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Technical Note

Managing Disasters Using Pressure Dependent Demand Analysis – Case Study of Shirpur Town

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ABSTRACT: Water is the most essential component for sustaining lives of humans and other living creatures. Supplying potable water with adequate residual pressure is a fundamental responsibility of city administration, which they do during normal conditions. But sometimes, abnormal conditions are formed resulting pressure deficient conditions during the daily operations of water distribution networks. These are caused due to common occurrences such as pump failure, pipe bursts, and isolation of major pipes from the system for planned maintenance work and excessive firefighting demands. Total water stop conditions may arise, when the major source supplying water to the city fails in natural disaster such as floods, Tsunami, earthquake or manmade disaster such as terrorist attack. Unlike the pipe failure, longer time is required for restoring water in case of source failure condition. In such situations, the quantity of water is generally decreased and the water distribution systems (WDS) may not be able to satisfy all consumers' demands. In this context, the assumption that all demands are fully satisfied regardless of the pressure in the system becomes unreasonable. A realistic behavior of the network performance can only be attained by considering demands to be pressure dependent. This paper aims to describe how pressure dependent demand analysis is useful for the simulation of disaster scenario due to source failure of the Shirpur town. The simulation of failure scenario is carried out using WaterGEMs software. The paper also aims to prepare the action plans for the recovery of water supply in such crisis conditions.

Keywords: Demand-Driven Analysis, Disaster, Disaster Management Plan, Hydraulic Model, Pressure Dependent Demand.

INTRODUCTION

Disasters are unpredictable before its occurrence. Also, the increased risks of terrorism have increased concerns for vulnerability of water distribution systems (WDS) to accidental and intentional contamination (Rasekh and Brumbelow,

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2014). It is a daunting task for water authorities to supply water in disaster situation which can be achieved only if some alternative disaster management plans have kept ready before the occurrence of any likely disaster. For this it is required to create a hydraulic model simulating normal and failure scenarios.

Hydraulic models are extensively used in the design and operation of water distribution systems that helps to predict possible changes under a wide range of operating conditions. Evaluation of real hydraulic performance of WDS when the disaster condition prevails is vital for future planning (Mani et al., 2013). In abnormal operating conditions, water distribution systems may be pressure deficient (Abdy Sayyed et al., 2013; Alemtsehay et al., 2014) and thus unable to satisfy demands in full (Mohd Abbas et al., 2014; Tanyimboh and Templeman, 2010; Suribabu and Neelakantan, 2011). A pressure dependent simulation is more suitable for networks with low pressure or under deficit condition. In a pressure-dependent simulation, both nodal demands and pressure requirement are considered simultaneously to obtain available flow, which is more realistic to actual conditions (Islam et al., 2014). Thus, pressure dependent analysis is utmost important, to quantify the amount of flow and pressure accurately to take vital decisions (Shirzad et al., 2013).

A case study of Shirpur town is presented here. Shirpur is a town in Dhule district of Maharashtra, India. It houses Asia's largest and India's first gold refinery. As per 2011 census, (India Census, 2011) town’s population was 77,002. Water supply of the town was disrupted due to heavy rainfall in the year 2005; entire headwork with pump house was inundated and the electric supply was disconnected due to failure. Since, the action plans for mitigation of the disaster were not ready, the city administration had to work hard and they manned the water supply operations by trial and error method. Therefore, the City administration felt a need of alternative arrangement in the form of Disaster Management Plans (DMP). This has mooted the authors to create a GIS based hydraulic model to remedies future disaster that may strike to the town.

Therefore, the objective of this paper is to describe how pressure dependent demand (PDD) analysis is useful in the simulation of disaster scenario due to failure of source of the Shirpur town. The simulation of failure scenario is carried out using WaterGEMs software. PDD analysis, presented here, helps to take exact decisions during the disasters. The paper also aims to prepare the action plans for the recovery of water supply in such crisis conditions.

MATERIALS AND METHODS

Present (Normal) Water Supplies

The town gets water from the jack well built in the upstream side of the pick-up weir across the Arunavati river. Raw water is treated in water treatment plant (WTP) and then pumped to various service tanks as shown in Figure 1. The present water supply of the town is 12.9 million liters per day (MLD) at the rate of 135 liters per capita per day (LPCD). Demand of 18 MLD for the year 2027 and 21.8 MLD for year 2042 has been considered. A GIS based hydraulic model is prepared for the demand of 18 MLD (intermediate stage). Water supply pumping hours of 20 hours and a peak factor of 2.5 (CPHEEO, 1999) has been considered in the model.

Various Scenarios Studied

As mentioned by Mani et al. (2013), in order to estimate the performance of a damaged water distribution network, hydraulic analysis is must. Therefore, system is analyzed for (i) Normal scenario (ii)

Failure (disaster) scenario and (iii) PDD with interlink scenario.

Normal Scenario

Objective of this scenario is to check the adequacy of pipe sizes and to check the velocity and pressure constraints. After running the model, it is observed that, the velocity of flow in pipes is less than 1.8 m/s and the minimum nodal pressure is more than 0.7 Kg/cm^2. Hence, the pipe sizes of existing system are in order.

Failure (Disaster) Scenario

When disaster struck the water supply source of Arunavati river in the year 2005 due to floods, the entire headwork along with pumps was inundated and the water supply of Shirpur town was totally hampered. Source failure scenario is simulated by closing the flow controlling valves in the hydraulic model and making the status of the pump- off. When the model run is taken for this scenario, pressures at all nodes become zero as indicated by red color in the model.

PDD Scenario

Pressure deficient conditions cannot be represented/simulated using the conventional demand driven analysis (DDA) as they give unrealistic results (Tabesh et al., 2002; Tabesh et al., 2014; Shivkumar and Prasad, 2014). This system of equations may be extended to include pressure-dependent demand functions to relate pressurized water availability to existing nodal head under pressure-deficit conditions (Laucelli et al., 2012). In DDA approach, it is presumed that demands are always satisfied, (Tabesh et al., 2002) irrespective of the available pressure. Therefore, to analyses such conditions, pressure dependent demand analysis is vital (Todini, 2006). In this analysis, following PDD Relationship (Zheng and Walski, 2006; Zeng et al., 2012; Minakshi Shrivastava et al., 2014) is used.

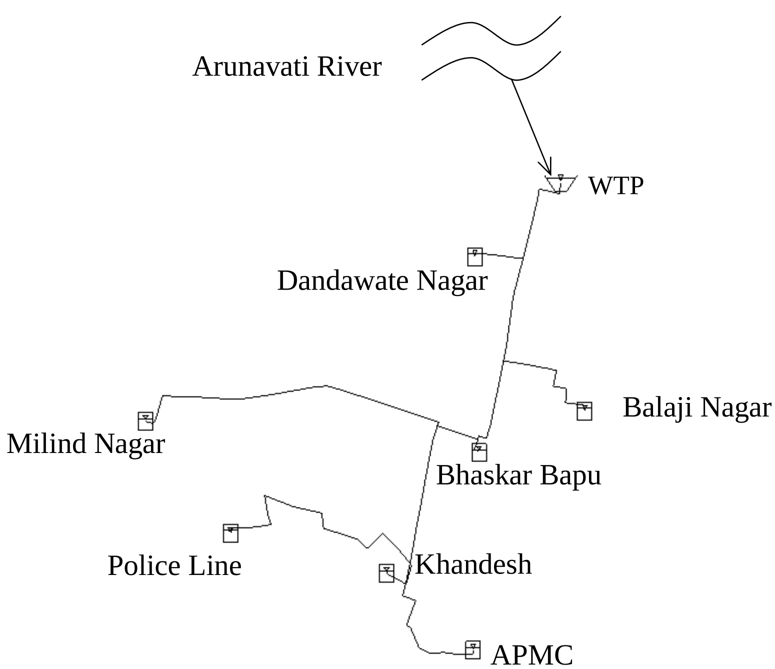

Fig. 1. Water supply system in normal condition

$$\frac{qi}{qri} = \begin{Bmatrix} 0 & Pi = 0 \\ \left(\frac{Pi}{Pri}\right)^{0.5} & Pi = 0 < Pi < Pt \\ \left(\frac{Pt}{Pri}\right)^{0.5} & Pi \geq Pt \end{Bmatrix} \quad (1)$$

where P_i: represents the calculated pressure at node i; q_{ri}: is the required demand at node i; q_i: is the calculated demand at node i; P_{ri}: denotes the required pressure that is deemed to supply full required demand; P_t: is the pressure threshold above which the demand is independent of nodal pressure and 0.5 is the exponent of pressure demand function.

Strategies

The strategy proposed to mitigate the disaster is to tap water from the alternate MIDC system which has its source from Tapi river. Interlink proposed from the tapping point on MIDC's system to the existing WTP would supply limited quantity of water to the affected parts of the Shirpur town which depended on Arunavati river source in normal scenario. This arrangement is shown in Figure 2. Dark black colored line indicates the water supply arrangement of Maharashtra Industrial Development Corporation's (MIDC) system and the interlink from tapping point to water treatment plant (WTP) is shown by dotted line.

Water from the alternate source is supplied in limited quantity through interlink, causing drop in the nodal pressures in the distribution system. In such situation water shall not reach to the inlet of the Elevated Service Reservoirs (ESR). Thus, it is pertinent to bypass the ESR.

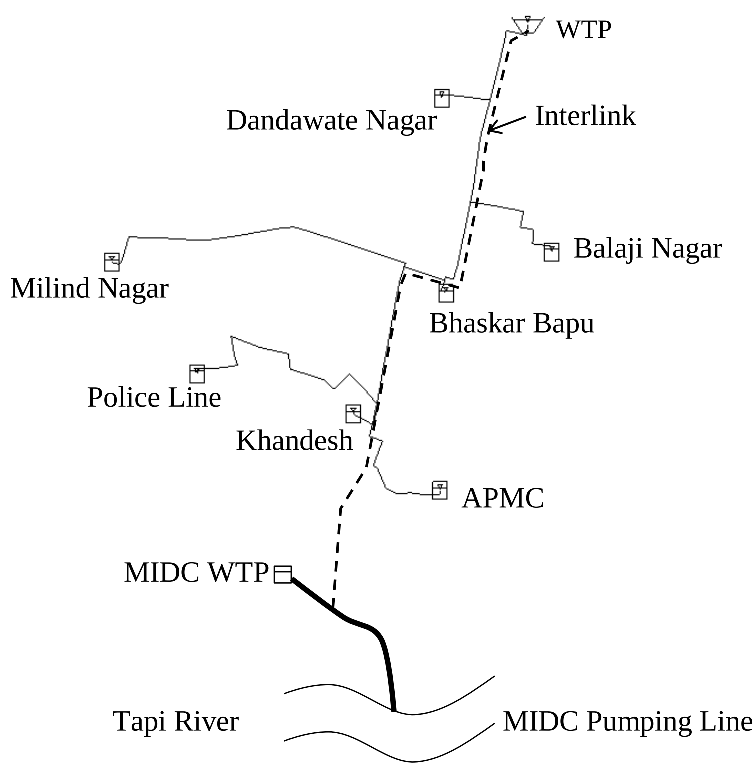

Fig. 2. Tapping of MIDC Water in disaster scenario using interlink

During crisis conditions, the main task would be to see how much water MIDC can curtail and use that limited water to meet the need of Shirpur town to sustain life of its residents. Thus, the quantum of water that the affected Shirpur town gets from the unaffected source of MIDC totally depends on how much water the MIDC can spare. Following PDD scenarios are studied as shown in Table 1.

For running the PDD scenario as shown in Table 1, hydraulic model is customized, which involves associating PDD function to each node, defining required pressure (nodal pressures of normal scenario) and threshold pressure (maximum pressure of normal scenario). Results of PDD analysis are compared for 2 scenarios as shown in Table 2.

RESULTS AND DISCUSSIONS

Scenario 1: Out of total 1163 nodes of distribution system, 369 nodes (31.72%) are having residual pressures more than 0 Kg/cm^2. Though the nodal pressures are less, they can serve the total demand of 3 MLD.

Scenario 2: Out of total 1163 nodes of distribution system, 817nodes (70.25%) are having residual pressures more than 0 $Kg/cm^2$and can serve the total demand of 6 MLD.

Scenario 3: When MIDC spares 50% of its water i.e. 7.5 MLD, out of the total 1163 nodes of distribution system, 1013 nodes (87.1%) are having residual pressures more than 0 Kg/cm^2.

These observations are useful while making the action plans for disaster mitigation purpose.

Table 1. PDD scenarios

Scenario	Donor Utility	Receiving Utility
1	MIDC spares 20% of its water which is 3 (20% of 15) MLD	Shirpur town gets 3 MLD water which is 16.67% of its normal supply
2	MIDC spares 40% of its water which is 6 MLD	Shirpur town gets 6 MLD water which is 33.33% of its normal supply
3	MIDC spares 50% of its water which is 7.5 MLD	Shirpur town gets 7.5 MLD water which is 41.67% of its normal supply

Table 2. Comparison of the results of 2 scenarios

Pressure Range (Kg/cm^2)	Scenario 1: MIDC Spares is 3 (20% of 15 MLD)					
	No. of Nodes	MLD	Population Served			
			20 LPCD	30 LPCD	40 LPCD	135 LPCD
< 0.2	144	0.50598	25299	16866	12649.5	3748
0.2-0.5	120	1.13616	56808	37872	28404	8416
0.5-1	80	1.1605	58025	38683	29013	8596
1-1.5	25	0.1973	9865	6577	4933	1461
> 1.5	0	0	0	0	0	0
Total	369	2.99994	149997	99998	74998.5	22221.8
Pressure Range (Kg/cm^2)	**Scenario 2: MIDC Spares 6 (40% of 15 MLD)**					
	No. of Nodes	**MLD**	**Population Served**			
			20 LPCD	**30 LPCD**	**40 LPCD**	**135 LPCD**
< 0.2	291	0.9257	46285.5	30857	23142.8	6857.11
0.2-0.5	278	1.8231	91153.5	60769	45576.8	13504.2
0.5-1	196	2.5111	125553	83702	62776.5	18600.4
1-1.5	46	0.6965	34825.5	23217	17412.8	5159.33
> 1.5	6	0.0517	2584.5	1723	1292.25	382.889
Total	817	6.008	300402	200268	150201	44504

Action Plan

Action plan during disaster and post disaster are discussed here.

Action Plan During Disaster

1. Emergency meeting should be called in the event of failure of the regular source of Arunavati. This meeting should be called by the District Collector and the authorities of the Shirpur Municipal Council (SMC) and MIDC (Gold Refinery) be invited.
2. The three scenarios, as discussed above, shall be placed in the meeting. Out of these, one scenario should be selected as per the convenience of donor utility. For example, suppose 2nd scenario is selected in the meeting, i.e., MIDC sparing 6 MLD water to the SMC.
3. Upon decision of MIDC supplying 6 MLD water, following actions shall be taken:
   a. Set flow of 6 MLD using a flow controlling valve on pipeline from tapping point to WTP by rotating the wheel on the valve till the reading of flow rate of 6 MLD appears on the bulk meter installed on the interlink,
   b. Set flow of 9 MLD using flow controlling valve on the pipeline from the tapping point to the MIDC node by rotating the wheel on the valve till the reading of flow rate of 9 MLD appears on the bulk meter on the line going to the node MIDC,
   c. Figure 3 shows the nodal pressures of the nodes having pressures more than zero and shall be studied in the common meeting.
   d. Area of the distribution system having sufficient pressures even during pressure deficient condition is shown by different colors in Figure 3. From these areas tanker filling spots can be fixed for supplying water to low pressure areas.
   e. A decision of supply rate amongst 20, 40 or 50 LPCD shall be taken. The lesser the LPCD value, the larger is the population that can be served.

Action Plan Post Disaster

1. Flow controlling valve that regulates flow to MIDC node and to WTP through interlink shall be closed. The flow setting of flow controlling valve on the pipeline from the tapping point to the MIDC node shall be again set to its original flow rate of 15 MLD.
2. Valve operation shall be made slowly to avoid water hanner.

CONCLUSIONS

Water supply is an essential service. If this service is hampered in the disaster, the water supply stops. This may create a hue-and cry situation in the town/city

- A GIS based hydraulic model shall be prepared for the city for which an alternate source shall be identified.
- Since pressure deficient conditions are formed, PDD analysis must be made for disaster scenario, which gives realistic values of available flow and pressure.
- Various scenarios shall be created as to how much a donor utility can spare water to the affected (receiving) utility and accordingly action plans are prepared
- A joint disaster management committee shall be formed in the chairmanship of the district collector who is responsible for law and order of the district
- A joint decision shall be taken to select appropriate scenario which can be implemented when disaster strikes
- Rehearsal of the action plan shall be made annually.

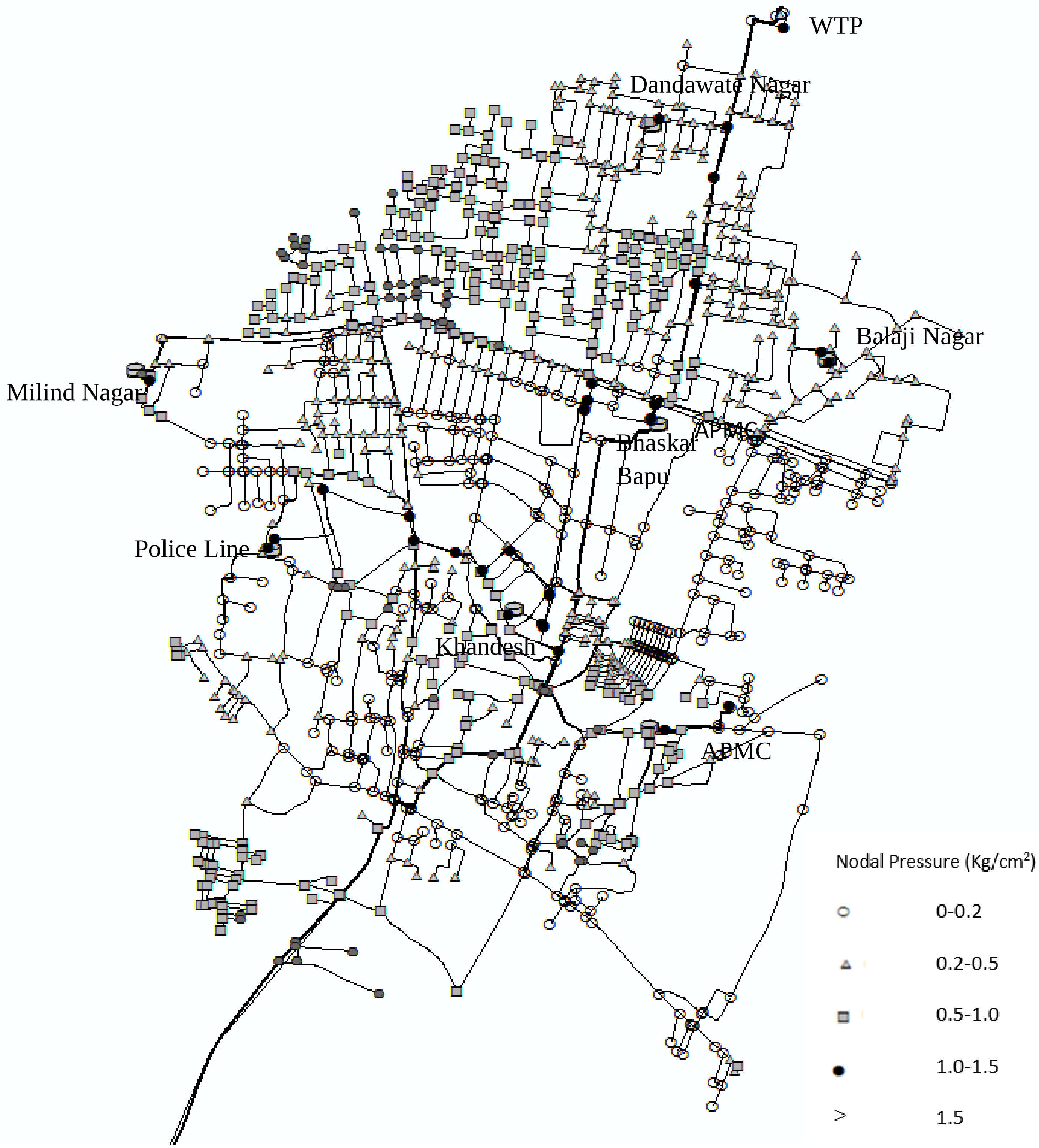

Fig. 3. Nodal pressures in Scenario 2

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