

## **Analysis of Existing Methods for Hydraulic Calculation of Flows in Water Distribution Channels**

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**Abstract:** This article analyzes the existing calculation methods used to determine water discharge and the main hydraulic parameters of flow in open-channel water distribution systems. It is shown that, in earthen channels, silting, scour, backwater effects, roughness, and changes in flow cross-section geometry can significantly affect the stability of calculation results. To improve existing approaches, the article substantiates the need to regularly refine calculation relationships using field control measurements, to select a minimal yet sufficient set of rapidly measurable parameters, and to automate the calculation process.

**Keywords:** water distribution system, open channel, water discharge, hydraulic calculation, velocity-area method, water-measuring flume, rating, channel deformation.

### **Introduction**

Efficient operation of water distribution systems is directly related to the reliable determination of actual discharge in canals, timely detection of deviations from the prescribed water-delivery regime, and correct selection of the operating mode of control structures. This task becomes more complicated in open irrigation canals because channel geometry, water level, velocity field, roughness, sediment regime, backwater conditions, and the condition of hydraulic structures change over time [1]. Therefore, under operational conditions, hydraulic calculation cannot be reduced to a single formula; it should be considered as an integrated algorithm that includes measurement of initial parameters, selection of a calculation scheme, determination of coefficients, verification of the calculated discharge against field measurements, and, when necessary, updating of the rating relationship.[2]

Although the theoretical basis for determining discharge in open channels is the integration of velocities over the flow cross-section, various simplified and rapid methods are used in practice. Each method is effective under certain conditions; however, in deformable channels carrying sediment-laden flows, the sources of error differ considerably. The purpose of this article is to comparatively analyze the existing methods for hydraulic calculation of flows in water distribution channels, identify their limits of applicability, and substantiate methodological approaches aimed at improving calculation accuracy.[3]

## Methodology

The following criteria were adopted for evaluating the methods: physical validity, number of measured parameters, sensitivity to field conditions, speed of application, labor intensity, potential for automation, and the main sources of operational errors.

### 1. Calculation Based on the Chézy–Manning Formula

Under steady and uniform flow conditions, the mean velocity of an open-channel flow is expressed by the Chézy formula:

$$\bar{v} = C \cdot \sqrt{R \cdot I}$$

where  $C$  is the Chézy coefficient;  $R$  is the hydraulic radius, m; and  $I$  is the hydraulic gradient. In practical hydraulic calculations, the Chézy coefficient is often expressed in terms of Manning's roughness coefficient  $n$ . As a result, the discharge is determined as follows:[4]

$$Q = (1/n) \cdot \omega \cdot R^{2/3} \cdot I^{1/2}$$

where  $Q$  is the water discharge, m<sup>3</sup>/s;  $\omega$  is the flow cross-sectional area, m<sup>2</sup>; and  $n$  is Manning's roughness coefficient. This formula is convenient for selecting design dimensions of a canal, assessing its conveyance capacity, and performing verification calculations. However, in earthen channels, the values of  $n$ ,  $R$ ,  $I$ , and  $\omega$  may deviate from their design values during operation. Silting may reduce the cross-section, scour may alter its shape, and vegetation growth and bank deformation may increase hydraulic resistance. Therefore, a single adopted value of  $n$  should not be treated as a constant coefficient over a long period [5].

Although Manning's formula is physically well founded, its result depends directly on the accuracy of the input parameters. In channels with variable geometry and resistance, a systematic bias in the calculated value of  $Q$  may occur. Therefore, the Chézy–Manning scheme should be periodically verified using field control discharge measurements.

### 2. Velocity–Area Method

One of the most direct methods for determining discharge in an open channel is the velocity–area method. In general, discharge is determined by integrating velocity over the flow cross-section; in practical calculations, the cross-section is divided into several elements and the partial discharges are summed:[6]

$$Q = \sum(\omega_i \cdot v_i)$$

The main advantage of this method is that it directly accounts for the actual shape of the cross-section and the real velocity distribution. Therefore, it serves as a reference control method for checking  $Q=f(H)$ ,  $Q=f(H,V)$ , and the calibration of hydraulic structures. However, the large number of measurement verticals and points, velocity fluctuations, the long duration of measurements, and changes in water level during the measurement period can affect the result. The monograph notes that the error limits differ for detailed, standard, and accelerated measurement schemes, which demonstrates the need to select an appropriate balance between measurement speed and accuracy [7].

Reduced current-meter schemes and float methods shorten the measurement time. However, the coefficients used to convert local or surface velocity to the mean cross-sectional velocity must be determined experimentally for the morphometric and hydraulic characteristics of each canal. Otherwise, increasing the speed of measurement may lead to greater systematic error.[8]

### 3. $Q=f(H)$ Rating Relationship

One of the most convenient methods in operational hydrometry is to determine discharge from water level. Initially, the water level  $H$  and control discharge  $Q$  are measured simultaneously at different stages of channel filling, and a rating curve is established:

$$Q = f(H)$$

The advantage of this approach is that, for routine water accounting, it is sufficient to measure only the water level rapidly. For this reason, the  $Q=f(H)$  relationship is widely used at staff-gauge stations and simple hydrometric posts. However, the relationship is single-valued only when channel geometry, hydraulic resistance, and downstream backwater effects remain relatively stable. As a result of silting and scour, the same value of  $H$  may correspond to a different value of  $Q$  than before. Under variable backwater conditions, the same water level may also occur at different discharges [9].

According to the results of our study, water-level corrections must be introduced to account for channel changes, and control measurements should be repeated regularly. Under conditions of intensive silting, the required correction may change over a short period. Thus, although the simplicity of the  $Q=f(H)$  method is its greatest advantage, it also becomes its main limitation under variable channel conditions.[10]

### 4. $Q=f(H,V)$ and Multivariable Relationships

When the  $Q=f(H)$  relationship ceases to be single-valued, it is advisable to introduce an additional hydraulic parameter into the calculation. In the simplest case, a characteristic velocity  $V$  is measured together with the water level  $H$ :[11]

$$Q = f(H, V)$$

This approach makes it possible to distinguish between flow regimes having the same water level but different flow intensities and partially accounts for the effects of backwater and unsteady processes. However, the representativeness of the selected velocity for the entire cross-section must be justified. In wide channels with nonuniform turbulence, the location of the velocity vertical, measurement depth, and the coefficient for converting the measured velocity to the mean velocity should be established through dedicated field investigations [12].

## Result and Discussion

Water-measuring structures are based on the principle of artificially creating a control section whose hydraulic characteristics are related to discharge, instead of fully measuring the complex velocity field in an arbitrary channel. For weirs and flumes, the generalized discharge equation may be written as:

$$Q = A \cdot C \cdot b_0 \cdot h_e^n$$

where  $A$  and  $n$  are a coefficient and an exponent dependent on the shape of the structure;  $C$  is the discharge coefficient;  $b_0$  is the effective width; and  $h_e$  is the effective head. For a rectangular sharp-crested weir,  $n=3/2$ , while for a triangular weir  $n=5/2$ ; the operating characteristic of a specific structure is refined by calibration [13].

The advantage of weirs is that they provide a simple and repeatable relationship between head and discharge. Their disadvantages include the required head loss, the influence of sediment on the approach geometry, and strict requirements for flow conditions. Their accuracy depends on

how closely the actual structure corresponds to the design geometry and on the absence of blockage and deformation [14].

## 1. Calibrated Hydraulic Structures

Using an existing control structure simultaneously as a discharge-measuring device offers considerable operational advantages. In this case, discharge is related to gate opening and to the upstream and downstream water levels:

$$Q = f(a, H_1, H_2)$$

where  $a$  is the gate opening, and  $H_1$  and  $H_2$  are the upstream and downstream water levels or heads, respectively. A multivariable model reflects the physical state of the flow more completely than the single-parameter  $Q=f(H)$  relationship. At the same time, Table 1. manual calculation and regulation become more complex. The discharge characteristic of the structure should be calibrated using a series of control discharge measurements under different operating regimes and rechecked whenever the geometry or mechanical condition changes [15]. This scheme is promising for automation because the actual discharge  $Q$  can be calculated in near real time from measured values of  $H_1$ ,  $H_2$ , and  $a$ .

**Table 1. Comparative Assessment of the Main Methods for Determining Water Discharge**

| Method                         | Main parameters   | Advantages                                               | Main limitations                                              |
|--------------------------------|-------------------|----------------------------------------------------------|---------------------------------------------------------------|
| Chézy–Manning                  | $\omega, R, I, n$ | Convenient for design and verification calculations      | Sensitive to changes in $n$ and channel geometry              |
| Velocity–area                  | $h, \omega, v$    | Accounts for the actual cross-section and velocity field | Labor- and time-intensive; affected by velocity fluctuations  |
| $Q=f(H)$                       | $H$               | Very rapid for routine water accounting                  | Requires a stable, single-valued relationship                 |
| $Q=f(H,V)$                     | $H, V$            | Partly accounts for backwater and unsteady effects       | A representative velocity must be selected correctly          |
| Weir/flume                     | $h_e$ , geometry  | Repeatable and suitable for automation                   | Sensitive to sediment, head loss, and installation conditions |
| Calibrated hydraulic structure | $a, H_1, H_2$     | Combines measurement and regulation                      | Multivariable; requires calibration and automation            |

## 7. Main Sources of Calculation Error

It is not sufficient to compare existing methods solely in terms of mathematical simplicity. The Table 2. measured discharge is jointly affected by the measuring instrument, channel condition, discretization, selection of coefficients, and stability of the flow regime. Therefore, in operational calculations, the error chain should be assessed in the sequence “measurement – calculation – calibration – control.”

**Table 2. Main Sources of Error in Hydraulic Calculations under Operational Conditions**

| Calculation scheme             | Main uncertainties                         | Resulting effect                                       | Mitigation measure                                                      |
|--------------------------------|--------------------------------------------|--------------------------------------------------------|-------------------------------------------------------------------------|
| Chézy–Manning                  | n, I, R, $\omega$                          | Systematic bias in Q                                   | Refine coefficients and cross-section parameters in the field           |
| $Q=f(H)$                       | Error in H, channel deformation, backwater | Shift of the rating curve or loss of single-valuedness | Use control discharge measurements and update the rating characteristic |
| $Q=f(H,V)$                     | H, V, and representativeness of velocity   | Scatter in the multivariable relationship              | Select an informative velocity indicator                                |
| Velocity–area                  | h, v, number of verticals, averaging time  | Random and discretization errors                       | Optimize the measurement scheme                                         |
| Weir/flume                     | Head, geometry, flow regime, sediment      | Error in the discharge coefficient                     | Cleaning, inspection, and compliance with standard requirements         |
| Calibrated hydraulic structure | a, $H_1$ , $H_2$ , gate condition          | Error in the calibration relationship                  | Recalibration and automation                                            |

## 8. Directions for Improving Existing Methods

The analysis shows that there is no single universal method for water distribution canals that provides the same accuracy under all conditions. The multi-point velocity–area method is reliable for control measurements but slow for operational management;  $Q=f(H)$  is rapid but sensitive to channel deformation and backwater; water-measuring structures provide a well-defined calibration relationship but require specific structural conditions; and calibrated hydraulic structures combine measurement and regulation but require processing of multivariable data.

Therefore, the most appropriate direction for improvement is not to replace one method entirely with another, but to integrate control measurements with rapid operational calculations. Periodic velocity–area control measurements can serve as the primary reference, while the coefficients of rapid relationships such as  $Q=f(H)$ ,  $Q=f(H,V)$ , or  $Q=f(a,H_1,H_2)$  are updated using these data. The relative discrepancy between the calculated and actual discharge can be evaluated using the following criterion:

$$\delta Q = |Q_{\text{his}} - Q_{\text{haq}}| / Q_{\text{haq}} \cdot 100 \%$$

If  $\delta Q$  exceeds the specified allowable limit, the rating characteristic, channel geometry, or resistance coefficients should be redetermined. This approach adapts the calculation to changing hydraulic conditions and makes it possible to obtain a more reliable value of the actual discharge for operational control.

## Conclusion

Existing methods for hydraulic calculation of flows in water distribution channels are intended for different physical and operational conditions, and each has specific advantages and limitations in terms of accuracy, speed, and labor intensity.

The Chézy–Manning formula is effective for design and verification calculations; however, in earthen channels, changes in the roughness coefficient, hydraulic radius, and flow cross-sectional area may lead to systematic errors.

Because the velocity–area method accounts for the actual cross-section and velocity distribution, it is one of the most informative approaches for control measurements, although it requires considerable time and labor.

Although the  $Q=f(H)$  relationship is one of the fastest methods for routine water accounting, silting, scour, and backwater effects may shift the rating curve. Under complex flow regimes, it is advisable to use  $Q=f(H,V)$  or other multivariable relationships.

Weirs, flumes, and calibrated hydraulic structures are well suited to automation; however, their reliability depends on geometry, flow conditions, and the validity of the calibration.

The main direction for improving calculation accuracy is periodic field control, regular refinement of calculation coefficients, and selection of a minimally sufficient set of rapidly measurable parameters that provides stable calculations under variable flow conditions.

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