Торайғыров университетінің хабаршысы
ҒЫЛЫМИ ЖУРНАЛЫ

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Торайғыров университетінің ХАБАРШЫСЫ

Энергетикалық сериясы

1997 жылдан бастап шығады

ВЕСТНИК Торайгыров университета

Энергетическая серия

Издается с 1997 года

ISSN 2710-3420

№2 (2026)

ПАВЛОДАР

НАУЧНЫЙ ЖУРНАЛ
Вестник Торайгыров университета

Энергетическая серия
выходит 4 раза в год

СВИДЕТЕЛЬСТВО
о постановке на переучет периодического печатного издания,
информационного агентства и сетевого издания
№ 14310-Ж
выдано
Министерство информации и общественного развития
Республики Казахстан

Тематическая направленность
публикация материалов в области электроэнергетики,
электротехнологии, автоматизации, автоматизированных и
информационных систем, электромеханики и теплоэнергетики

Подписной индекс – 76136

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https://doi.org/10.48081/BGQF2124

SRSTI 44.35.01

https://doi.org/10.48081/BGQF2132

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CLASSIC AND MODERN METHODS OF WATER FLOW CONTROL IN OPEN NATURAL CHANNELS

In this study an analysis and classification of water flow management methods in open natural channels is presented taking into account the characteristic of hydraulic processes and operating conditions. Theoretical fundaments of water flow regulation, classic methods of water flow and level control and retaining method as the most sustainable methods of forming hydraulic regime are also reviewed. The limitations of conventional approaches in conditions of nonstationarity, variability of tributaries and uncertainty of hydraulic process are analyzed. The necessity of transition to intellectual control systems based on combinations of classic hydraulic control systems, mathematic modeling and modern methods of control theory is substantiated. The retained method is considered not only as conventional hydraulic method, but also as perspective base for construction of adaptive and predictive controlling water flow regime algorithms in complex water management and hydropower systems. Received results can be used in designing, modernization and digitalization of water resources control systems. Practical significance of the study lies in the possibility of applying the findings in the development of automated monitoring system, decision support and management of water management facilities. Suggested approaches contribute to increasing of regulation reliability, reducing water losses and sustainability of hydrotechnical systems functioning. These approaches create preconditions for Implementation of intellectual technologies in practice of water resources management on various levels of management systems.

Keywords: open channels, water flow, water flow management, retained method, hydraulics of open channels, intellectual control, hydropower, energy systems.

Introduction

Water resources play a vital role and, in several cases, play a decisive role in energy. All main industrial enterprises were placed near to natural water resources. Rivers, artificial distributive and irrigational networks are necessary energy sources in water infrastructure in our country. The problems of effective water flow control in such systems are paramount in ensuring sustainable water and energy supply. These issues become especially crucial in moment of flood process regulation and agricultural lands irrigation during drought periods. Regulation and protection of ecological balance of water resources, the issues are regulated by the law, that's why water flow regulation is becoming a priority today [1;2].

For the energy sector water flow regulation in open channels affects the operation of process equipment. Thus, work efficiency of hydro electrical station depends on hydraulic structures. The amount of water, directly used to generate energy, affects the sustainability of energy system, using open water resources.

Kazakhstan plans to increase the share of renewable energy sources, which creates a need to increase the flexibility of energy systems using intelligent management of hydraulic regimes of water resources.

The problems of water flow control, commonly, solved on the classic hydraulic methods, developed in fundaments of theory of open channels flow and practice of operating of hydraulic structures. These methods focused on maintain the given level of water or flow rates using local regulating structures [3].

However, in modern exploitation conditions of water management systems characterized with the uncertainty increase, associated with variability of tributaries uneven water consumption and impact of climate factor. These factors lead to decrease of conventional methods of control and necessitates their revision and development based on intelligent approaches.

In Kazakhstan, issues of rational use of water resources occupy a key place in public administration. The Concept of Water Policy of the Republic of Kazakhstan for 2024–2030 emphasizes the need for digitalization of water management, the implementation of automated control systems and intelligent solutions for water monitoring and distribution [4]. In the Address of the President of the Republic of Kazakhstan "Kazakhstan in the Era of Artificial Intelligence: Current Challenges and Their Solutions through Digital Transformation" dated September 8, 2025, Kassym-Jomart Tokayev noted the acute water shortage and significant losses in existing canals, sometimes reaching 50–60 %, outdated water metering and control systems, as well as the need to implement digital technologies and artificial intelligence for effective management of the water sector [5].

Understanding and analyzing classic hydraulic methods that form base of regulating water flow and level of water in open channels is the key step in developing effective approaches to modern water flow management.

Materials and methods

The description of unsteady water flow in open channels has been a great of interest to engineers. Saint-Venant, French engineer, developed a set of hyperbolic nonlinear partial differential equations accurately describing the one-dimensional dynamic of unsteady flows in open channels.

The movement of water in open channels described by Saint-Venant's unsteady flow equations, presenting as the system of differential conservation of mass and momentum equations. These equations are taking into account the changes in flow rates, water level and flow velocity in time and space, allowing to analyze in both steady-state and transient regimes.

When deriving the Saint-Venant equations, the following assumptions are typically made:

– the flow is one-dimensional, meaning the velocity is uniform across the entire cross-section, and the water level in the cross-section is horizontal;

– the curvature of the streamlines is small, and vertical accelerations are negligible, resulting in hydrostatic pressure;

– the effects of boundary friction and turbulence can be accounted for using resistance laws similar to those used for steady-state flow;

– the average slope of the channel bed is small, so the cosine of the angle between the bed and the horizontal can be taken to be equal to unity;

– the change in channel width along the x-coordinate is small.

Theoretical description usually assumes the absence of distributed lateral inflows and outflows, allowing for more general and representation to present the dynamics of lateral flows. However, in real hydraulic systems the presence of the lateral inflows and outflows is typical phenomenon, so the Saint-Venant equations and corresponding analysis methods can be generalized taking into account additional sources and drains of water, which

On the picture 1 the water flow in open channel along the longitudinal x-axis are depicted. The cross-section of the channel, direction of the flow, average flow rate V(x,t) and water flow Q(x,t) through the cross-section A(x,t). The flow rate is defined as Q(x,t)=A(x,t)V(x,t).

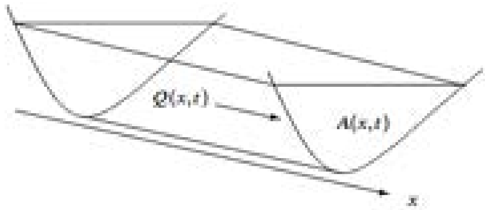

Figure 1 – Flow measurements in an open channel along the flow (longitudinal axis – abscissa X)

Continuity equation (conservation of mass):

q
$$\frac{\partial Q(x,t)}{\partial x} + \frac{\partial A(x,t)}{\partial t} = 0, \qquad (1)$$

Equation of momentum (conservation of momentum):

$$\partial \frac{Q(x,t)}{\partial t} + \frac{\partial}{\partial x}\frac{(Q^2(x,t)}{A(x,t)}) + gA(x,t)\frac{\partial Y(x,t)}{\partial x} - gA(x,t)\left(S_b(x) - S_f(x,t)\right) = 0, \qquad (2)$$

where x is the longitudinal coordinate, t is time, A(x,t) is cross-sectional area of the flow (m²), Q(x,t) is flow rate through section A (m³/s), V(x,t) is average speed in section A (m/s), Y(x,t) is water depth (m), is hydraulic slope (friction slope), is bed slope, g is acceleration due to gravity (m/s²).

Using Saint-Venant equation allows for an adequate description of flow dynamics in open channels, however their practical application in operational control problems requires significant computational resources and precise specification of model parameters. Therefore, simplified empirical relationships are widely used in engineering practice to analyze steady-state conditions and develop control methods [7].

The friction angle is modeled using the classical Manning formula:

$$S_f = \frac{Q^2 n^2}{A^2 R^{4/3}}, \qquad (3)$$

where n – Manning's coefficient , R – hydraulic radius, defiend by R=A/P along the wetted perimeter ratio.

The variables in this section of channel are depicted in figure 2. These models widely used by civil engineers and hydraulic engineers. Also, these models precisely describe flows if they are given taking into account the geometry and operating conditions of the channels.

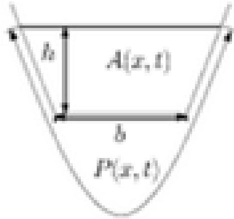

Figure 2 – Flow measurements in an open trapezoidal channel, cross-section.

The given dependences shows that water flow management can be implemented by changing the level of water, flow slope or channel capacity, flow slope or channel capacity. These are the principles upon which classical management methods used in open channels are based.

In general, the classic methods of water flow management in open channels are based on management of basic hydraulic parameters: flow rate, water level, and hydraulic gradient. These methods developed within the framework of traditional hydraulics and for a long time formed the basis of water management practices.

It is noticeable that in real open channels included in Saint-Venant equation and Manning formula are subject to significant uncertainty. The coefficient of roughness of the riverbed, the form of the cross cross-sectional area and the actual hydraulic slope may change over time due to siltation, channel overgrowth, seasonal fluctuations of water levels and anthropogenetic factors.

Classic methods of management essentially come down to regulation of geometric and energy flow characteristics, excluding distributing dynamics and predicting traits of hydraulic systems. Under these circumstances the efficiency in unsteady conditions and variability of hydraulic processes are limited, necessitating the development of intelligent approaches to water flow management.

Classic water flow control methods.

Flow control (Q-control) involves setting the desired water flow rate and regulating the flow capacity of the channel using hydraulic structures such as gates, stopcocks, segmental valves, and adjustable weirs. This method is widely used in water intake and distribution systems where a specified volume of water must be supplied to the consumer. Its main advantage is its ease of implementation and the ability to directly control flow. However, Q-control is highly sensitive to changes in water levels and hydraulic conditions and does not take into account the inertia of long open channels.

Water level control (H-control) is based on maintaining a set water level in a control section of the channel. Changing the water level indirectly changes flow rate, which helps stabilize the flow regime. A distinction is made between control based on the upstream level and control based on the downstream level. In practice, float regulators, automatic weirs, and constant-pressure devices are used. This method is characterized by relative stability and ease of automation, but its main drawback is the localized nature of the effect and the inability to precisely control flow under transient conditions.

The backwater method of water flow control is based on creating an adjustable backwater by changing the tailwater level. This creates a predetermined hydraulic gradient in the channel section, ensuring stable water flow over a long section. The backwater method is widely used in canals with a low longitudinal slope and is characterized by high hydraulic stability. However, it is characterized by significant inertia due to the propagation of wave processes in the open flow, which complicates operational control during sudden changes in water consumption.

In the basis of presented we can make a conclusion, that the most effective management in the condition of using water intake units of local areas is managing by flow rate, because of its simplicity in implementation with direct control of water supply, but due to high sensitivity to fluctuations, it reacts on inertial of flow. A more stable regime is achieved with water level controlling, which simplifying automatized system and gives opportunity to use indirect control. This type of control is more efficient to use in channels with constant operating conditions. The backwater method of controlling water flow creates a stable regime on extended sections and simultaneously reduces sensitivity to random local disturbances, but will result in a delay in control.

Results and discussion

Development of automatization and computing technology significantly changed the way to water flow manage in open channels and water management systems. Modern control methods are based on mathematical models of hydraulic processes, real-time monitoring systems, and control theory algorithms, which improve the accuracy and stability of regulation.

A more efficient methods is considered as adaptive systems of control, predictive control based on models and intellectual methods, using elements of unclear logic and neural networks. These approaches take into account the nonlinear character of hydraulic processes, unsteadiness of flow regimes, uncertainty of channel parameters and influence of external disturbances. As the result the higher accuracy of water flow regulation and reduction of resources.

Analysis of scientific indicates, that model-oriented methods of control significantly improving the performance indicators of water management systems. The use of predictive control reduces deviations in water flow and levels of water, and adaptive methods improve the dynamic characteristics of the system and the efficiency of water resource distribution.

Classic methods of water flow controlling have the limitations: low adaptivity, local nature of regulation, absence of predictive mechanisms and insufficient consideration of the dynamics of extended hydraulic structures. In modern water management systems these limitations become crucial.

The transition to intellectual systems of management, combined with the classic hydraulic principals with the methods of data analysis, optimization and machine learning is a pressing issue. The use of described above ensures a comprehensive accounting of dynamic properties of processes, enlarging efficiency of water flow control and sustainable functioning of water management systems.

The results of analysis confirms that the implementation of modern methods of water flow control is perspective direction, ensuring the growth of efficiency, reliability and adaptivity of water management systems.

Conclusions

Based on the analysis and classification of water flow regulation methods in open natural canals, it can be concluded that classical control methods and the backflow method retain practical value. However, they have limitations related to their low adaptability to changing conditions, the local nature of regulation, and the lack of a predictable hydraulic regime.

The proposed approach to the intelligent development of classical methods allows the backflow method to be considered not only as a traditional method of water flow regulation but also as a fundamental platform for building modern intelligent open canal control systems.

The combination of the backflow method with modern data processing, parameter identification, and adaptive and predictive control opens up opportunities for improving the accuracy of water distribution, reducing water losses, and ensuring stable system operation under non-stationary and uncertain hydrological processes.

Future research can focus on optimizing intelligent control algorithms and integrating them into real-time monitoring systems, which will enable the development of fully automated and highly efficient water resource management systems.

The results achieved are of great importance not only for water resource management systems, but also for hydropower, since improving water flow regulation methods will increase the efficiency of hydroelectric power plants, the reliability of hydraulic structures, and the stability of energy systems under changing hydrological conditions.

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Received 01.04.26.
Received in revised form 14.04.26.
Accepted for publication 22.05.26.

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01.04.26 ж. баспаға түсті.
14.04.26 ж. түзетулерімен түсті.
22.05.26 ж. басып шығаруға қабылданды.

АШЫҚ ТАБИҒИ АРНАЛАРДАҒЫ СУ ШЫҒЫНЫН БАСҚАРУДЫҢ КЛАССИКАЛЫҚ ЖӘНЕ ЗАМАНАУИ ӘДІСТЕРІ

Осы мақалада гидравликалық үдерістер мен қолдану жағдайларын ескере отырып, ашық табиғи арналардағы судың шығынын басқару тәсілдерін талдап, жіктеу ұсынылған. Дәстүрлі әдістердің шектеулері өзгермелі, тұрақсыз гидрологиялық үдерістер жағдайында қарастырылған. Классикалық гидравликалық қағидаларды, сондай-ақ математикалық модельдеуді және қазіргі заманғы басқару теориясының жолдарын біріктіретін интеллектуалды басқару жүйелеріне ауысу қажеттілігі дәлелденген. Бөгет әдісі су ағыстарын бақылап реттеудің теориялық негіздері, су деңгейі мен ағынды асырудың классикалық тәсілдері, сонымен қатар гидравликалық реттілікті қалыптастырудағы ең нәтижелі жолдардың бірі болып саналады. Мақалада бұл әдіс дәстүрлі гидравликалық әдіс ретінде ғана емес, сондай-ақ кешенді су шаруашылығы және гидроэнергетикалық тораптардағы су ағындарының режимдерін болжамдық алгоритмдерді құруға арналған болашағы зор негіз ретінде қарастырылады. Гидравликалық үлгілерді деректерді талдау *және оңтайландыруға арналған интеллектуалды алгоритмдермен қосу мүмкіндіктері көрсетілген. Қол жеткізілген нәтижелер суды басқару жүйелерін жоспарлау, жаңарту және цифрландыруда пайдаланылуы мүмкін. Зерттеудің практикалық маңыздылығы автоматтандырылған бақылау, шешім қабылдауды қолдау және су шаруашылығы нысандарын басқару тораптарын әзірлеу кезінде қолдануға мүмкіндік береді. Ұсынылған әдістер су шығынын азайтуға, реттеудің сенімділігін арттыруға, сондай-ақ гидротехникалық жүйелердің тұрақтылығын қамтамасыз етуге ықпал етеді. Осы тұрғыда бұл интеллектуалды басқару технологияларды су ресурстарын басқару жүйелерінің әртүрлі сатысында қолдануға негіз болады.*

Кілтті сөздер: ашық арналар, су шығыны, ағынды басқару, бөгет әдісі, ашық арналар гидравликасы, интеллектуалды басқару, гидроэнергетика, энергетикалық жүйелер.

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Поступило в редакцию 01.04.26.
Поступило с исправлениями 14.04.26.
Принято в печать 22.05.26.

КЛАССИЧЕСКИЕ И СОВРЕМЕННЫЕ МЕТОДЫ УПРАВЛЕНИЯ РАСХОДОМ ВОДЫ В ОТКРЫТЫХ ЕСТЕСТВЕННЫХ ПРОТОКАХ

В данной статье представлен анализ и классификация методов управления расходом воды в открытых естественных протоках с учетом особенностей гидравлических процессов и условий эксплуатации. Ограничения традиционных методов предусмотрены в условиях изменчивых, неустойчивых гидрологических процессов. Доказана необходимость перехода на интеллектуальные системы управления, сочетающие в себе классические гидравлические принципы, а также математическое моделирование и пути современной теории управления. Подпорный метод считается одним из наиболее эффективных в формировании гидравлической последовательности, наряду с теоретическими основами регулирования контроля водотоков, классическими подходами к повышению уровня воды и *стока. В статье данный метод рассматривается не только как традиционный гидравлический метод, но и как перспективная основа для построения прогностических алгоритмов режимов водотоков в комплексных водохозяйственных и гидроэнергетических сетях. Показаны возможности подключения гидравлических моделей с интеллектуальными алгоритмами для анализа и оптимизации данных. Достигнутые результаты могут быть использованы при планировании, модернизации и оцифровке систем управления водными ресурсами. Практическая значимость исследования позволяет применять при разработке узлов автоматизированного контроля, поддержки принятия решений и управления водохозяйственными объектами. Предлагаемые методы способствуют снижению расхода воды, повышению надежности регулирования, а также обеспечению устойчивости гидротехнических систем. В этом контексте это интеллектуальное управление является основой для использования технологий на различных этапах систем управления водными ресурсами.*

Ключевые слова: открытые протоки, расход воды, управление потоком, подпорный метод, гидравлика открытых каналов, интеллектуальное управление, гидроэнергетика, энергетические системы.

Теруге 09.06.2026 ж. жіберілді. Басуға 30.06.2026 ж. қол қойылды.
Электронды баспа
5,86 Mb RAM
Шартты баспа табағы 34,4. Таралымы 300 дана. Бағасы келісім бойынша.
Компьютерде беттеген: А. Б. Шукитова
Корректор: А. Р. Омарова, Д. А. Кожас
Тапсырыс № 4557

Сдано в набор 09.06.2026 г. Подписано в печать 30.06.2026 г.
Электронное издание
5,86 Mb RAM
Усл. печ. л. 34,4. Тираж 300 экз. Цена договорная.
Компьютерная верстка: А. Б. Шукитова
Корректор: А. Р. Омарова, Д. А. Кожас
Заказ № 4557

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