Wastewater Flow Monitoring for Mumbai, India

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ABSTRACT:

As part of the preparation of a wastewater master plan for Mumbai, India, a megacity of 12 million inhabitants, information on sewer flows was needed for planning and design purposes. Over a 30-month period, more than 110 sites were instrumented, and the resulting data was analyzed to detect land use trends, and daily, weekly and seasonal patterns of flow generation. The results were employed to calibrate hydraulic models of the districts and wards in the city, and to project growth-related needs for wastewater conveyance and treatment facilities. This paper describes the monitoring program carried out, the main difficulties encountered, and some of the key findings.

R. V. Anderson Associates Limited (RVA), a major Canadian consulting firm, was founded in 1948, and has been developing planning, design and operational capabilities to meet a growing demand for environmental infrastructure both in Canada and internationally. RVA has been active in South Asia, the Middle East, the Caribbean and Eastern Europe. PHE Consultants is a Mumbai-based municipal consulting firm. The two firms have worked together on South Asia projects since 1994.

1. Introduction

The work described in this paper was part of a World Bank Financed project called Wastewater Feasibility Studies - Stage II, carried out for the Municipal Corporation of Greater Mumbai by a joint venture of R.V. Anderson Associates Limited (Canada) and Mott MacDonald Ltd. (UK) from 2000 – 2003.

The objective of the project was to develop a 25-year Wastewater Master Plan (year 2025) for the Municipality of Greater Mumbai, at which time the metropolitan regional population is expected to be 26.5 million persons with a water demand of over 18,000 mld.

The activities carried out under this project, in addition to the flow surveys described in this paper, included hydraulic modeling, water quality studies, various feasibility studies (including Private Sector Participation), environmental and operational assessments, and preliminary design of the preferred alternative.

Throughout the project, a "design by consensus" approach was followed, involving staff consultation, workshops and seminars, and study visits designed to maximize capacity building and technology transfer within the organization.

The first step in any wastewater planning exercise is to assess current sanitary flow volumes and rates so that reliable projections can be made of long-range infrastructure needs. Hydraulic models, preliminary and detailed designs, and operational assessments all require projections of future flow rates.

A flow-monitoring program was carried out to establish dry weather sewage flows in the Mumbai sanitary sewer system. The objective of the program was to provide information for the preparation of a Waste Water Master Plan for Mumbai and its environs.

The first phase of the flow survey was carried out from February 2000, and was suspended in June of 2000 just prior to the monsoon season. The second phase commenced during the dry season in October 2000 until March of 2001.

While the focus was primarily on the dry weather sanitary flows, 60 storm drain and nallah locations were also surveyed in order to provide data for picking up surface flows (ie nallahs) into the sanitary system from slums and un-serviced areas.

System Description

The sanitary sewer system of Mumbai dates back to the 1880's, and has evolved into seven independent zones. The sewer infrastructure consists of approximately 1400 km of sewers, 52 pumping stations, preliminary treatment facilities and outfalls. **Figure 1 and Table 1** provide some key system details.

Current population data was difficult to obtain because the project commenced near the end of a census period (2001 Census to begin shortly) and was difficult to estimate because of significant transient population and slum dwellers. Nevertheless, population data was collected from the previous Census records (1991, 1981, 1971) and the population density trends for each administrative ward were developed and projected for future decades until end of planning horizon. The data produced was verified for year 2000 by means of random field counts for small tributary areas. Further verification of population was achieved in early 2002 based on 2001 census data.

Figure 1: General Layout

Table 1: Sanitary Sewer System								
Zones	1 Colaba	2 Worli	3 Bandra	4 Versova	5 Malad	6 Bhandup	7 Ghatkopar	**Tot/Avg**
Manholes	1040	14,700	11,500	5,380	12,000	3,840	4,930	53,390
Sewers (km)	32	338	326	145	307	104	135	1,387 km
Population*	28,784	49,714	47,119	31,346	323,487	129,764	17,969	628,183
Flow (lpcd)*	264	215	332	405	150	264	245	213

***** Monitored Catchments only.

Monitoring Program Design

The flow-monitoring program was designed to provide current flow data from residential, industrial, commercial and Institutional areas to identify the different wastewater generation rates. Sites were identified on:

- Tertiary or tributary catchment areas that could be used to develop unit flows related to land use;
- Trunk sewers from a large upstream area with varied land use and population;
- Nallahs and storm drains to estimate the foul sewage and infiltration from untreated from non-sewered slum areas.
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Some 110 installations (operating 14 days per installation) were included in the program: 40 installations in the tributary system; and 70 installations in the trunk system. An additional 45 sites had to be instrumented to capture other areas of interest, and to allow for relocation of monitors where the original sites proved non-productive.

The monitoring was carried out in circular sewers ranging in size from 120 mm diameter to 1800 mm diameter, as well as oval sewers up 1800 x 2700 mm dimension. Some monitoring was also done in both open and closed rectangular drains.

Automatic recording velocity-area meters were used for measuring and recording the flow in the sewers, storm drains, and nallahs (drains). In many of the nallahs however, it was also necessary to carry out manual surveys, due to the difficulty in installing meters and the irregular cross-sections encountered. Manual surveying was done by measuring the velocity with a portable velocity probe across a section of nallah, calculating the average velocity, and applying it to the measured cross section.

Site Selection

Maps of the sewer system were reviewed and analyzed to identify candidate sites for the monitoring program. Sites were selected to include diverse land uses and drainage areas in order to generate characteristic flows that could be applied to planning and design. Sewers that were surcharged or influenced by pumping stations operations were avoided.

Field surveys were conducted to establish the accessibility and assess the hydraulic characteristics of the candidate locations. Sites in heavy traffic areas were avoided for the safety of personnel, as well as to not impede the extremely dense flow of traffic in the City, where traffic control would have been difficult, to say the least.

Prior to installation of the flow monitors, many sewers were desilted and closed circuit television (CCTV) inspection was done where necessary.

Strict safety measures were observed while installing the flow monitors. At least one more upstream manhole was kept open sufficiently in advance for ventilation. Special gas monitoring instruments were used to check percentage of gases such as methane, hydrogen sulfide, carbon mono-oxide and oxygen in the sewer and forced and suction draft ventilation fans were installed before entering the manhole for installing monitors.

Operational Issues

It was difficult to find larger areas with only one type of land use, as most of Mumbai tends to be a mix of residential, commercial, institutional, and even industrial usage. It was also difficult to determine how much of the slums in each catchment area were connected since the slums are serviced mainly through the communal toilet blocks or aqua-privies.

Flow monitoring data was reviewed with a view to the impact of water supply timing on the measured sanitary flows. Most areas of Mumbai receive water for only a few hours at a time, to reduce the demand on the water supply system. This would logically be evident in an increase in sewage flow coincident with water being available.

Due to the low-lying nature of much of the municipality, infiltration and inflow may be impacted by tides. The 14-day monitoring period was established to cover both highest and lowest tides within the tide cycle.

A number of problems were encountered which made the flow monitoring more difficult. The following were some of the difficulties encountered:

- Sewer pipes contained excessive silt, and some were subject to surcharging due to reduced capacity.
- Pumping stations operation was on a manual basis causing surcharging in the sewers, making monitor readings inaccurate.
- Due to undersized force mains / rising mains, required number of pumps could not be operated to avoid surcharging in the incoming sewers for accurate flow measurement.
- Not all of the sewer lines and manholes were shown on the plans provided, or were not found in the field.
- In some cases the incoming sewer was lower that the outlet sewer. This created a siphon condition causing surcharging and inaccurate readings.
- Dips in the vertical alignment of the sewer caused ponding and monitors could not be installed.
- Frequent debris fouling the flow meter sensor prevented recording of velocity.
- Some manholes shown were difficult to locate in the field and others were inaccessible.
- Heavy road traffic made some manholes inaccessible.
- Excessively high flows and velocities in some manholes caused monitors to wash away.

While the goal was to obtain fourteen days of recorded flow data at each location, due to the above problems, data records from shorter periods was sometimes used.

Staff Training

Field staff training was given in all the planning and technical areas required for the monitoring program to produce reliable results, including equipment operation, safety procedures, site selection and installation, and data analysis and quality control. The training was for a period of 10 to 15 days for the staff, based on their function and responsibility. Monitoring team leaders received training in the United Kingdom and the North America.

Data Management / Quality Control

Observations were recorded in a field log along with comments on any unique problems noted during the meter installation and data downloading. Regular checks were made to ensure that meters remained clear of obstructions, were cleaned as required, and that the sewer remained clear. Meters were calibrated regularly to ensure accurate depth and velocity measurements. Meters were relocated where necessary to more reliable sites.

The accumulated data was downloaded from the flow monitors and the raw data was checked for gaps and indications of fouling of the sensor. Fouling would be evident by periods of zero velocity without depth changes. This would also indicate surcharging, especially upstream of pumping stations if the pumps were not able to keep up with the flow into the stations.

The flow curves were plotted along with plots of velocity versus depth (scattergraphs) and checked for proper relationships. This would show up evidence of unusual diurnal patterns, influence of pumps upstream and downstream, and surcharging of the sewer.

Only the data that passed the QA procedure was used for analysis. Some data where pumping station influence was evident was also used, but only for total flow purposes. A parallel QA/QC process was carried out in both India and Canada as the data became available.

Nallah Flows

The major problem in monitoring of the storm drains and nallahs was determination of tidal effects. Since all of the storm drainage is connected to the sea, the influence of tides is felt in many of the drains. Due to the flat topography of some of the areas, the tidal influence can extend inland from the sea for a considerable distance.

The amount of debris and garbage in the drains and nallahs also caused frequent instrument sensor fouling problems. Some of the nallahs had depths of 3.0 metres and were quite wide, which made measuring difficult.

During the study, a survey of 60 nallahs and storm drains was carried out to determine the magnitude of the sanitary or dry weather flows that would require diversion to treatment facilities. **Table 2** summarizes the range of flows measured in the nallahs in the Eastern suburbs of Mumbai.

Table 2: Summary of Nallah Flows(Eastern Suburbs)

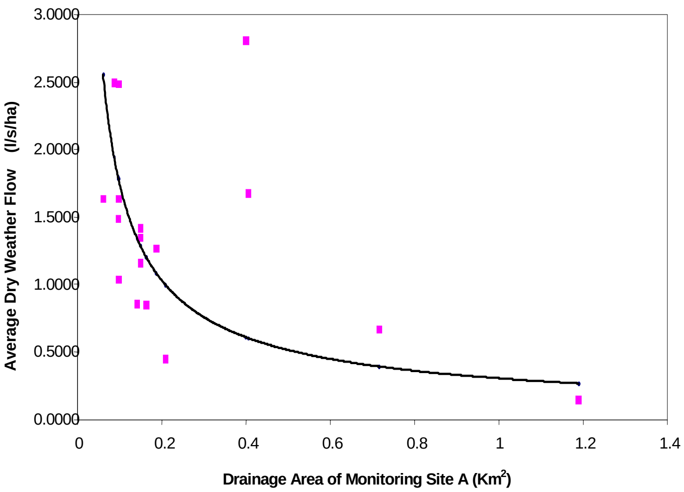
Site	Nallah	Details at Monitored Point			Unit Flow	
		Flow mld	Catchment Area km^2	Slum Pop'n	mld/km^2	Lpcd
1	Boundary ACC	84.7	2.754	16450	30.77	5151
2	NanepadaNahur	9.5	2.113	34635	4.50	274
3	Ushanagar	41.5	2.245	55375	18.47	749
4	Gamdevi	33.0	0.484	33865	68.15	974
5	Dadar colony	27.0	2.619	278465	10.31	97
6	Crompton	14.3	1.912	26170	7.47	546
7	Kanjur	21.5	0.986	94715	21.78	227
8	Pantnagar	43.4	1.973	14785	22.01	2937
9	Somaiya	521.2	2.462	67205		7756
10	Nehrunagar	105.6	0.341	16000	309.6	6599
11	PMG	19.3	0.147	10250	131.5	1887
12	Deonar main	33.9	1.530	13000	22.13	2605
13	Children Aid	27.7	3.598	18000	7.69	1537
14	Deonar branch	6.3	0.569	-	11.05	-
15	Subhash Nagar	12.5	2.910	-	4.31	-

Based on results of the flow survey carried out in the storm drains and nallahs, there appears to be a wide range in flows, and no evident relationship to a slum population or the drainage area. However, useful indications of areas of high infiltration, such as site 5, were observed.

Observations and Analysis

The overall per capita flow was calculated using the adjusted average flow for each site and the sewered population upstream of the site. The adjusted average flow was the measured average daily flow less the calculated infiltration component. **Figure 2** shows the results obtained.

Figure 2: Average Dry Weather Flow



As shown in Table 1, the average sewage flow per person in the tributary areas or catchments was 197 litres per capita per day, which is generally in accordance with water consumption rates in the City, and tends to support a design allowance of 220 lpcd for most serviced areas.

Water consumption for the slums ranges from 60 to 90 lpcd for the year 2000. However, at present very few slums are connected to the sanitary sewer system and a major portion of sewage from the slums discharges into the storm drainage system or nallahs. This is why it was necessary to monitor the main nallahs.

Analysis of the results indicated that socio-economic status, type of residential area, per capita water supply, time of water supply, population of area, and local water storage did not affect the sewage flow rates very much. This was most likely due to the combined effects of mixed land use, on-site water tanks, pump station operations, and nallah flows entering the sewer system.

Typical diurnal curves for Mumbai are illustrated on **Figure 3**. Morning and evening peaks were evident at most sites, except where influenced by unduly large pumping station operations.

The peak factors, which were measured on the diurnal curves, were plotted and compared to Babbitt formula curve. **Figure 4** shows the results.

Figure 3: Typical Diurnal Curves

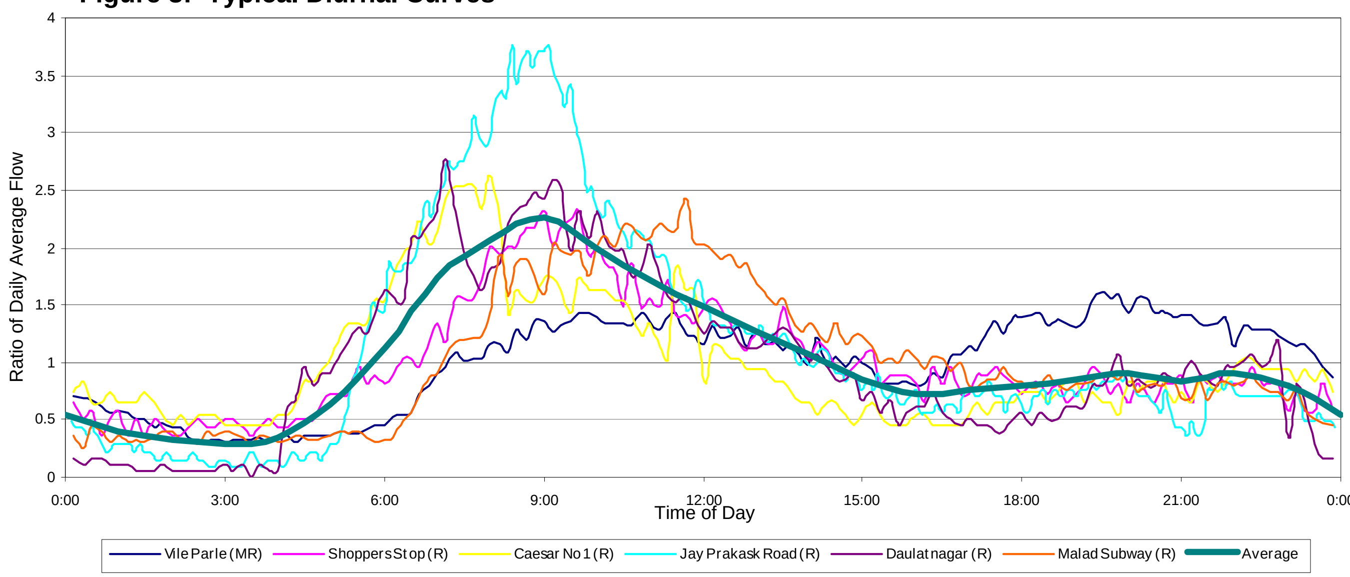
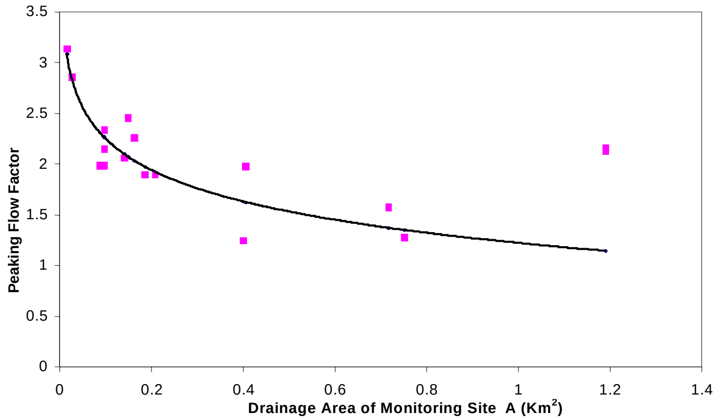


Figure 4: Peak Flow Factor



Observed peak factors ranged from about 3.2 for very small areas, to about 1.25 for larger areas, both consistent with typical values for sanitary sewer design.

Conclusions

The flow survey program was carried out to collect information on existing sanitary sewage flows during the dry season for the purpose of preparing a waste water master plan. Wet weather monitoring was not carried out and should be considered in the future to obtain more information on inflow and infiltration during the summer monsoon season and to provide the City with information to better manage the system.

However, the data obtained were considered sufficiently reliable for calibrating the sewer models and providing diurnal curves, and average flows and peaking factors from the different areas of the city.

From the diurnal curves, analysis of the ratio of peak flow to average flow was undertaken to determine the peaking factor. Peaking factor for flow is generally dependent on the contributory population. As the population increases, the peak flows are dampened and the factor is reduced.

Nallah and storm drain monitoring showed wide variation in flows between drains, however the data obtained from this programme provided a satisfactory base from which to predict nallah flows.

It was not possible to draw any clear relationships between flow and specific land use, which remains another area for further research.

Thorough staff training involving visits to equipment manufacturers, and workshops and short courses by RVA specialists was an important factor in programme success, especially in view of the very difficult field conditions encountered.

Well defined criteria for monitoring site inspection and evaluation, including formal field reports was also an important factor for success. This enabled a parallel QA/QC program to go on between Canada and India as the new data became available week-by-week, and early indications of problems could be identified and addressed.

Acknowledgement

The assistance and direction of the staff of the Water Supply and Sewerage Division of the Mumbai Municipal Corporation, and the Project Management Unit, in particular, Mr. S. Palav, during the Monitoring project, was greatly appreciated.