IOSR Journal of Mechanical and Civil Engineering (IOSR-JMCE)
e-ISSN: 2278-1684, p-ISSN: 2320-334X, Volume 22, Issue 3 Ser. 3 (May. – June. 2025), PP 53-61
www.iosrjournals.org

Real Time Water Distribution System with Smart Sensors for Sustainable Cities

Dr S. Sampath[1], B. Suresh Kumar[2], M. Nagaraj[3]
[1,2,3]*(Canal Automation Division, Central Water & Power Research Station, Pune, India)*

Abstract: *Accurate measurement of discharge in open channel is critical for effective water resource management. Conventional method to measure the discharge often require instruments to be in direct contact with the flow, posing a risk of damage due to physical wear and tear as well as under extreme flow conditions. Recent advancements in remote sensing have enabled the development of non-contact measurement techniques using Doppler radar and image analysis. The present study focus on validating a non-contact radar-type discharge measurement sensor installed by Maharashtra Industrial Development Corporation (MIDC) at main water distribution channel at Jambhul water treatment plant (WTP), in Ambernath, a suburb of Mumbai. This water canal is the primary source of potable water for Kalyan, Navi Mumbai &Ambernath Municipalities. To validate the accuracy of this sensor, Central Water & Power Research Station (CWPRS) has conducted the flow measurements by moving boat Acoustic Doppler Current Profiler (ADCP) and compared the results with the non-contact type radar sensor. The error in discharge measurements obtained from the radar sensor, when compared with the ADCP measurements by CWPRS, ranged from -0.68% to +0.72%. This deviation in the discharge measurement is of ±1%, which falls well within the acceptable limit, hence acceptable for real time measurements.*

Keywords: Electromagnetic, Radar, ADCP[2], Discharge Measurement[1]

Date of Submission: 10-06-2025 Date of Acceptance: 25-06-2025

I. Introduction

The present techniques adopted for the measurement of water discharge in canals[1,2,5] usually rely on mechanical[6], electromagnetic[3] or acoustic velocimetry instrumentation[5] requiring contact with the flow. As a consequence of safety and logistic issues, limit the applicability of conventional methods to gauge the flow in canals. Noncontact methods based on remote sensing techniques to measure water surface velocity using Doppler radars[4] or image sequence analysis have been developed in the past two decades.

Accurate measurement of discharge of Maharashtra Industrial Development Corporation *(*MIDC) canal is important for various stake holders like Kalyan, Navi Mumbai & Ambernath Municipalities which supplies drinking water for the Mumbai City Suburbs, Irrigation Dept, Local Industries and water contractors. Canal flow data of the MIDC is used for managing the releases of water from the upstream reservoirs, forecasting the requirement of flow and scheduling the releases of flow to the various stake holders. The demand increases due to the increase of water demand with respect to growth in population which escalates further during summer months. The need for accurate real time flow data has become important to manage the available water resources efficiently[10].

The radar based non contact type of flow measurement system deployed by the MIDC to have continuous flow measurement in its distribution canal have made monitoring system quite efficient. To evaluate this radar based flow measurement system, MIDC has requested Central Water & Power Research Station *(*CWPRS) to conduct flow measurement using Acoustic Doppler Current Profiler (ADCP) simultaneously at the site where the non contact type radar based system is deployed. Therefore the study aims to compare the results of Non contact sensor data with that of ADCP and provide an efficient realtime water distribution system with smart sensors for sustainable urban cities.

This paper examines discharge measurement studies using data collected on February 15th and 16th, 2024, to validate the effectiveness of a non-contact radar sensor and develop a gauge discharge curve. Section 2 provides an overview of the study area, focusing on the MIDC drinking water plant and its distribution channel. Section 3 outlines the methodologies employed, along with their underlying principles. Section 4 presents a comparative analysis of the data obtained from various measurement techniques. Section 5 discusses the limitations of the adopted methods, while Section 6 offers concluding remarks on the findings.

II. Description of study area

MIDC has established one of the largest water supply scheme known as Barvi Water Supply Scheme near village Jambhul, about 7 kms away from Ambernath Railway station in the year 1973as shown in Figure 1. The initial capacity of this water works was 300 Million Liters per day (MLD) which was enhanced and augmented in various stages in the year 1989, 1996 & 2002 and now reached to 900 MLD installed capacity. Presently, 800 MLD drinking water is being supplied to various Municipal Corporations / Councils, such as Kalyan-Dombivali Municipal Corporation (KDMC), Navi Mumbai (NMMC), Thane (TMC), Ambernath, Badlapur and villages on the route of MIDC's Water Supply Distribution mains. Industrial areas at Ambernath, Badlapur, Dombivali, TTC, Wagle Estate Thane etc. in Mumbai Metropolitan Region (MMR) are also fed for drinking water from this Scheme. The main source of water for this plant is from Bharvi Dam of Thane District, Maharashtra.

The MIDC plant consists of various facilities like pumping stations, 52 Nos. of filter beds, 10 Nos. of clariflocculators as shown in figure 2, 24 MLD Recycling plant, 3 x 22.5 ML & 1 x 27.5 ML capacity Hill Service Reservoirs with associated mains and Water testing laboratory at Water treatment Plant (WTP) for monitoring water quality to WHO standards.

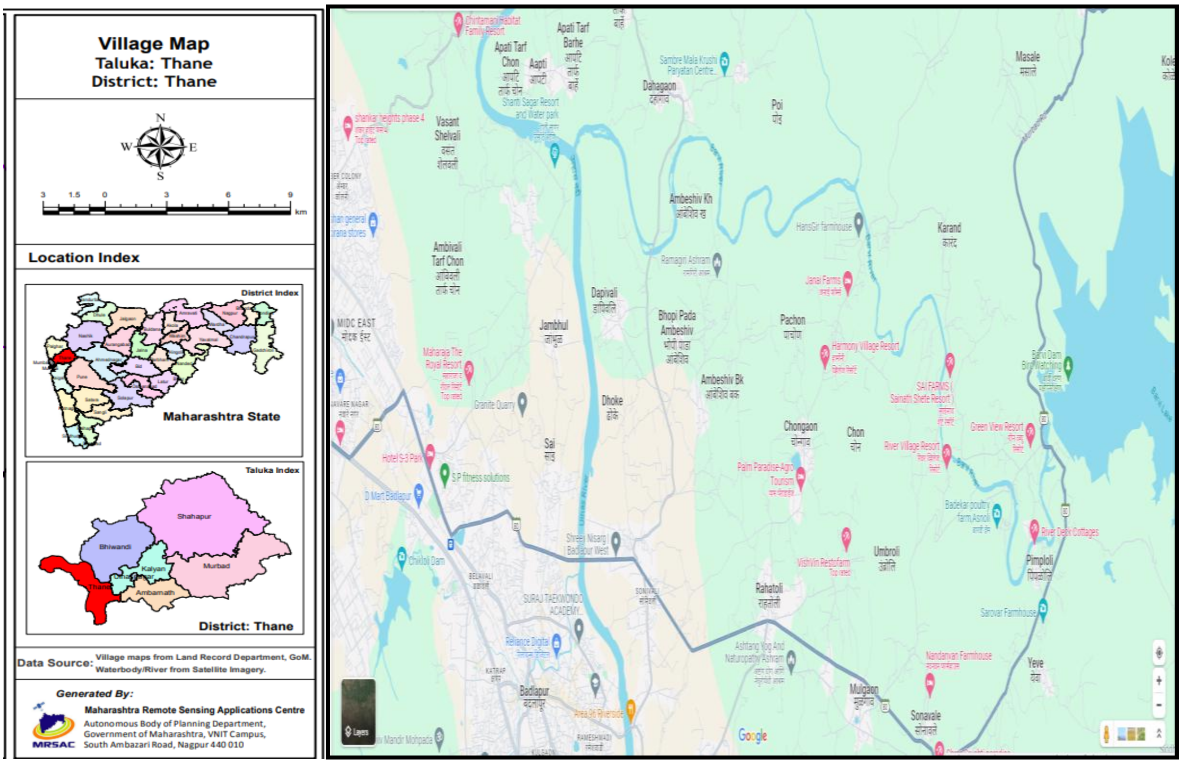

Fig 1: Location Map of Barvi Dam and Barvi Water Treatment Plant

2.1 Water Distribution Channel

Water from the Jambhul WTP is lifted by 17 No of pumps (maximum) into the channel at the measuring site as shown in the satellite image as figure 2, the water then flows to the storage tanks of the MIDC. The channel is lined and is of rectangular shape and designed to carry discharge of 40,000 Cubic meter per hour at head. It has an irrigation potential of carrying 800 MLD discharge per day to cater to the needs of Industry and drinking water supply.

Fig 2: Satellite Image of Barvi Water Treatment Plant

III. DATA COLLECTION METHODS

The data was collected by Non contact sensor as shown in figure 4 which measures water surface velocity and level without physical contact, using radar waves, and by the ADCP as shown in figure 5 which measures water current velocities using the Doppler shift principle. These emit acoustic pulses and analyze the frequency shift of the return signal reflected from particles in the water[7].

3.1 Non contact Radar type sensors

MIDC has installed SQ-R non contact radar type discharge sensors from Sommer Messtechnik, GmbH, Austria to measure the continuous flow velocity of the water distribution channel which measures surface velocity and depth of the canal and thereby computes the discharge flowing through the canal section[9].

3.1.1 Principle of Measurement of SQ-R non contact type Radar Sensor

The SQ-R non contact type radar sensor measures the flow velocity and water level at the water surface. Figure 3 shows the schematic view for discharge measurement principal of SQ-R radar sensor. The features of SQ-R sensor are provided in Table -1.

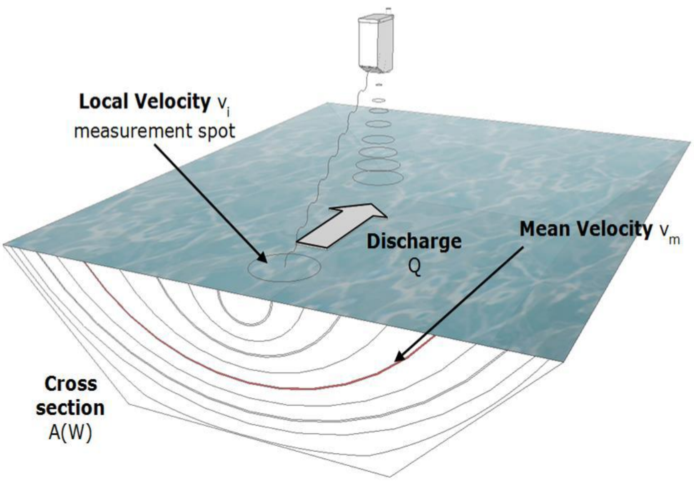

Figure 3: Principle of measurement of the SQ-R radar sensor

3.1.2 Principle of Surface Flow Velocity Measurement (V-Surface)

The non contact type of measurement of the flow velocity is based on the principle of the Doppler Effect. The radar sensor transmits a signal with a constant frequency in a specific angle to the water surface. Then the signal is reflected back. Due to fluid movement, a shift in frequency is observed. This shift in frequency is linearly proportional to the velocity of fluid. The reflected signal is received by the antenna of the radar sensor. Thus by comparing the transmitted frequency to the frequency of the reflected signal from the water surface the local velocity can be determined.

3.1.3 Principle of Water Level measurement (Stage or H)

The water level measured by the non contact type sensor uses the principle of transit time measurements of reflected signals. The radar sensor is installed above a river and transmits a short micro wave impulse in the direction of the water surface. This impulse is reflected from the water surface and is recorded by the same sensor now working as receiver. The time difference in release and reception of the signal with the known travel speed of the signal gives the depth of the water from the sensor, which is again subtracted from the total depth of the sensor to the canal bed to give the net water column depth.

3.1.4 Estimation of Mean Velocity (V_Mean)

Surface velocity is typically higher than mean velocity (which represents the velocity averaged over the depth). Use a velocity coefficient (α) to convert surface velocity to mean velocity

$V_{mean}=\alpha \times V_{surface}$ ....Eq (1)

Typical values for α range from 0.7 to 0.95, depending on channel roughness, shape, and flow conditions.

3.1.5 Calculate Cross-sectional Area (A)

The cross-sectional area is estimated from the measured stage and a known or estimated channel geometry (e.g., trapezoidal, rectangular, or natural). If the geometry is known

$A=f(H)$ ………………….Eq (2)

This can be determined from surveyed cross-sections or approximated for engineered channels.

3.1.6 Compute Discharge (Q)

Finally discharge is computed using the equations (1)&(2) by velocity-area method as given in equation (3).

$Q=V_{mean} \times A$ ……………..Eq (3)

Figure 4: Non contact type radar sensor at the site

Table – 1: The Non Contact type sensor features installed at the site (SQ-R) Sommer Messtechnik

Velocity	
detectable measurement range	0.08…15 m/s (depending on waves)
Accuracy	± 1 %
Resolution	1 mm/s
Direction recognition	+/-

Measurement duration	5…240 s
Measurement interval	8 s…5 h
Measurement frequency	24 GHz (K-Band)
Radar opening angle	12°
Distance to water surface	0.05…35 m (0.16...114.83 ft)
Vertical inclination	Measured internally
Water level	
Measurement range (distance between level sensor and water surface)	0.05…8 m (0.16…26.25 ft)
Deviation	≤ 2 mm
W-band (80 GHz technology)	W-band (80 GHz)
Opening angle	8°

3.2 Acoustic Doppler Current Profiler (ADCP)

The ADCP is an acoustic instrument designed to measure discharges in river/canal, three dimensional water currents, depths and bathymetry from a moving or stationary vessel[9]. Water-velocity measurements are made by transmitting sound at a known frequency into the water and measuring the Doppler shift, or change in sound frequency, from signals reflected off particles in the water[16].

The primary advantages of making discharge measurements using the ADCP[3] as compared with point velocity meters such as the current meter are that, the time required to complete a measurement is reduced[4], the ADCP allows for data to be collected throughout most of the water column and cross section rather than at discrete points, the ADCP is deployed at the water surface appreciably reducing the chance of snagging by debris, the instrument can be boat-mounted thus, eliminating the installation, maintenance, and liability of costly manned cableways/cradle arrangement[5]. The features of ADCP used by CWPRS are given in Table-2.

Table 2 : The River Ray ADCP of Teledyne make equipment has following features:

Profiling Range — Distance	0.06 to 60 m
Profiling Range -- Velocity	±20 m/s
Velocity — Accuracy	±0.25% of measured velocity ±0.2 cm/s
Velocity — Resolution	0.001 m/s
Number of Cells	Up to 200
Cell Size	0.01m (Automatic Selection)
Transducer Configuration	Phased Array Janus 4-beam 614.4 KHz Janus 30° Slant Angle
Depth — Range	0.30 to 100 m
Depth — Accuracy	1%
Depth — Resolution	0.001 m
Discharge Measurement Range	0.4 to 60 m
Discharge Measurement	Computations Internal
Bluetooth Range	Up to 200 m

The ADCP plays a crucial role in measuring discharge rates across the canal section. The process involves mounting the ADCP system on a hydro boat, which is then maneuvered from one end of the canal to the other, ensuring comprehensive data collection across the entire section. The measurement process is divided into three key phases: Start Edge, Transect, and End Edge, each contributing to the final discharge calculation.

To determine total discharge, the ADCP considers multiple components, including the Start Edge, Top Estimate, Measured Area, Bottom Estimate, and End Edge. However, only the Measured Area is directly computed by the ADCP, while all other sections are extrapolated using the Velocity Profile Extrapolation method. This approach utilizes the power law velocity profile, as defined in the River Surveyor Manual by Teledyne RD Systems, ensuring accurate estimations of unmeasured areas. Since water velocity varies within the canal—being slower near the edges and faster in the center—the power law velocity profile method effectively captures these variations.

To enhance measurement reliability, each gauge observation undergoes four cycles of ADCP data collection. By averaging these four measurements during data processing, errors and anomalies are minimized, resulting in more precise discharge readings. This procedure is systematically repeated for different gauge depths, allowing researchers to establish discharge trends under varying conditions.

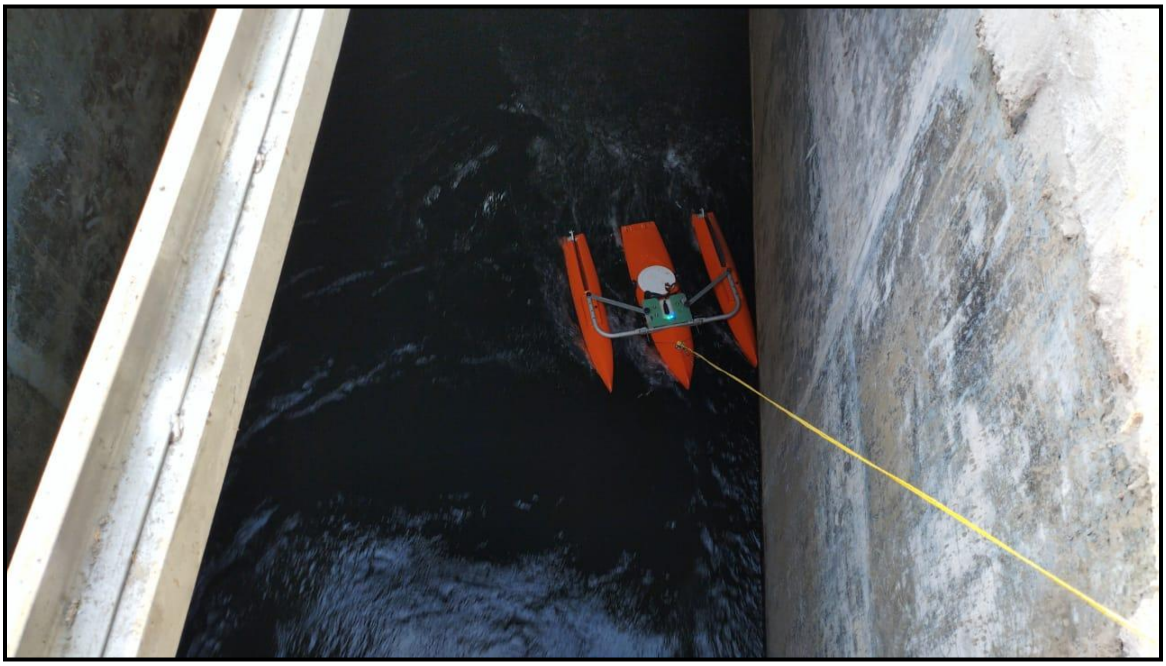

Figure 5: Discharge measurement using ADCP at the site

The visual representations in Figure 5 illustrate the ADCP measurements recorded at the gauging site, demonstrating how the hydro boat navigates across the canal while collecting real-time data. Additionally, Figure 6 provides a pixel-based analysis of the water discharge distribution, offering deeper insights into spatial variations in flow dynamics.

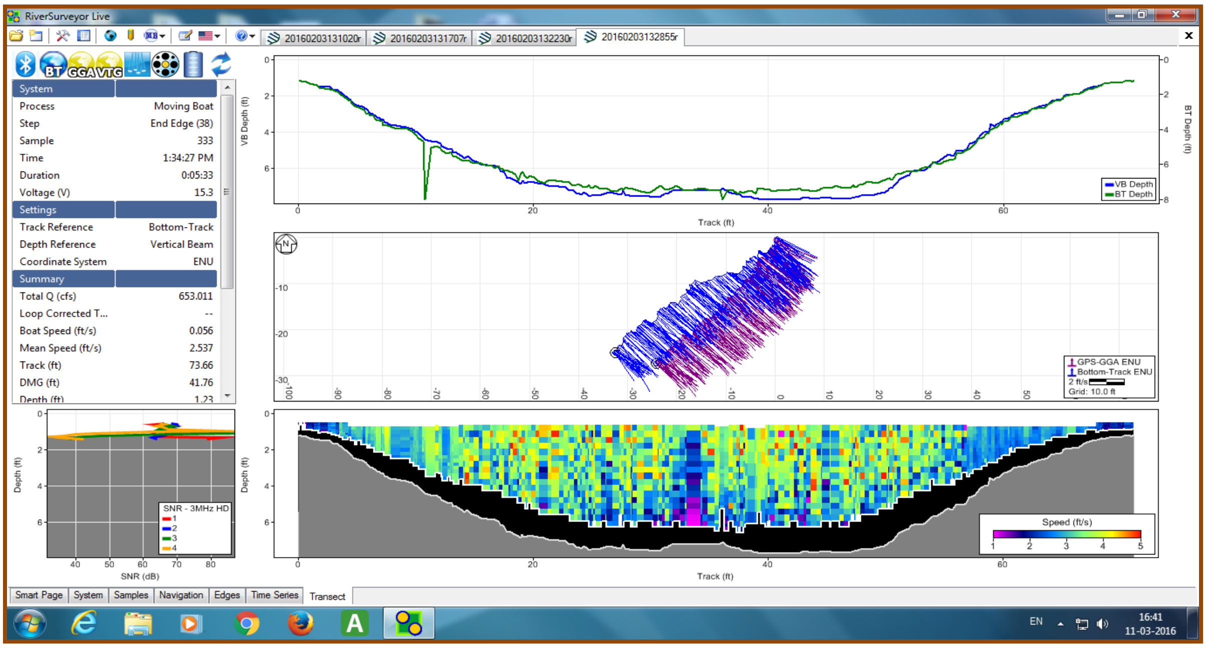

Figure 6: Typical Insight of the pixel data of ADCP

IV. Results and Discussions

The Gauge / depth measurement and the discharge values as observed at the MIDC measurement site of Ambernath where the Non-Contact radar type sensor is installed is given in Table 3. The gauge discharge data of the MIDC water distribution channel provides valuable insights into the performance of the non-contact radar sensor and its comparison with the CWPRS ADCP method. The measurements were conducted on February 15th and 16th, 2024, with varying numbers of running pumps influencing the recorded discharge values. The gauge depth fluctuated between 1.71 meters and 1.93 meters, reflecting changes in water levels during the observation period. The non-contact radar sensor consistently measured discharge values close to those obtained from the CWPRS ADCP method, with percentage variations ranging between -0.68% and 0.72%. Such minimal discrepancies indicate a high degree of accuracy in the radar sensor's readings, reinforcing its reliability as an alternative measurement tool. Additionally, the data highlights how variations in pump operations impact discharge rates, offering practical insights for optimizing the distribution process[13]. The comparison between these two measurement methods provides essential validation for the non-contact radar sensor, confirming its feasibility for ongoing use in hydrological assessments[14,17].

This gauge discharge data provides essential insights that can significantly improve water distribution efficiency. By analyzing the relationship between the number of running pumps, gauge depth, and discharge rates, operators can make data-driven decisions to optimize pump usage. If discharge rates remain stable with fewer pumps running, it indicates an opportunity for energy savings without compromising water supply.

Additionally, the comparison between the non-contact radar sensor and CWPRS ADCP measurements highlights the sensor's accuracy. A reliable and validated sensor enables real-time monitoring, reducing the need for manual measurements and improving operational responsiveness. With precise discharge data, operators can adjust flow rates to match demand, preventing overuse or shortages in different areas of the distribution network.

Furthermore, tracking percentage variations helps in identifying discrepancies or inefficiencies in measurement methods[14], ensuring consistent water distribution[11]. Over time, this data can support predictive maintenance strategies, helping operators anticipate pump wear, detect anomalies, and prevent costly failures. Ultimately, these insights aid in improving resource management, lowering operational costs, and ensuring a stable and efficient real-time water distribution system[12,15].

TABLE – 3: GAUGE DISCHARGE DATA OF MIDC WATER DISTRIBUTION CHANNEL

Sl.No.	**Date**	**Time**	**Running Pumps**	**Gauge/Depth**	**Non contact sensor**	**CWPRS ADCP**	**% Variation**
			in Nos.	**in Mtr**	**Q in cum/hr**	**Q in cum/hr**	**(ADCP-NCS)/ADCP*100**
1	15:02:24	16:55 to 15:10	17	1.925	34125.7	34328	0.59
2	16:02:24	10:50 to 11:05	17	1.93	34302.14	34452	0.72
3	16:02:24	11:30 to 11:45	16	1.88	32325.75	32363	0.12
4	16:02:24	12:10 to 12:25	15	1.82	29890.7	29850	-0.13
5	16:02:24	13:00 to 13:15	14	1.75	27256.58	27071	-0.68
6	16:02:24	13:50 to 14:05	13	1.71	25388.6	25380	-0.03

The non contact type sensors, measure the velocity of flowing water from distant place. The deviation in measured discharge may be due to the turbulence, water currents, sediment deposition, aquatic growth, rapids and falls etc., which contribute to the detrimental in accuracy of flow meter. The accuracy of the flow meter is also susceptible to the bubbles and the water currents effects to a certain extent. The sediment depositions may also affect the accuracy of the flow meter considerably. The sediment deposition at gauging sections must be regularly cleared and the actual profile of the sediment deposition is to be measured periodically in order to incorporate the actual correction factor in the flow meter.

The gauge and discharge data as observed on MIDC water distribution channel is given in Table – 3 and the same is plotted in Figure – 7. This plot indicates that relationship between gauge and data is non-linear. A statistical analysis of this data using method of least square, revealed following relationship between depth of flow and discharge and is given in equation(4).

$Q=6712.5\ D^{2.4791}$ - - - - - - - - - - - - Eq (4)

Where

Q = Discharge in cubic meter per hour m^3 /Hr and

D= Depth / Flow depth in Mtr.

The above relationship has a correlation coefficient (R^2) = 0.998 It would be seen that the correlation coefficient is very high and the standard error (0.0031) is well within the reasonable limit i.e., 5%. The results of the statistical analysis thus indicate that the quality of field data is accurate and the error in estimation of discharge will, therefore, be reasonable. A rating curve and a chart, prepared on the basis of above relationship, are given in Figure – 5 and Table – 4 respectively. It may, however, be mentioned that the above rating curve and chart should be used within the observed range of data. Any extrapolation of the rating curve / chart may likely to cause additional error. It may also be mentioned that these rating curve / chart are valid as long as the site conditions under which the field measurements were carried out are not changed i.e. no silting or no scouring of canal bed, canal lining not disturbed or removed, no weed growth in the canal, the downstream cross section also is not changed.

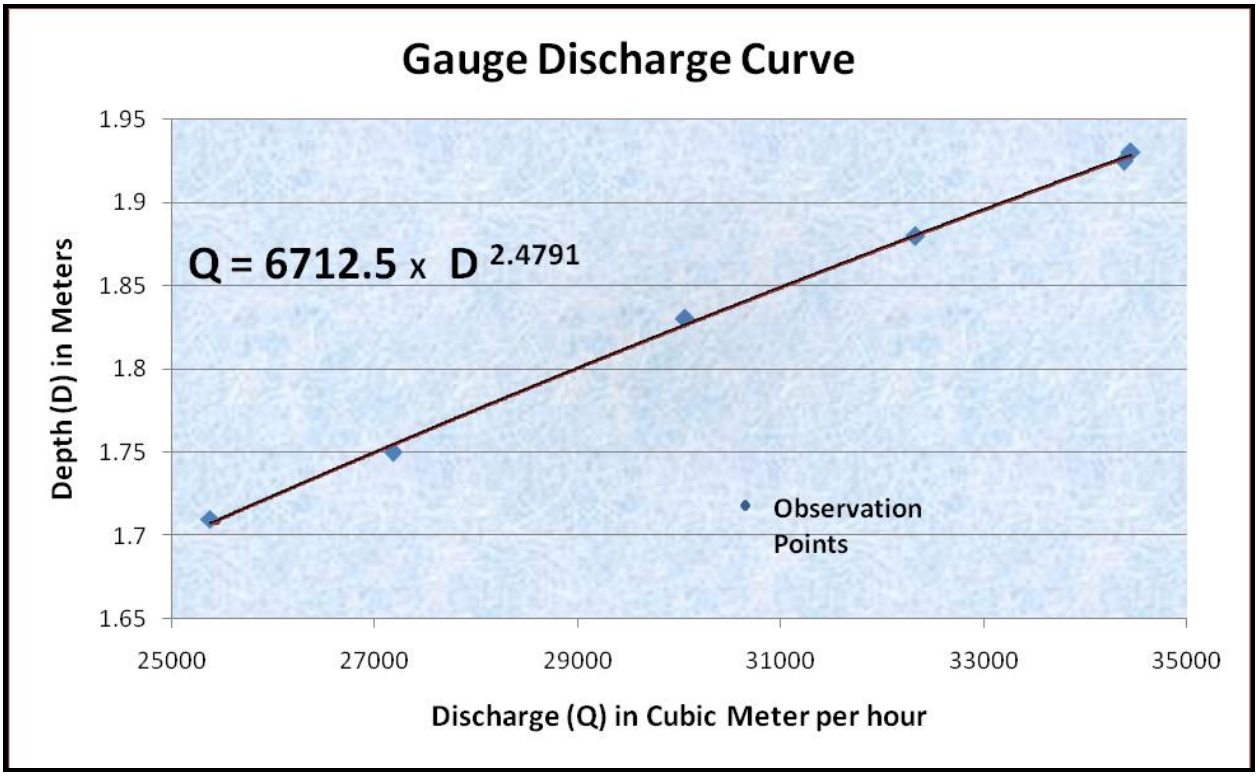

FIGURE 7: GAUGE-DISCHARGE CURVE OF MIDC Water Distribution Channel

TABLE – 4 : RATING CHART OF MIDC WATER DISTRIBUTION CHANNEL

Gauge(G) in Mtr	Discharge(Q) in m^3 /Hr	Gauge(G) in Mtr	Discharge(Q) in m^3 /Hr
1.71	25380.78	1.84	30674.95
1.72	25750.33	1.85	31092.06
1.73	26307.00	1.86	31512.55
1.74	26687.57	1.87	31936.43
1.75	27071.41	1.88	32363.71
1.76	27458.53	1.89	32794.38
1.77	27848.95	1.90	33228.47
1.78	28242.68	1.91	33665.99
1.79	28639.72	1.92	34106.93
1.80	29040.08	1.93	34328.69
1.81	29443.78	1.94	34551.31
1.82	29850.81	1.95	34999.14
1.83	30261.2		

V. LIMITATION OF MEASUREMENTS

Discharge measurements made either in the laboratory or in the field have some limitations. Even in case of laboratory measurements carried out under conditions stipulated in BIS / ISO standards, the uncertainty in the discharge measurements could be up to ± 0.5% by weight measurements, ± 1.5% with thin plate weirs and ± 2.5% in case of Standing Wave Flume. In case of field measurements, the major sources of the error are generally in the determination of flow area and estimation of average velocity[6,7]. ADCPs also can experience several types of errors during measurements, primarily due to factors affecting the instrument's orientation, the environment, and the data itself. These include heading errors, tilt errors, acceleration errors, flow disturbance errors, and errors related to the ADCP's internal algorithms.

The rating curves / rating charts given in the paper may, therefore, be adopted keeping in mind the limitations of the discharge measurements which can be reduced but cannot be totally eliminated.

VI. Conclusions

In this paper the field studies for rating of MIDC water distribution channel carried out by CWPRS, Pune following recommendations / conclusions are made[8]:

i) The gauge and discharge data is given in Table 3 and plot of gauge vs. discharge is given in Figure 5. A statistical analysis of the above field data revealed following relationship between gauge and discharge of the best fit curve.

$$Q=6712.5\ D^{2.4791}$$

Where Q = Discharge in cubic meter per hour m^3 /Hr and

D = Gauge / depth in meter.

ii) Rating curve and rating chart based on above statistical relationship are given in Figure 5 and Table 4 respectively.

iii) The deviation in percentage of error of non contact sensor is of -0.68% to +0.72% with respect to flow discharge measured by ADCP of CWPRS.

iv) The deviation in discharge measurement is of ± 1% which is within acceptable limits.

Acknowledgements

We express our sincere gratitude to Dr. Prabhat Chandra, Director, CWPRS, Pune, for his continuous encouragement and invaluable guidance throughout the course of this study. We are especially thankful to Shri A.A. Purohit, Additional Director, for his guidance and support during the preparation of this paper. We gratefully acknowledge the cooperation extended by Shri Ramesh Patil, Executive Engineer, Shri P.D. Talekar, Deputy Engineer, and the staff of MIDC for their generous support and assistance during the field measurements.

References

[1]. Hershey RW (1985), "Stream flow measurement", Elsevier Applied Science Publishers
[2]. River Surveyor Manual for M9 by Sontek Systems.
[3]. Nihei, Y., Irokawa, Y., Ide, K., and Takamura, T. (2008) "Study on River-Discharge Measurements using Accoustic Doppler Current Profilers", Journal of Hydraulic, Coastal and Environmental Engineering, vol.64, No.2, pp.99-114.
[4]. Chauhan et al./ International Journal of Advances in Earth Sciences, Volume 3, Issue 2, 2014, 81-86
[5]. Teledyne RD Instruments (2006) "Acoustic Doppler Current Profiler Principles of Operation a Practical Primer".
[6]. ISO 748: 2007, "Measurement of liquid flow in open channels – Velocity are methods"
[7]. WMO 1980 Manual on Stream Gauging. Vol I, Fieldwork. Vol II, Computation of Discharge
[8]. Development of rating curve for main water distribution channel for MIDC at Jambhul, Ambernath, Dist Thane. Technical Report No. 6226, March 2024, CWPRS.
[9]. Ultrasonic Flow Sensing Module. ScioSense [Online], Available at: https://www.sciosense.com/ufm-01- ultrasonic-flow-sensing-module/
[10]. Rijo, M. 1999. SCADA of an upstream controlled irrigation canal system, pp.123–136. In A.J. Clemmens and S.S. Anderson (eds.). Modernization of Irrigation Water Delivery Systems. Proc. of the USCID Workshop. Phoenix, USCID
[11]. Vudhivanich, V., J. Kaewkulaya, P. Sopaphun, W. Suidee and P. Sopsathien. 2000. Development of Water Allocation Strategy to Increase Water Use Efficiency of Irrigation Project. Kasetsart J. (Nat. Sci.). 34: 145–58.
[12]. Vudhivanich,V. and W. Sriwongsa. 2004. Development of Supervisory Control and Data Acquisition System for Canal Regulator. Engineering Journal Kasetsart 53: 1–1 1
[13]. Clemmens, A.J. 1987. Delivery system schedules and required capacities, pp.18–34. In D.D Zimbelman (ed.). Planning, Operation, Rehabilitation and Automation of Irrigation Water Delivery Systems, ASCE. New York
[14]. Malaterre, P., Rogers, D., &Schuurmans, J. 1998. Classification of canal control algorithms.ASCE Task
[15]. Committee on Canal Automation Algorithms, J. Irrig. Drain Eng., 124:1(3).
[16]. United States Bureau of Reclamation.1973.Water systems automation – a state of the art report. United
[17]. States Department of the Interior.
[18]. Nihei & Takamura, 2008. Study on river-discharge measurements using acoustic doppler current profilers
[19]. Muste M., Yu K., Pratt T.C., Abraham D. ADCP Measurements at Fixed River Locations, ASCE 2002-10-25