Hydrometric flow measurement in water management

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Abstract. The main problem in the operation of irrigation systems is to ensure the accuracy and reliability of measuring the main hydrometric parameters in managing water resources of irrigation facilities. When operating systems with pumping stations, it becomes necessary to measure a set of technological parameters, which can be divided into the following groups by type: hydraulic parameters (flow rate, fluid pressure, water flow in the channel), parameters of pumping units, linear-angular parameters (channel section length, channel width, gate movement, mixed parameters (clear area, flow depth, wetted perimeter length). Analysis of existing methods and instruments for measuring water flow for the rational use of water resources is used in all areas the volume of water taken from the water intake and supplied to the irrigation network. This task contributes to operational and control of pumping station parameters without hydrometric instruments at the stations themselves. The problem of organizing automated technological accounting of irrigation water at graduated hydraulic structures equipped with gates and operating in a flooded or backwater-variable mode is solved by new hydrometric methods with the integrated use of ultrasonic, acoustic, or float level gauges as part of modern microprocessor devices that convert water level readings at such structures into flow and runoff readings, according to the calibration characteristic each specific building. The article presents the recommended water metering devices for different hydraulic flow regimes and water quality. To speed up the process of measuring water flow in canals with flow rates of 1-10 m³ / s and large facilities of pumping stations with flow rates of 10-200 m³ / s, types of standard weirs, flumes of various profiles, and water measuring nozzles are recommended. According to the working formulas, changes in water flow are determined, taking into account the error of the gauging station and the indicated weirs.

1 Introduction

The problem of rational use of water resources is in all areas of the national economy. It is especially relevant for machine water lifting systems (MWLS) when using energy-efficient
operating technologies. These technologies are based on constant water accounting and water distribution. In modern conditions, including paid water use, water accounting allows the collection, analysis, and processing of information using a set of methods designed to improve the water resources management system and the operation of water management facilities. It also allows not only to maximize the satisfaction of water consumers but also to increase efficiency. The main task of MWLS water accounting is to account for the volume of water taken from the water intake and supplied to the irrigation network, considering the sum of water losses throughout the flow path of pumping stations. These systems use devices that measure water flow - flow meters for these purposes. In the conditions of a growing shortage of water and energy resources, the accuracy of flow measurement becomes an urgent task, especially in the southern republics.

To further improve the system of water resources management and operation of water facilities, ensure the efficiency of the implementation of irrigation and melioration projects, as well as the development of science in this area, the Decrees of the President of the Republic of Uzbekistan define priority areas for the rational and efficient use of water resources, ensuring reliable and safe operation of water management facilities.

One of the principles of water management is to ensure development and management to solve the problems associated with limited water resources, increase the efficiency of their use, and impact sustainable development. One of the ways to improve the efficiency of water use and operation of the MWLS is to reduce unproductive losses, mainly hydraulic ones [1, 2].

2 Methods

There are several measurement methods for determining the water flow at reclamation facilities. The most common methods use weirs, fixed channels of trapezoidal, rectangular, triangular, or parabolic profile, ultrasonic, radar, and Transit-Time methods [3, 4]. Based on these methods, many devices for determining water flow rates have been created: level gauges, radar and Doppler flow meters, submersible cross-correlation flow meters, and time-pulse flow meters.

In foreign projects, SANIIRI water measuring flumes, thresholds, and nozzles of the round section have found applications [5, 6]. Flowmeters capable of solving complex problems of measuring water flow are ultrasonic flowmeters.

Flow meters based on level meters and radar flow meters have high flow measurement errors since level meters measure only the level, and the speed is assumed to be constant. The water flow measured by Doppler and cross-correlation flow meters depends on the number of solids in the flow. But since the water in the channels and closed pipelines on the MWLS has a large amount of them, these flow meters have a low flow measurement accuracy.

3 Results and Discussion

The Republic of Uzbekistan is the republic most saturated with pumps; more than half of the pumping capacities of the entire Central Asian region are concentrated here. The experience of operating the MWLS is very important for developing countries, where climatic and hydrological conditions are close [7, 8]. These conditions include the coordinated management of river basins, basin departments of irrigation systems, and surface and ground waters. At present, one of the most important requirements for many types of pumps has become their reliable and efficient operation [9, 10]. A review of works
devoted to improving operating modes of centrifugal pumps showed that the developed mathematical models describe individual processes, and most of them are not suitable for developing the most beneficial operating modes in conditions of unsteady water movement.

At present, effective water resources management and water accounting are carried out with the help of new technical devices and modern water measuring instruments [11,12]. These tools are used to speed up the process of measuring water flow in small rivers and canals with flow rates of 1–10 m$^3$/s and large MWLS facilities with flow rates of 10–100 m$^3$/s [13,14]. The following types of standard weirs and flumes are recommended: weirs with rectangular, triangular, and trapezoidal cutouts; with a threshold of a triangular or rectangular profile, SANIIRI water-measuring rapids, Venturi and Parshala flumes, fixed channels of various symmetrical profiles, SANIIRI water-measuring nozzles [12].

The indicated types of water measuring devices designed to measure water are shown in Figure 1.

![Types of water meters](image1)

**Fig. 1.** Types of water meters

The gauging station must have a control gate in the head part, inlet and outlet straight sections, a water meter, and a hydraulic rail (Figure 2).
All these water-measuring devices previously met the standards' departmental requirements, making it possible to manufacture and use such measuring devices based on the calculation results without individual calibration.

To facilitate the selection of the location and type of water meter depending on the hydraulic flow regime and water quality, it is recommended to use Table 1.

**Table 1.** Recommended types of water meters for different hydraulic flow regimes and water quality

<table>
<thead>
<tr>
<th>Slopes and mode of water flow</th>
<th>Water composition</th>
<th>Maximum flow, Q m$^3$/s</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>The slopes are large and medium; the flow is steady</td>
<td>Content of suspended sediments up to 1.0 kg/m$^3$</td>
<td>WT, WCh, LS, LP, LV, PS, FR</td>
</tr>
<tr>
<td></td>
<td>The sediment content is more than 1.0 kg/m$^3$, and the presence of fin and debris</td>
<td>LS, LP, LV, PS, FR</td>
</tr>
<tr>
<td>Slopes are medium and small; the flow is unsteady</td>
<td>Content of suspended sediments up to 1.0 kg/m$^3$</td>
<td>NS, FR</td>
</tr>
<tr>
<td></td>
<td>The sediment content is more than 1.0 kg/m$^3$, and the presence of fin and debris</td>
<td>FR</td>
</tr>
</tbody>
</table>

Symbols: WT - Thomson spillway; WCh - weir Chipoletti; LP - Parshal's tray; LV - Venturi flume, LS - SANIIRI water flume; PS - SANIIRI water-measuring threshold; NS - SANIIRI nozzles of round or rectangular section; FR - a fixed channel of a trapezoidal, rectangular, triangular or parabolic profile.

In the practice of water accounting, rack gauging stations are most widely used. Suppose on a straight section of an earthen canal or a river, a hydraulic gate is broken, equipped with a gauging bridge, a level gauge, and calibrated to obtain the flow dependence $Q = f(H)$. In that case, such a hydraulic gate will be called a lath gauging station.

The resulting discharge curve $Q = f(H)$ can be used if the cross-section of the canal or river is unchanged. To prevent this from happening, almost all gauging stations on irrigation systems are equipped with lined sections of canals. If the canal runs in an earthen channel, then the canal section is lined in the hydraulic section, in the form of a concrete belt, and all these hydraulic sections will be called fixed channel (FR) hydroposts.
Weir Chipoletti WCh-50 is designed for sprinklers with a flow measurement range from 5 to 80 l/s; WCh-75 for sprinklers with a flow measurement range from 15 to 230 l/s.

Weir WCh-50 refers to trapezoidal weirs with a thin wall and side slopes 1:4. It is made from sheet steel 3–4 mm thick and corners to ensure structural rigidity. The width of the spillway crest (b = 50 cm) is made with a tolerance of ± 2–3 mm, other dimensions with a tolerance of ± 5–10 mm; the edge of the drain hole must be smooth, and clean, without notches and protrusions. The level gauge is made of anti-corrosion metal. The spillway WCh-75 is made of steel 4 mm thick; the spillway is without notches and protrusions. The main comb size b = 75 cm is performed with a tolerance of ± 5 mm, and other dimensions with a tolerance of ± 10 mm. The level gauge must be made of metal with an anti-corrosion coating.

The SANIIRI weir belongs to trapezoidal weirs with a thin wall and side slopes 1:1. It is made of 3-4 mm thick sheet steel and corners to ensure structural rigidity.

The width of the weir crest is carried out with a tolerance of ± 2–3 mm, and other dimensions - with a tolerance of ± 5–10 mm; the edge of the drain hole must be smooth and clean, without notches and protrusions.

Determination of water consumption is carried out according to the working formulas:

for triangular weir

\[ Q = 1.4H^2 \sqrt{H}, \text{ } m^3 / s \]  \hspace{1cm} (1)

for trapezoidal weirs

\[ Q = 1.9bH \sqrt{H}, \text{ } m^3 / s \]  \hspace{1cm} (2)

where: b is spillway threshold width, (m); H is water pressure above the weir, (m).

The empirical formula for calculating the flow through the Parshal flume:

\[ Q = 0.372(3.278H)^n \]  \hspace{1cm} (3)

where: \( n = 1.57 \cdot b^{0.03} \)

The SANIIRI flume is a short flume with vertical walls converging to the downstream and a horizontal bottom. The conjugation of the tray with the channel in the upper and lower pools is carried out by openings; at the same time, a well is arranged in the water part. Exceeding the threshold above the channel bottom is optional. The level gauge is attached to the tray's front wall; the zero of the rail must coincide with the mark of the bottom of the tray (Figure 1).

The empirical formula has the form:

\[ Q = 1.72bH^{1.55}, \text{ } m^3 / s \]  \hspace{1cm} (4)

The operation of the SANIIRI flume in Uzbekistan and the Chipoletti weir in Kyrgyzstan are shown in Figure 3.
The SANIIRI water metering threshold is designed to measure the flow rate of a liquid with a large number of suspended particles (up to 40-50 g/l) in trapezoidal channels.

Flow equation for threshold SANIIRI:

\[ Q = C[b_0 + (mh)]\sqrt{2gh^2} \]

where \( C \) is flow rate, \( m \) is slope setting, \( b_0 \) is threshold width at the top, \( h \) is water depth above threshold.

Level \( h \) is measured from the upper plane of the threshold.

The cost of building one gauging station, equipped with the Cipoletti spillway following the requirements of the standards, today costs about 100-125 US dollars \([8, 11]\). A survey of the MWLS showed that almost the entire head part of the main canals is equipped with various types of water meters. However, outlets to farms did not have water meters at the head (Figure 4).

In practice, the measurement of water flow is still carried out by calculating the cross-sectional area of the water flow (river, canal) in the alignment of the lath gauging station and multiplying it by the average velocity measured in this section (the "speed - area" method). To calculate the cross-sectional area of the flow of large rivers with great...
depth and flow rate, for example, the Amu Darya river, echo sounders installed on mobile crossings (motor boats, ferries) are used. On rivers and large canals with a depth of 5-6 m, water measurement is carried out using a special hydrometric load, which is used using a winch with a cradle suspension. On small rivers and canals, depth measurements are made at gauging stations of the "fixed channel" type with the help of gauging rods lowered by hydrometers from the bridge (Figure 5 a). The equipment of gauging stations is changing with the help of new designs for measuring the flow velocity of the ISV-01 metering meter (Figure 5b) and the hydrodynamic tube of the HDT type (Figure 5c).

The flow rate measurement is carried out using a "hydrometric turntable", the number of revolutions directly proportional to the flow rate at the measurement point. The hydrometric meter has been the most common means of measuring flow in the water industry.

The meter is designed to measure the average speed of the water flow to determine the water flow using the "area-velocity" method. Scope - open irrigation and drainage systems, natural and artificial riverbeds, canals, waste collectors, and other watercourses.

Functionality is not limited to measuring the speed of water movement, determining the flow rate of water in a stream using the "area-velocity" method. Still, it provides for the display of channel parameters, average velocities, and total flow for the selected object, indicating the date and time of measurement, saving information when the power is off and information output to a computer via the RS-232 interface.

The level gauge is designed to measure the water level in canals (reservoirs) equipped with standardized narrowing devices or gauging stations of the "fixed channel", "weir with free flow" type, with subsequent calculation of the flow and volume of water according to the calibration characteristic of the gauging station.

To simplify the process of measuring water flow, gauging stations of the "fixed channel" type are calibrated by repeated water flow measurements in the entire range from the minimum Qmin to the maximum Qmax; level h (Figure 6a). The pressure-flow characteristic is used in determining the pump flow and can characterize the improved parameters of the upgraded pump (Figure 6b).
Known ultrasonic, radar, and thermal flow velocity meters are difficult to operate and are used mainly for scientific purposes and at large objects of the MWLS.

An important direction in improving the accuracy and reliability of accounting for water consumption was clarifying the water consumption taken by pumping stations. Equipped at the beginning of the 21st century with ultrasonic flow meters, many pumping stations' open channels and pressure pipelines are currently out of order due to the lack of periodic inspections and repairs by manufacturers [15-18]. Currently, the costs of pumping stations are determined by the parameters of pumping units. Considering that the service life of many pumping units exceeds 35-40 years, it can be assumed that the determination of water flow rates by the parameters of pumping units is not entirely correct. This fact was confirmed during control measurements of water discharges behind the pressure basin of the pumping stations of the Karshi and Jizzakh canals in 2017 [7, 9]. A comparison of the measured water flow rates and deliveries, calculated according to the parameters of the pumps, showed a discrepancy of about 30%. Thus, equipping pumping units with modern flow meters and adjusting the flow characteristics of pumping units using traditional methods for measuring water flow is the primary task of the solution, which will increase the accuracy and reliability of accounting for water flow.

Radar non-contact flowmeters measure the level and velocity of surface runoff to measure water flow in open channels and closed free-flow pipelines. They are a type of ultrasonic device that works based on the "velocity-area" method, measuring both the level of the flow and its speed of flow. The flow meter radar is shown in Figure 7.
The radar flow meter's main advantage is simple installation and maintenance since the non-contact sensor is located above the flow surface and does not have contact with water. Radar flowmeters measure the speed of the flow, but this is not the speed of the entire flow, but only the surface layer.

With a steady flow, the flow velocity changes in time, neither magnitude nor direction. The water surface is relatively calm and smooth. There are no heavily silted or eroded areas in the canal bed; the water level practically does not change, and nothing prevents water flow. For a steady flow in a non-eroded channel, for each section along the length, there is an unambiguous dependence of the flow rate on the water level \( Q = f(h) \).

With unsteady flow, its elements (velocity, depth, flow rate, etc.) change in time and length. The dependence \( Q = f(h) \) for unsteady motion is ambiguous. This nature of the flow movement is typical for heavily silted channels with small bottom slopes overgrown with aquatic vegetation. An unsteady flow movement is also observed when pumps take periodic water from the canal, the flow rate of which is a significant proportion of the water flow in the canal.

Based on all this set of features, a hydrometer or a water user on site can determine the mode of flow movement, taking into account the characteristics of the composition of irrigation water. Suppose the content of suspended sediments exceeds values of more than 1 kg/m³, or the flow transports a large amount of floating debris. In that case, there will be constant silting of the weir thresholds and clogging of the openings of water measuring devices (nozzles), and as a result, the gauging station will cease to perform its functions. Level gauges should be installed in stilling wells and niches. The dimensions of the damping devices should ensure the reduction of high-frequency fluctuations in the liquid level.

To obtain a reliable calibration dependence, at least 5-10 flow rates should be obtained at levels evenly distributed over the entire flow measurement range of the FR-type gauging station (Figure 8).

\[ H, \text{ cm} \]
\[ Q, \text{ m}^3/\text{s} \]

Fig. 8. Graph of flow rate versus water level \( Q = f(H) \)

The minimum number of water flow measurements, depending on the depth of water in the channel: up to 0.5 m 5, up to 1.0 m 6, up to 1.5 m 8, up to 2.0 m 9, up to 3.0 m, and more 10 Values of average discharges \( Q_{av} \) and levels \( H_{av} \) are obtained as a result of summing at least three measured values of levels and discharges divided by their number when calibrating the gauging station in one step.
The error of the gauging station type FR consists of the sum of squared errors: the main errors of the means for measuring the speed of the water flow (gauging meter) $\sigma_1 \leq 1.5$; water level $\sigma_2 \leq 1$; water consumption $\sigma_3$; plotting $\sigma_4 \leq 2$ [17]. The post error is calculated according to the dependence:

$$\sigma_G = \sqrt{\sigma_1^2 + \sigma_2^2 + \sigma_3^2 + \sigma_4^2} \quad (5)$$

Measurement of water flow using weirs and flumes is indirect. For the primary values of the flow coefficients ($C_e; C_v$), root-mean-square relative errors are known, and the law of addition of such errors is valid for them.

Only the maximum errors of a single measurement are known for other quantities. To assess the flow measurement error, it can be assumed that the doubled root-mean-square error of a series of measurements is equal (at a confidence level of 0.95) to the maximum error of a single measurement.

RMS relative error of flow measurement, %, referred to the upper limit of measurement of the device [18]:

$$\sigma_s = Q_p \sigma_Q, \quad (6)$$

where $\sigma_Q$ is RMS relative error of flow measurement; $Q_p$ is measured flow in fractions of the upper measurement limit of the flow meter $Q/\dot{Q}$.

The mean square relative error of the flow coefficient, depending on the type of weir or flume, is given in table 2.

**Table 2. RMS relative error of the flow coefficient.**

<table>
<thead>
<tr>
<th>Type of water meter</th>
<th>RMS relative error of the flow coefficient, $\sigma_s$, %</th>
</tr>
</thead>
<tbody>
<tr>
<td>Venturi flume</td>
<td>1(2)</td>
</tr>
<tr>
<td>Weir Chipoletti (Ch)</td>
<td>2</td>
</tr>
<tr>
<td>Weir with rectangular sill</td>
<td>3</td>
</tr>
<tr>
<td>Water flume SANHRI</td>
<td>3</td>
</tr>
<tr>
<td>Tray Parshala</td>
<td>4</td>
</tr>
</tbody>
</table>

Before carrying out certification or verification, the gauging station must be cleared of sediment, water-measuring devices must be thoroughly cleaned, and have access for their inspection. The inlet and outlet channels must be cleared of silt, driftwood, and plant thickets.

### 4 Conclusions

1. The article solves the problem of organizing water resources management based on automated technological accounting of irrigation water at graded hydraulic structures of the MWLS, equipped with gates and operating in a flooded or backwater-variable mode. This problem can be solved by using ultrasonic, acoustic, or float level gauges in combination with modern microprocessor devices (controllers) that convert water level readings at such facilities into flow and runoff readings according to the calibration characteristic of each specific device.
2. The criterion for accounting for water supply at pumping stations today is pumps' passport performance without considering the year of manufacture and physical wear. At the beginning of the growing season, joint measurements of water flow rates are carried out at gauging stations equipped behind the pressure basins of pumping stations, and the measurement data are used to control modes and mutual settlements.

3. To maintain a reliable water supply at pumping stations, it is necessary to equip all pumps with stationary ultrasonic flow meters. State support is needed to establish the production of new hydrometric instruments based on measuring the flow velocity to replace technically and morally obsolete instruments.

4. It is not advisable to use flow meters based on level meters and radar flow meters at commercial water metering units since they have high flow measurement errors. Level gauges measure only the level, and the speed is taken as a constant value, which leads to a high measurement error. Although radar flow meters measure the flow velocity, it is not the flow velocity of the entire flow but only the surface layer, leading to a high measurement error.

5. It is necessary to revise or cancel national standards that contradict the requirements of technical regulations and do not meet economic development objectives, to amend existing standards in accordance with modern achievements in science and technology.

References


