Algorithm for computer modeling of combined irrigation systems hydraulic parameters

V V Borodychev¹, M N Lytov¹ and A S Razin²

¹ Volgograd branch of All-Russian Research Institute of Hydraulic Engineering and Land Reclamation named after A.N. Kostyakov, 9 Timiryazev Street, Volgograd, 400002, Russia
² Volgograd State Technical University, 28 Lenin Avenue, Volgograd, 400005, Russia

E-mail: vkovniigim@yandex.ru

Abstract. A feature of combined irrigation systems is the integration of various technologies and methods of irrigation with the implementation of such a possibility on the basis of a single technical system. The hydraulic calculation of such systems is more complicated, since it is assumed that it is possible to implement various modes of operation, which differ by the combination of hydraulic parameters. The operating modes are determined by the combination of the involved irrigation technologies carried out simultaneously. The research has proposed an algorithm for the computer simulation of combined irrigation systems hydraulic parameters. The algorithm implements the principle of step-by-step calculation and formation of statistical screenshots of the hydraulic parameters of the system based on the basic calculated dependencies of classical hydraulics. Static screens can be performed at any time interval, which allows to assess the dynamics of the process under changing external conditions, as well as study the system under different operating modes. The algorithm has built an ingenious system of objects identification, making it possible not only to verify the uniquely defined knots of stems section, but also to organize serial search nodal points in accordance with the architecture of the construction of hydro-reclamation systems.

1. Introduction

Comprehensive analysis of different methods and technologies for irrigation of allows to make a justified conclusion of failure of any of these solutions for regulation of systemic problems hydrothermal mode of phytoecosystem and protecting crops from climate risks [1, 2, 3, 4, 5]. Most promising approach is to combine different methods and irrigation technologies to achieve complex objectives. The designs of combined irrigation systems proposed by scientists in the All-Russian Research Institute of Hydraulic Engineering and Land Reclamation are a fairly successful example of the implementation of this approach [6, 7]. However, today such systems exist only in the format of experimental projects. There is also no adapted methodology for designing such systems, taking into account the peculiarities of the integration of technologies. These problems decision is associated with the need to simulate the hydraulic parameters of a combined irrigation system because the hydraulic calculation has been and remains the basis for the design of any irrigation and drainage systems.

The hydraulic model for structures of combined irrigation with a closed pressure water supply network includes the statics and dynamics of pressure and flow characteristics at each section of the water conduit and functional elements of the system. The actual water pressure at each point of the
system is determined by the operating characteristics of the pumping system at the selected operating modes, and by the pressure losses in the structural elements of the system. In turn, the pressure loss depends on the design of the functional elements of the system and the speed of water movement, determined by the flow characteristics in the region of the selected section. The flow characteristics in each section of the system, in the general case, depend on the design and pressure-flow characteristics of the outlets, as well as the modes of their simultaneous use. With combined irrigation, one should also take into account the modes of alternate or joint use of outlets of different types with their individual pressure-flow characteristics.

2. Materials and methods
Determination of flow rates and head losses at each of the sections of the system is the main task that the developed algorithm must solve. In accordance with generally accepted techniques, the total head loss is the sum of local head losses and head losses along the length. Local pressure losses arise in connection with the change in water flow regimes and are determined in direct relationship with the design of the functional element of the system, where these changes occur. As the rule, the value of local pressure losses is included in the technical characteristics of the structural and functional element of the system, and for some cases, it has standard calculation methods. These are point, nodal values, which are included in the sum of the total head losses for the corresponding segments of the system.

The value of the head loss along the length has a continuous, distributed characteristic with not always linear parameters. The head losses along the length are not the same for different modes of water flow, and also significantly depend on the speed of its movement along the water conduit. Modes of water flow, in turn, also depend on the speed of its movement and a number of other conditions, including the material and diameter of the water pipes, the properties and state of the transported liquid itself. But if we take the pipe materials and liquid properties to be the same, which is generally typical for a complex-designed system of combined irrigation, then the number of parameters that will determine the change in the flow regime of transported water in pipelines is significantly reduced. And the most significant factor again becomes the speed of movement of the transported water in the conduits.

The speed of water movement in pipelines is determined by its flow rate over the section and the diameter of the pipeline itself. Hence it follows that the change in this parameter, which determines the loss of water pressure along the length of the water conduit, occurs either at the junctions of the water conduits of the system, with different diameters of the pipeline, or at the nodes of moisture collection and branching of the flow. The head loss along the length between these nodes remains constant, of course, provided that the above initial conditions remain unchanged.

The dynamics of the hydraulic parameters of the combined irrigation system is determined by the change in the kinematic viscosity of the irrigation water due to the influence of daily and intraseasonal fluctuations in the ambient temperature, the change in the operating modes of the pumping station, and the change in water consumption due to the simultaneous activation of a different number of irrigation modules. The specificity of combined irrigation is also the possibility of changing the water flow rate in the irrigation module, depending on the mode of joint operation of different types of outlets. In statics, with unchanged design parameters of the combined irrigation system, the pressure-flow characteristics change along the irrigation pipelines, from the water intake and pumping station to the irrigation pipeline in the outlets, inclusive. The static screen of hydraulic parameters is a set of pressure-flow characteristics for any coordinate point of the combined irrigation system. In this case, the dynamics of the process can be reflected by a sequence of static screens taken at any given interval.

3. Results and discussion
To describe the static screens of the hydraulic model of the combined irrigation system, it is necessary to select the coordinate system relative to which this data can be presented. In general, the system is represented by a network of pressure water pipelines with various hydraulic devices and structures located on them that regulate the transport and distribution of irrigation water. Coordinates for this kind
of objects can be specified in a linear system. To do this, it is necessary to identify an extended object and set a point on it in any convenient form:

$$X(ID,L),$$

where $ID$ is the identifier of the linear object, $L$ is the distance from the beginning of the extended object to the desired point;

or:

$$X(ID,t),$$

where $t$ is a characteristic name that makes it possible to verify the point coordinate on the identified extended object.

The identifier of an extended object of the combined irrigation system can be the serial number (level) of the water conduit, numbered, for example, from the pumping station or from the head unit of any segment of the system for which the model is being built. On the identified extended object, the coordinate can be specified metrically (by the distance from the beginning of the object), or by the number of the nodal point at which the structural (interface unit) or consumption characteristics (branching unit) of the extended object change. The first method allows to find a pressure-flow date pair for any point in the system, while the second gives a screen only for nodal points. However, in practice, it is important to know the pressure-flow characteristics precisely at the nodal, characteristic points, which give an idea of the operation of the system. In this case, when determining pressure-discharge data pairs by coordinates specified metrically, additional manipulations are required to verify compliance with the nodal point. When using the second method, there is no need for such calculations, and the pressure-flow characteristics between the nodal points, taking into account the linearity of the process, can be easily restored.

Thus, to set the coordinate on any, arbitrarily distributed network of combined irrigation, it is necessary to indicate the ordinal level of the water conduit and the name (ordinal number) of the nodal point for which the required date-pair is calculated (Figure 1). For computer calculations, this coordinate can be represented as a name given by a sequence of identifying numbers. In this case, another problem arises: after all, strictly speaking, the ordinal level of a water conduit cannot identify the desired extended object, since there can be several water pipelines of a certain level. The name of the coordinate should provide comprehensive information for guaranteed identification of the object. Taking these requirements into account, the following scheme for forming the numeric coordinate name was proposed:

- the ordinal level of the conduit is determined by the ordinal number of the number located in the numerical sequence;
- the number determines the number of the nodal point on the water conduit of the system, determined in the direction of movement of irrigation water when performing the transport function.

For example, in the name name_1:5:4:12, - the number 1 characterizes the branching node of the flow on the first from the considered segment, the water conduit of the system (the main pipeline, if the model assumes coverage of the irrigation system as a whole). The number 5 characterizes the number of the branching point on the second-level water conduit, and it is known that this water conduit is connected to the first-level water conduit at the flow branching point 1. This approach makes it possible to reliably identify the water conduit as the sought-for extended object in the linear coordinate system. The number 4 indicates the flow branching node number four in the third level water conduit, connected to the flow branching node five on the second level water conduit. And finally, the number 12 gives the final idea of the desired coordinate, defining it as the twelfth nodal point (the last number in the numerical sequence of the name can indicate both the branching node of the flow and the interface, characterized by a change in any design parameters of the water conduit itself) of the water conduit of the fourth level, connected in node 4 to the third level water conduit, which in turn in node 5 is connected to the second level water conduit, connected in node 1 to the first level water conduit. Thus, the coordinate name gives a complete picture of the path from the input section of the considered segment of the irrigation system to any given nodal point on the combined irrigation system.
Figure 1. Algorithm for step-by-step calculation of combined irrigation systems hydraulic parameters.

The scheme used for the formation of the name of the coordinate in machine language provides convenient tools for organizing the enumeration of coordinates to form a complete screen of the pressure-flow characteristics of the combined irrigation system. Enumeration of coordinates begins with the water conduit of the highest level, with a sequential transition to the water conduits of the second and subsequent levels. Accordingly, at the beginning of the search, the name has the shortest record (one number), with the values of the nodal point number on the first water conduit of the irrigation system segment for which the model is being compiled. Then another numeric entry is added to the name, indicating the second-level water conduits. Enumeration is carried out sequentially by a pair of numbers: the numbers of the nodal points on the second-level water conduit connected to the first nodal point of the first-level water conduit are alternately changed, after which the same enumeration is carried out for the water conduit connected to the second nodal point of the first-level water conduit, etc. The
procedure is repeated until the calculation covers all the nodal points of the system (or the segment of the irrigation system for which the calculation is made).

The next important task for creating a static screen of a hydraulic model of a combined irrigation system is to determine the flow rate of irrigation water at a given coordinate point. The water flow rate for a given section is determined by the total flow rate of all outlets installed and operated after the section. To solve this problem, it is necessary to determine all the outlets installed on the branch of the irrigation system after the section, and also establish which of them are involved and which are not. The performance parameters of the involved outlets, verified by the known pressure-flow characteristics, are sent to the adder, where the desired value is calculated.

The basic core of the calculations carried out to determine the water flow rate for an arbitrarily given section is an algorithm for enumerating coordinates with constraints. Limitations include the following:

- enumeration of coordinates should be carried out only within the branch of the irrigation system, which is located after the design section. This requirement is ensured by fixing the parameters of the name of the calculated coordinate when organizing the procedure for enumerating coordinates. Let us suppose, the name of the design section is name_3:5:2. The parameters of this name when iterating over the N-dimensional array are fixed and remain unchanged, - name_3: 5; 2:... r^N: r^N;
- the search should include only those coordinates that correspond to the water pipes of the last level. This requirement is determined by the fact that the water pipelines of the last level are irrigated, and the nodal points located on them (flow branching nodes) are outlets. This means that the name of any location participating in the exhaustive search must have the parameter r^N: name_3:rr:...r^N.

Enumeration of coordinates limited in this way makes it possible to take into account all outlets located after an arbitrarily specified design coordinate. For each coordinate participating in such a limited search, a procedure for identifying the type of outlet is performed. To identify the type of outlet by the name of the coordinate, a formula for their placement on the irrigation pipeline is required. It is assumed that this formula is known and included in the source data. The result of this procedure is a pair of data: the coordinate and type of outlet, which allows identifying the technical characteristics, and, consequently, the pressure-flow curve of the device.

The next step is to find out if the identified outlet is involved in the technological process directly at the estimated time (screen time). The algorithm for solving this problem is based on data on the operating mode of outlets of various types, as well as on information about whether irrigation is carried out on a given irrigation module. The first of these data packages is specific for combined irrigation systems, a distinctive feature of which is the use of several fundamentally different types of outlets for irrigation. The differences lie in the implementation of different irrigation methods aimed at preferential regulation of various factors of plant life. At the same time, even if only two types of outlets are used, three combinations of inclusion can be realized: when outlet type A is enabled, when outlet type B is enabled and when these outlets work together.

The second data packet is formed based on the need for irrigation on this irrigation module. The data are dynamic in nature, but for this algorithm they are also assumed to be initial. It should be borne in mind that combined irrigation involves the implementation of different irrigation methods aimed at solving different problems. And, consequently, the need for their implementation may arise at different times, as well as have different recurrence.

If the water outlet identified for the coordinate is not involved in the technological process, then the execution of further calculation procedures is ignored, the algorithm returns the count to the beginning of the coordinate enumeration procedure with restrictions. The cycle is repeated. If a water outlet is enabled, then the necessary technical information is retrieved for it, including information about the performance at given (working) heads. At the output, the procedure provides a pair of data: coordinate - water flow rate for a given nodal point. Information about the flow rate at a given irrigation outlet is entered into the integrator, and the algorithm initiates a new calculation cycle with the implementation of the procedure for a limited search of coordinates.

The integrator sums up all the information received about the water discharge by the outlets of the segment of the combined irrigation system located after the calculated nodal point (section). Upon
completion of the full cycle of coordinates enumeration in the computational segment, the integrator has data on the total water consumption for the design cross-section of the combined irrigation system at the time of the screen.

With the data on the total flow rate, it is possible to calculate the water flow rate for an arbitrarily chosen design section of the combined irrigation system. To solve this problem, the algorithm offers the well-known relationship [8, 9]:

\[ V_\text{calc} = \frac{4Q_\text{calc}}{\pi d^2_\text{name}}, \]

where \( V_\text{calc} \) is the estimated speed of water flow in a given section of the water conduit of the combined irrigation system; \( Q_\text{calc} \) is the found value of the water flow rate for a given section of the water conduit; \( d_\text{name} \) is the diameter of the pipeline in a given section corresponding to the coordinate name.

The value of the pipeline diameter at the level of the calculated coordinate is assumed to be known and included in the initial data array. However, to select the correct value of the diameter, a procedure for identifying the initial data by the coordinate is required. For this, for example, can be used information about the level of the conduit, extracted and the length of the name of the coordinate name. The same procedure should be carried out for a parameter equal to the length of the section of the water conduit between two adjacent coordinates - the coordinate of the design section and the previous coordinate along the water transport path. This parameter is necessary to determine the head loss along the length for a given, calculated, section of the water conduit. To determine the head loss along the length, the algorithm offers a well-known calculation formula:

\[ \Delta H_\text{by length} = \lambda \cdot \frac{l_\text{calc} \cdot V_\text{calc}^2}{d_\text{name}^2 g}, \]

where \( \Delta H_\text{by length} \) is the pressure loss along the length of the calculated section of the water conduit of the combined irrigation system; \( g \) is the acceleration of gravity, approximately equal to 9.81 m/s\(^2\); \( \lambda \) is the value of the coefficient characterizing the hydraulic resistance along the length.

As we have already noted, the coordinate system adopted by the algorithm is based on the nodal points where the nature of the water flow changes. These are branching points of the flow or junctions of water conduits, water outlets, possibly other functional devices. These devices are characterized by their own resistance to the movement of water, which determines the so-called local pressure losses. Methods for accounting for this kind of head loss are diverse, there is a sufficiently strong theoretical basis for modeling local resistances [10], often such information is included in the device's passport data, empirical coefficients are used that establish the proportion between local head losses and length. In practice, the last two calculation options are more often used, which are given as an example in the proposed algorithm. Total head losses within the design section of the system are determined by the sum of local head losses and head losses along the length:

\[ \Delta H_\text{calc} = \Delta H_\text{by length} + (\Delta H_\text{local}^{\text{calc}}, \Delta H_\text{local}^{\text{input data}}), \]

where \( \Delta H_\text{calc} \) is the total head loss for the calculated section of the pipeline of the combined irrigation system; \( \Delta H_\text{by length} \) is the value of the pressure loss along the length for the calculated section; \( \Delta H_\text{local}^{\text{calc}} \) is the estimated value of local pressure losses; \( \Delta H_\text{local}^{\text{input data}} \) is passport value of local pressure losses.

The cumulative values of the head losses determined for the section of the combined irrigation system, preceding and directly including the calculated coordinate, allows you to determine the actual level of water pressure at the point corresponding to this coordinate. The algorithm for solving this problem provides for the procedure of step-by-step subtraction of head losses relative to the coordinate preceding the calculated one:

\[ H_\text{name} = H_{(\text{name}-1)} - \Delta H_\text{calc}^{\text{total}}, \]

where \( H_\text{name} \) is the head value at the point corresponding to the calculated coordinate; \( H_{(\text{name}-1)} \) is the value of the head at the nodal point preceding the calculated coordinate.
This procedure is the last in the body of the cycle of calculations carried out with respect to a given (calculated) coordinate of the combined irrigation system. The values of the head at a given design point, as well as the coordinates of this point, as well as the total water flow for the corresponding cross-section coordinate, at the end of this procedure, are sent to the data array formation unit. At the same time, a new calculation cycle is initiated for the next system coordinate.

The generated data array is a set of character-numeric values that determine the pressure level and water flow rate and identify them with the coordinate name. Data are written to the array sequentially, in accordance with the implemented algorithm for enumerating coordinates.

Data output can be carried out in symbolic or graphic format. The latter implements the possibility of constructing a geo-oriented graph of a combined irrigation system using known coordinates, indicating the levels of pressure and water flow.

4. Conclusion

Studies suggested the algorithm for computer modeling hydraulic parameters of combined irrigation systems. The algorithm implements the principle of statistical screenshots of the hydraulic parameters of the system. Static screens can be performed at any time interval, which makes it possible to assess the dynamics of the process under changing external conditions. The algorithm has built an ingenious system of objects identification, making it possible not only to verify the uniquely defined knots of stems section, but also to organize serial search nodal points in accordance with the architecture of hydro-reclamation system. The proposed algorithm makes it possible to determine the pressure-flow characteristics of a combined irrigation system with known (specified) design parameters for any arbitrary specified section or to perform a full screen of the hydraulic parameters of the system by calculation methods.

References
[1] Gonzalez- Dugo V, Goldhamer D, Zarco-Tejada P J and Fereres E 2015 Improving the precision of irrigation in a pistachio farm using an unmanned airborne thermal system *Irrigation Science* **33**(1) 43-52
[2] Lafond J A, Gumiere S J, Hallema D W, Periard Y, Jutras S and Caron J 2015 Spatial distribution patterns of soil water availability as a tool for precision irrigation management in histosols: characterization and spatial interpolation *Vadose Zone J.* **14**(6) 66-78
[3] Tutum C C, Guber A K, Deb K, Smucker A, Nejadhashemi A P and Kiraz B 2015 An integrated approach involving EMO and hydrus-2d software for SWRT-based precision irrigation *IEEE Congress on Evolutionary Computation* 885-892
[4] Vieira R G, da Cunha AM, Ruiz LB and de Camargo AP 2018 On the design of a long range wsn for precision irrigation *IEEE Sensors J.* **18**(2) 773-780
[5] Rojo F, Kizer E and Upadhyaya S A 2016 Leaf monitoring system for continuous measurement of plant water status to assist in precision irrigation in grape and almond crops *IFAC PapersOnLine* **49**(16) 209-215
[6] Borodychev V V and Lytov M N 2019 Technical and technological foundations for regulating the hydrothermal regime of agrophytocenosis under irrigation conditions *Scientific Life* **14**(10) 1484-1495
[7] Dubenok N N and Mayer A V 2018 Improvement of system of the intra soil fine-streaming irrigation of long-term plantings in the combination aerosol moistening *Proc. of the Nizhevolzhsk Agrouniversity Complex: Science and Higher Professional Education* **51** 269-275
[8] Golovanchikov A B, Dulkin T A, Prokhorenko N A and Merentsov N A 2020 Optimization of technological parameters and diameter of the pipeline, taking into account energy and resource conservation *Transactions of the TSTU* **26**(1) 91-99
[9] Korneev I V and Danilchenko A N 2020 Methods for calculating the pressure loss along the length in irrigation networks pipelines *Scientific Life* **15**(4) 468-481
[10] Golubev V O 2016 Generalized mathematical model of the vapour-liquid stream through pipes and local hydraulic resistance *Math Designer* 1 58-64