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# Decentralized infrastructure approach for successful water supply systems in India: use of multi-outlet tanks, shafts and manifolds

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## ABSTRACT

The design and operational practice of water supply schemes (WSSs) in India is discussed in the context of the prevailing performance of the systems. Issues such as the tremendous gap in design and operation, unskilled manpower, and unmanageably large operation zones are identified as the main causes of the failure of WSSs in India. The failure of large-scale infrastructure creation in meeting service requirements is also discussed. The optimum scale of operation is estimated based on the ideal design and prevailing population densities in India. This work proposes a decentralized infrastructure approach through the use of multi-outlet tanks, shafts and manifolds. Each of these components is described in detail, and the manner in which these will help improve the current operation of WSSs in India is documented. Specifically, multi-outlet tanks will help achieve a design that enables the establishment of district metering areas for water distribution, shafts will serve as hydraulic separators between subzones, and manifolds will achieve a controlled water supply at various stages of the WSSs. These simple low-cost components will help to achieve water supply operations with minimal need for human intervention and automation.

**Key words** | decentralization, India, manifolds, multi-outlet tanks, shafts, water supply

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## INTRODUCTION

In India, most water supply schemes (WSSs) are typically designed for 24 × 7 operation. The designs are based on rigorous survey and primary data collection, and entire WSSs are designed and simulated using the hydraulic modeling software. The Central Public Health and Environmental Engineering Organization (CPHEEO) in India is responsible for issuing guidelines for infrastructure creation related to water supply and sanitation, including municipal solid waste management. The water supply manual (CPHEEO 1999) is the prime reference for all engineers in India for WSS designs and operations.

Once the design is completed, the WSS will be constructed by the contractor through a competitive bidding process. Typically, a contractor may operate the scheme for a specific time period defined in the contract, after which it needs to be handed over to the relevant government body, e.g., urban local bodies (ULBs). In this process, most design documents and construction details are not passed on to the ULBs, which do not have the skilled manpower to understand the designs and/or operate the WSSs. Hence, even with a robust technical approach used during the design, WSSs do not end up delivering 24 × 7 water supply (McKenzie & Ray 2009). This is true even for the initial stages (i.e., in the first 5 years after commissioning) when the scheme component sizes are oversized and the demands are comparatively lower than the ultimate design capacities.

One of the main reasons for not being able to achieve 24 × 7 continuous water supply in India is that the schemes

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are not operated as designed, i.e., there exists a gap between the demand pattern considered for the design and the one that actually gets applied during the operation (Abu-Madi & Trifunovic 2013; Klingel & Nestmann 2014). Operators tend to divide the systems into small zones and try to smooth consumer resistance by increasing the pressure in the systems by creating unified diversions of flow to a particular area. An inevitable result of such an operation is that the consumers do not become accustomed to the 24 × 7 water supply and tend to consume more in the available water supply hours, unknowingly. Consumers try to store water in their personal storage systems and consume water during supply hours (Vairavamoorthy *et al.* 2007). Such an intermittent water supply is prevalent globally in developing countries, owing to circumstances such as poor system operation, unplanned expansion of the network, unskilled manpower, and interrupted electricity supply (Klingel 2012; Galaitsi *et al.* 2016; Reyes *et al.* 2017; Simukonda *et al.* 2018).

Most Indian cities are not yet capable of achieving 24 × 7 water supply in spite of the amount of investment being made on revamping the infrastructure and setting up high-end automation (Kalbar *et al.* 2014). It is possible to achieve consumer satisfaction through intermittent water supply as per the guidelines developed by Vairavamoorthy & Elango (2002). This study builds on this approach and showcases the manner in which a decentralized approach to infrastructure creation will help in achieving successful water supply systems in India, in intermittent as well as 24 × 7 continuous modes. We discuss, in detail, the application of multi-outlet tanks, shafts and manifolds for water supply, and the manner in which these components improve the hydraulic efficiency of the system or help in addressing operational problems.

## LARGE-SCALE CENTRALIZED INFRASTRUCTURE – CAUSE OF FAILURE OF WSS

Urban water supply in India relies on creating centralized infrastructure, in particular, large-scale storage tanks. For example, the sizes of the storage tanks in cities typically vary from 5–10 million liters (ML) to 10–25 ML in metro cities. These tanks serve the purpose of storage when the incoming supply is lower than the outgoing demand or vice versa. Additionally, these storage volumes are estimated based on achieving 24 × 7 continuous water supply based on the demand within the next 30 years. However, in actual field conditions, the operation is in the intermittent mode i.e., 1–2 h of supply. This creates two issues. First, the operator, over a period of time, assumes that there is infinite storage for utilization and any convenient operational schedule can be used to operate the zones. Often, local politicians interfere with the operation schedule. This also leads to high peaks (approximately 8–10) in parts of the network, causing significant drops in pressure. Second, as a huge amount of storage is available, the ULB starts expanding the network in any direction indiscriminately. This creates a huge unmanageable network under each of the storage systems in most cities in India, and consequently, implementing district metering areas (DMAs) becomes impossible.

The unmanageable and untraceable water distribution network created under such conditions leads to illegal connections, mixing of operational zones of storage tanks, increase in leakages owing to the difficulty of maintaining and tracing the leaking pipes, and rise in non-revenue water (Kulkarni *et al.* 2014; Dimaano 2015). This shows that the large-scale centralized infrastructure approach leads to failure of WSSs.

## OPTIMUM SCALE OF OPERATION

The use of optimum scale of operation is essential as very small- or very large-scale systems tend to fail. Here, we propose an optimum scale of operation for storage tanks. As shown in Figure 1, the first principle that should be implemented while creating storage is that the tank should be at the center of the serving area. This is obvious from the point of view of hydraulics, because if the tank is at the center, all areas can be reached with maximum possible available head.

Typically, storage tanks are placed at a height of 12–15 m (whether elevated or ground-based, the effective height is typically in this range). As per the CPHEEO guidelines, the minimum pressure head requirement at the ferrule point is 7 m. Hence, the effective head available for distribution is 8 m. Considering this head available at the tank, a typical head loss of 3–5 m/km in the main distribution

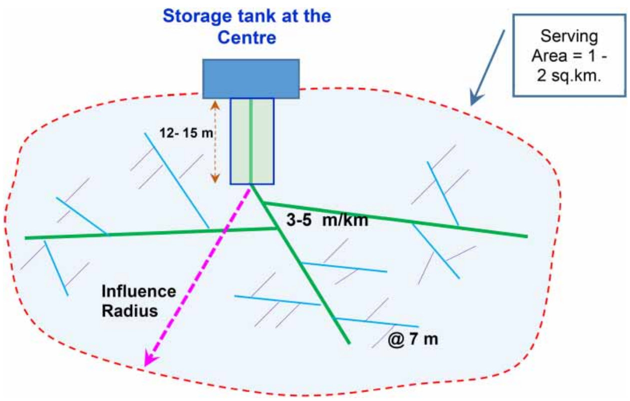


**Figure 1** | Influence zone of the storage tank.

line and additional losses in the laterals, the maximum serving area or influence zone can be estimated to be 1– 2 km$^2$.

Next, the optimum storage of the tanks can be estimated using the influence zone of the tank and the prevailing population density in the rural and urban areas. Table 1 tabulates the various population densities of the areas and the respective volume required for serving the population under the influence area. The results show that the range of storage tanks in Indian conditions should be from 0.1 to 2.5 ML.

## MULTI-OUTLET TANKS TO ACHIEVE BETTER HYDRAULIC EFFICIENCY AND EASE OF OPERATION

Storage tanks play an important role in delivering water at adequate pressure to consumers and bridging the gap between demand and supply. At present, in Indian cities, storage tanks are constructed such that they have only one outlet. However, for achieving better hydraulic efficiency, ease of operation and an equitable pressure influence zone, it is hydraulically efficient to use multi-outlet tanks. As shown in Figure 2, multi-outlet tanks offer segregation of service zones and the same head is available at the start of each outlet.

Multi-outlet tanks help in dealing with the following situations:

i. In areas with rapid urbanization and where population growth is difficult to predict: Separate outlets will not hamper the operation of all influence zones because of unexpected population growth in certain small areas.
ii. Maintaining separate DMAs: As each outlet can be designed to serve a small population, this will automatically create DMAs as per the guidelines of WHO (2001), i.e., this design enables DMAs to be implemented in the field without requiring any field intervention from the operator.
iii. In hilly areas where the serving area of the tank has significant elevation differences: The separate outlets will avoid effects of ground undulations on the entire zone and equitable pressure can be established easily by express feeders.
iv. When land is not immediately available for a new ESR: One of the standby outlets can be used to serve the new area.
v. Dampening of the peak demand and hence optimizing investment.

**Table 1** | Estimation of optimum storage requirement as per the varying population density (demand considered is 135 LPCD and storage is 1/3 of the demand)

| Population density persons (km$^2$) | Influence area (km$^2$) | Population to be served by the tank | Demand (L per day) | Storage required (L) | Storage required (ML) |
|---|---|---|---|---|---|
| 2,000 | 1.33 | 2,655 | 358,377 | 119,459 | 0.12 |
| 5,000 | 1.33 | 6,637 | 895,943 | 298,648 | 0.30 |
| 10,000 | 1.33 | 13,273 | 1,791,886 | 597,295 | 0.60 |
| 15,000 | 1.33 | 19,910 | 2,687,829 | 895,943 | 0.90 |
| 20,000 | 1.33 | 26,546 | 3,583,772 | 1,194,591 | 1.19 |
| 25,000 | 1.33 | 33,183 | 4,479,715 | 1,493,238 | 1.49 |
| 30,000 | 1.33 | 39,820 | 5,375,658 | 1,791,886 | 1.79 |
| 35,000 | 1.33 | 46,456 | 6,271,601 | 2,090,534 | 2.09 |
| 40,000 | 1.33 | 53,093 | 7,167,544 | 2,389,181 | 2.39 |

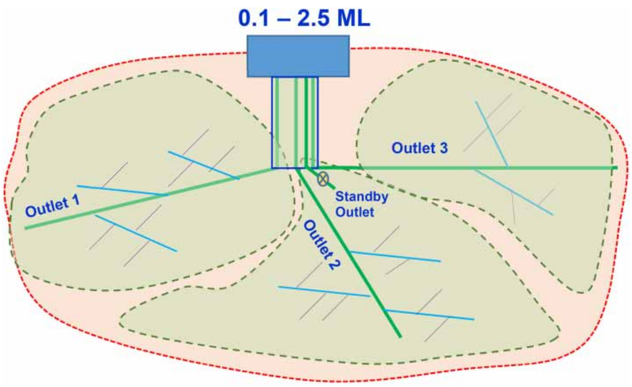


**Figure 2** | Multi-outlet tanks with influence zones.

vi. In India, there is a tendency to construct the storage tanks near the existing storage. This results in mixed influence zones of the individual storage tanks, and the advantage of widespread distribution is lost. Multi-outlet tanks help in avoiding such situations.

The multi-outlet tanks basically mimic the situation in which the storage is placed on the consumer's roof, which is basically the key to achieving improvements in service. As per the authors' field experience in India, the increase in the cost of multi-outlet tanks compared to single outlet tanks is 3–8%. However, owing to dampening of peak demand, there is a reduction in the distribution cost of 10–15%.

For all practical purposes, it is effective to provide three outlets at the initial stage and one blank/standby outlet for future expansion that can meet future demand due to unplanned extensions from the same storage tank. The sizes of the outlets can be determined as per the standard hydraulic modeling process. This will also optimize the present working demand, which is expected to be met with the curtailment of the valve opening in the present stage. In the initial stages, the draining capacity of the system is more than the actual demand as per the design peak factor. A multi-outlet system allows time-staggering among the outlets (i.e., each outlet can be opened individually), which helps in matching with the peak factor, and fast draining of the storage can be avoided.

## SHAFTS FOR HANDLING FIELD PROBLEMS

Shafts are basically a vertical pipe structure, with the top of the shaft open to the sky as shown in Figure 3. The internal inlet pipe in the shaft is a divider of the incoming head and demand side, which works as a hydraulic separator. Shafts are typically located on the leading distribution line, which generally carries 1.2–1.5 times the average flow. Shafts have one inlet and can have more outlets at the same or at various levels, and with varied diameters as per the particular demand of the sub-influence zone leading to creation of

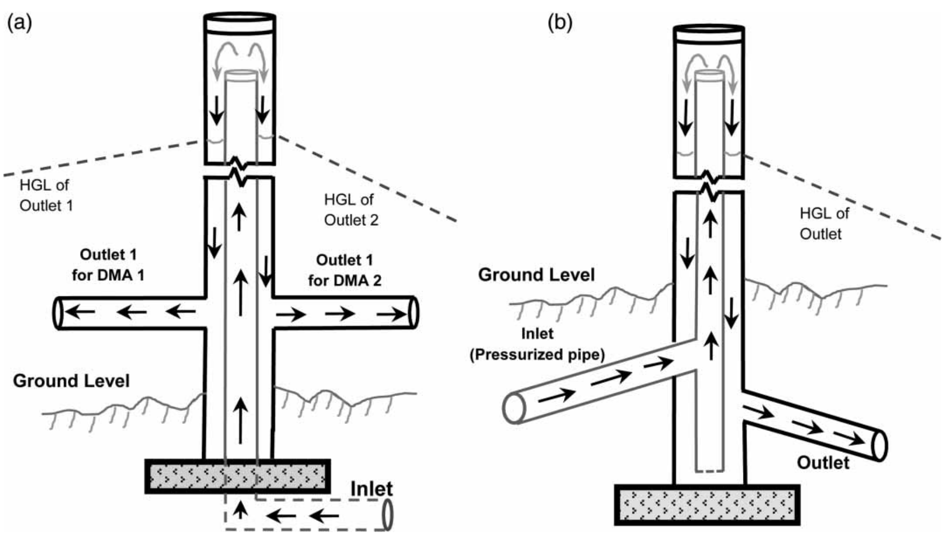


**Figure 3** | (a) Shaft for distribution. (b) Shaft for transmission main.

separate influence zones. These outlets can have variable operating times and feature preset valve opening. This will control the peak factors in the split zones. The height of the shaft will be dependent on the inlet velocity and the characteristics of the outlet(s). Shafts basically act as directed storage near the consumer and help in matching the demand patterns, resulting in peak dampening.

Shafts serve the following purposes:

i. In the low-lying areas of the influence zone of the tank, a shaft can be implemented to stop unnecessary draining of the water as it will affect the pressure in other areas. The shaft will basically disconnect the hydraulic grade line (HGL), and a new HGL can be established as per the requirement of the residual pressure to be maintained in the low-lying area.
ii. Shafts can avoid multiple tapings at the headworks of WSS as well as to the existing storage tanks.
iii. When land for an elevated service reservoir is not available, a temporary shaft can be created, and water can be provided intermittently.
iv. Shafts can be constructed at the end of the distribution system, to take the load during the peak of water supply. The head available in the shaft will be useful to satisfy the peak demand of the tail-end consumers of the influence area. Appropriate volume can also be provided in such shafts to serve the peak hour demand.
v. In the distribution system, the shaft takes out the additional head from the upstream side and helps in achieving equal water distribution on the downstream side by operating the appropriate threads of the valves on the multi-outlets. This is shown in Figure 3(a).
vi. Shafts can also be used on the transmission line as shown in Figure 3(b), where the inlet is the rising (pumping) main and the shaft works as a separator between the upstream high-pressure line and downstream low-level line. The water cushion shown in Figure 3(b) will help in dampening the water hammer effects.
vii. A shaft, as designed in Figure 3(b), will help in achieving autocontrol on system flow variations, which is very useful as the schemes are expected to function for more than 30 years with increasing demand.
viii. As shafts have smaller diameters than the conventional storage tanks, the effect of any reduction in the downstream demand will significantly increase the head in the shaft, which helps in maintaining the overall system pressure for a longer duration with the same flow.

## MANIFOLDS FOR ACHIEVING CONTROLLED GRAVITY

Manifolds are basically a pipe-valve arrangement (or assembly), as shown in Figure 4. The inlet diameter (D) and outlet diameter (D) are the same. The inlet diameter is distributed into three pipe-valve systems, typically of 1/3 of the area of pipe (D). There are two ends for the drum systems. The system is initially closed by valves, so that there is pressure on the incoming side. Once the valves are opened, the pressure will be reduced until the pipeline is filled, up to the next similar manifold or storage. It is necessary to maintain equal pressures on the incoming and outgoing sides. This can be done by the separator valve, and fine-tuning can be achieved by the bypass valve as shown in Figure 4. Once the pressures are equated on both sides of the system within the similar manifolds, stable readings in that portion are held. Such a stabilized manifold system has a tendency to auto-balance in the optimal range of diurnal and seasonal variation of flows.

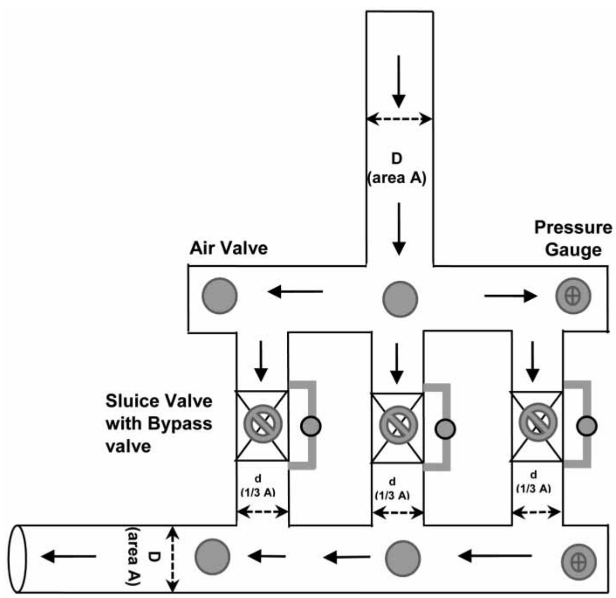


**Figure 4** | Manifold system for stage-wise control of the flows in the system (D is the internal diameter of the inlet/outlet pipe and A is the internal area of inlet/outlet pipe, d is the internal diameter of the small pipes having area of 1/3 A).

If the main pipes have smaller diameters, the internal assembly valves can be of smaller size and the number of pipe-valve systems can be reduced to 2. To achieve a successful gravity system, 2–3 consecutive manifolds down the line will balance the entire system, and equal pressures will be maintained everywhere. With a manifold system in place, there is no necessity to intervene with valve operation on a daily basis. Only monitoring of pressures will indicate the performance of the system.

In the case of steep slopes where there is a possibility of draining, using a manifold will help avoid the unnecessary drop in HGL from the source, and systems flows at various sections will be maintained as per the design. Basically, a manifold system operates as a perfect pressurized feeder to the distribution, such that 'the volume of water that goes out is then replenished.'

Typically, WSSs in India are designed for a 30-year period. Hence, during the first year of operation of the scheme, the commissioned pipe diameters in the transmission line (e.g., from water treatment plant to various storage tanks) are larger for the initial phase of the WSSs. Hence, there is the chance that the pipe will not be running full (i.e., open channel flow may persist or there may be standing water column condition). In this situation, manifolds can help in achieving a controlled release of the water flow each year. For example, during the first 10 years of the scheme, opening only one valve may be sufficient to meet the demands of the population. For the second decade, two valves can be opened, and similarly, in the last 10 years all three valves can be operational.

This type of implementation of manifolds offers very high flexibility in the commissioning and operation of WSSs. Owing to stage-wise usage of the 1/3A size pipelines in the manifold system, controlled gravity can be achieved successfully. The manifolds can be very helpful at the outlet of the storage tanks in the distribution. A similar valve-opening strategy can be used to match the demand and the flow in the distribution system.

## CONCLUSIONS

Currently, most WSSs in India are designed to provide $24 \times 7$ water supply. However, actual operation is intermittent. This is caused by factors such as the tremendous gap in design and operation, large-scale centralized infrastructure development, and lack of skilled man-power. This leads to problems such as unequal distribution of water, small zones in the distribution with high pressure, more potential for water contamination, higher physical losses, a huge quantum of nonrevenue water, and accelerated deterioration of infrastructure. These facts suggest that the design and operation of WSSs in India has to be 'minimum maintenance oriented design and operation'. The goal of the new or retrofitted WSSs in India should be that there is limited scope for the operator to intervene in the operation of the system.

In this work, we have suggested a decentralized approach to infrastructure development of WSSs in India. The alternate design of the schemes using infrastructure components such as multi-outlet tanks, shafts and manifolds will help in addressing the prevailing problems in WSSs. These infrastructure components offer significant advantages while operating the WSSs and tackling field situations that are prevalent in WSSs in India. The integrated use of these components will help in achieving WSSs in a decentralized manner and with low overall cost. The systematic use of these components in a WSS offers considerable control in the operation of the WSSs throughout their lifetimes. We hope that the present study will help planners, designers and engineers in India to adopt widespread use of these components and achieve successful WSSs that meet consumer needs satisfactorily.

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