preferable if engineers concerned with water distribution networks, in general, and those concerned with their design, in particular, have good knowledge of optimization approaches and their application to water distribution networks. Several publications as detailed in 'References' are available on this topic, which may help and guide the practicing engineers to design successfully the optimization approach of water distribution network.

REFERENCES

1. Bhawe, PR, Optimal Design of Water Distribution, Published by Narosa Publishing House, India, ISBN 81-7319-505-6, (2003), 1-15.
2. Chase, D. V., and Ormsbee, L. E. 1993. "Computer generated pumping schedules for satisfying operation objectives." Journal American Water Works Association, 85, 54-61.
3. Jowitt, P. W., and Germanopoulos, G. 1992. "Optimal pump scheduling in water supply networks." Journal Water Resource Planning Management, 118, 406-422.
4. Lansley, K. E., and Awumah, K. 1994. "Optimal pump operations considering pump switches." Journal Water Resource Planning Management, 120, 17-35.
5. López-Ibáñez, M., Prasad, T. D., and Paechter, B. 2005. "Optimal pump scheduling: Representation and multiple objectives." Proc., 8th Int. Conf. on Computing and Control for the Water Industry, D. A. Savic,
6. Walters, G.A., King, R. and Khu, S.T., eds., University of Exeter Press, Exeter, U.K., 117-122.