

Estimation of Novosibirsk Water Intakes Work Conditions under Daily Regulation of Ob River Flow by Novosibirsk HPP

Alexander SEMCHUKOV¹, Arkadiy ATAVIN¹ and Vladimir DEGTYAREV²

¹Institute for Water and Environmental Problems of the Siberian Branch of Russian Academy of Sciences
Morskoy ave. 2, 630055 Novosibirsk, Russia
email: iwep@ad-sbras.nsc.ru

²Novosibirsk State University of Architecture and Civil Engineering
Leningradskaya st. 113, 630008 Novosibirsk, Russia
email: email@sibstrin.ru

Abstract

Numerical algorithm of high accuracy was developed for simulation of rapidly changing unsteady flow in an open channel of arbitrary shape. The algorithm was applied for the estimation of daily regulation of Ob river flow by Novosibirsk Hydroelectric Power Plant on work of Novosibirsk water intakes situated downstream of it.

1. Introduction

The Novosibirsk Hydroelectric Power Plant has a lowland reservoir with relatively small operating storage. In a low-flow period of a low water year (for example, in winter) the critical water scarcity occurs in the reservoir, and the water level often falls below the dead water level. In that case, HPP has to work under policy of strict economy and spend no more water than it is necessary to cover peak demands for electricity. In other time of day, water discharge is performed according to some very low technical norm. The pronounced unsteady nature of water movement in some periods of time can lead to fall of water levels near water intakes of Novosibirsk below the values regulated by the Reservoir Water Management Rules, even under average daily discharge corresponding to sanitary norm. In that case, the inlets deepening may be not sufficient, and it may lead to air suction and thus breaking of normal work of pumps.
The situation is aggravated by gradual lowering of mean water level downstream Novosibirsk HPP during the period of its exploitation caused by stream channel degradation because of HPP effect and sand and gravel mining from the river bed (Maltcev and Bavsky 2000).

For the purpose of estimation of the influence of daily regulation of Ob river flow by Novosibirsk HPP on work of Novosibirsk water intakes, the numerical algorithm of high accuracy for simulation of rapidly changing unsteady flow in an open channel of arbitrary shape was developed (Semchukov et al. 2003).

2. Governing equations

In Novosibirsk a lot of work on numerical simulation of unsteady flow in open channels was done by the Institute for Hydrodynamics of the Siberian Branch of Russian Academy of Sciences (Vasiliev 1999).

For simulation of unsteady water movement, one-dimensional equations of Saint-Venant are used (Atavin 1975, Stoker 1957):

equation of continuity (mass conservation law)

$$\frac{\partial \omega}{\partial t} + \frac{\partial Q}{\partial x} = q,$$

(1)

dynamic equation (momentum conservation law)

$$\frac{\partial Q}{\partial t} + \frac{\partial}{\partial x} \left( Qv - g \omega \left( \frac{\partial z}{\partial x} + \frac{Q|Q|}{K^2} \right) \right) = 0.$$

(2)

Here \(\omega\) = cross-sectional area, \(m^2\); \(Q\) = discharge, \(m^3/s\); \(z\) = water level, \(m\); \(q\) = distributed water inflow, \(m^2/s\); \(g\) = acceleration of gravity, \(m/s^2\); \(t\) = time, \(s\); \(x\) = coordinate along bed axis (at the line of greatest depth), \(m\); \(v = Q/\omega\) = mean velocity, \(m/s\); \(K\) = conveyance of a bed.

Conveyance \(K\) is defined by the Chezy formula \(K = \omega C \sqrt{R}\), where \(C = 1/n, R^{1/6}\) is the Chezy factor defined by Manning equation, \(m^{1/2}/s\); \(n\) is the roughness factor, \(s/m^{1/3}\); \(R\) is the hydraulic radius, \(m\). For a river we can assume \(R = h\), where \(h = \omega/B\) is the mean depth (\(B\) is a stream width, \(m\)).

It is assumed that the flow is subcritical. In this case one border condition must be given for both inflow and outflow sections of river reach under consideration (Atavin 1975, Rozhdestvensky and Yanenko 1978).

In simulations described below, the water discharge as a function of time is given at the inflow section and a discharge rating curve (dependence of water discharge on water level) is given at the outflow section:
\[
Q(x_0, t) = Q_{in}(t), \quad Q(x_{out}, t) = Q_{out}(z) .
\]

An initial distribution of discharge and water level are given as initial conditions:
\[
Q(x, t_0) = Q_{start}(x), \quad z(x, t_0) = z_{start}(x) .
\]

3. Numerical algorithm

Schematization of river bed is performed in the following way: a certain number of base sections are selected at the considered reach of river bed. These sections are situated in characteristic points of the bed, i.e. in the places of biggest widening and narrowing, biggest and smallest depth and at the ends of considered reach. A few levels are selected at each section and for each level a bed width is found. Then geometric parameters are linearly interpolated along the river: first levels with certain number from the bottom are interpolated and then – bed widths at these levels. If the river has a few branches at a certain distance from the dam, a section is built to cross all branches, widths of branch beds at the same levels are summed up and then the branch beds are considered as a single bed.

To prevent negative numerical effects, associated with a sharp change of bed geometric parameters, the diffusive procedure for smoothing morphometric information was developed (Semchukov et al. 2003).

The roughness factor, defining frictional force, plays a special role among morphometric characteristics of a bed. It is defined for each area between base sections based on bed character (Agroskin et al. 1964) and then can be specified by water level measurements under steady flow. The numerical procedure basing on numerical solution of Saint-Venant equations for steady flow was developed for this purpose.

The explicit two step finite-difference scheme of Lax-Wendroff of second order of accuracy by time and space was used for flow simulation (Lax and Wendroff 1960).

The Saint-Venant equations are solved in ‘discharge–cross-sectional area’ variables \((q - \omega)\), which allows to write the finite-difference scheme in almost divergent (almost conservative) form. Namely, all terms of equations (1-2), except of the term describing work of hydrostatic force, are approximated in divergent form similar to (Ostapenko 1993). Such approach allows obtaining an efficient numerical method, allowing simulation of rapidly changing flow with high precision.

The algorithm based on Saint-Venant equations written in characteristic form (Atavin 1975, Stoker 1957) was developed for numerical realization of border conditions.

The uniform grid was used and the time step was automatically chosen each time to provide stability of the finite difference scheme (the Courant number had to be not greater than 1).
4. Simulation results and conclusion

In this work the 19.4 km long Ob River reach limited by section 200 m downstream Novosibirsk HPP dam, and section of Novosibirsk river gauge situated in the central part of the city, is under consideration. The scheme of this reach is given at Fig. 1. The right-bank and left-bank river intakes situated at 1 km and 12 km distance downstream dam, respectively, were chosen for analysis. Farther they will be designated as intakes № 1 and № 2.

The only noticeable tributary at the considered reach of the Ob River is river Inya, but its discharge and distributed discharge were not taken into account in these simulations because of their relative smallness in the considered period of time.

Fig. 1. Ob river reach under consideration.
The constant discharge $Q$, corresponding to its mean value during the period of simulation, and water level $z$, uniformly decreasing along the river, were given as initial conditions. Then, simulation with constant discharge at the inflow section, corresponding to its initial value, was performed until achievement of steady state (as practice showed, steady state is achieved in a few hours). Then discharge at the inflow section began to change according to its hydrograph.

In Fig. 2 the dotted line (1) displays the simulated profile of water level along river under constant discharge 1300 m$^3$/s under roughness factor values defined by bed character, and solid line (2) – the same profile, but obtained under specified values of roughness factor. Here daggers designate the measured values of water level. The lower solid line designates the bottom level along the line of greatest depths. This figure shows that, as a whole, the used numerical model correctly describes the stream flow under roughness factor values, defined by bed character.

In Fig. 3 the graph of real HPP discharge during March 16-17, 1988, is given. By that date the considered reach is usually free of ice, which justifies usage of the present stream flow model. During the first day of simulation time (corresponding to March 15), the discharge was constant to achieve steady state of stream flow. In

![Fig. 2. Simulated water level profile under constant discharge of 1300 m$^3$/s under initial (1) and specified (2) values of roughness factor.](image)
Fig. 3. HPP discharge graph at March 16-17, 1988.

Fig. 4. The graphs of water level near intakes № 1 (A) and № 2 (B) under such discharge are given. Here the dotted lines designate the inlet levels.

In this case, the normal water level condition of intake № 1 is not provided once a day during 1 hour 10 minutes – 1 hour 40 minutes and at that time the water level falls up to 13-14 cm below the necessary one. The water level at intake № 2 continues to be acceptable, but close to critical. We see that under such graph of discharge, the uninterrupted work of intake № 1 is not provided in spite of the fact that the mean discharge is 918 m³/s, which is more than 2 times bigger than the sanitary norm, and minimum discharge is 276 m³/s, which is also more than the value of 240 m³/s, allowed for daily regulation (the maximum discharge is 2593 m³/s).

The simulations with cyclically changing HPP discharge with 450 m³/s mean value (minimal sanitary discharge for winter conditions) and 12 hours oscillation period were also undertaken. The amplitude of oscillation was 10%, 20% and 50% of the mean value. Already at the 20% discharge oscillation, the normal water level condition of intake № 1 is not provided 2 times a day during 4 hours and at that time the water level falls up to 7-8 cm below the necessary one, and at 50% discharge oscillation, the water level at intake № 2 is critical 2 times a day during 2-3 hours.
The given simulations show the importance of accounting for impact of daily regulation of Novosibirsk HPP discharge on water supply of Novosibirsk and the necessity of additional research on choosing allowable conditions of daily regulation of discharge during winter low-water period.

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References


Rozhdestvensky, B.L., and N.N. Yanenko, 1978, Systems of quasi-linear equations and their application to gas dynamics, Moscow, 687 pp. (in Russian)


Vasiliev, O.F., 1999, Mathematical modeling of hydraulic and hydrologic processes in water bodies and streams (review of works carried out in the Siberian Branch of Russian Academy of Sciences), Vodnye Resursy 5, 600-611 (in Russian).

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