Experience on Hydrologic Substantiation of Projected Reservoirs

A. A. SOKOLOV

State Hydrological Institute, Leningrad, USSR

The control of river discharge by means of reservoirs, some of which are nearly as large as the greatest lakes of the world, has caused a need to develop methods for forecasting (computing) the hydrologic regime of these reservoirs and predicting the environmental changes that they cause. As a result of theoretical, field, and experimental studies carried out in the USSR, United States, England, France, Italy, and other countries, a number of practical recommendations have been made recently on the computation of water, heat, and salt balances; dynamics of the water masses; transformation of shores and bottom; and silting of the projected reservoirs.

At first these recommendations were mainly based on the results of investigations of lakes that had been considered natural analogs of man-made reservoirs. Later, permanent hydrometeorological observatories were established at a number of reservoirs to check the methods of hydrologic computation used for projecting and to supply hydrometeorological information and forecasts for reservoir operation. Such observatories have been established, for example, on all the reservoirs of hydrologic power plants on the Volga, Don, Dnieper, Angara, and other large rivers of the USSR.

The International Symposium on Hydrology of Lakes and Reservoirs at Garda in 1966, organized by the International Association of Scientific Hydrology (IASH) in cooperation with the United Nations Educational, Scientific and Cultural Organization (Unesco), and the Symposium on the World Water Balance at Reading in 1970, organized by Unesco and the World Meteorological Organization (WMO) with the support of IASH, were of great importance for the generalization of methods for computing the hydrologic regime of the projected reservoirs.

Scientific papers presented at these symposiums showed that, though considerable progress has been achieved in the branch of hydrology under study, there are still many gaps in the complicated problem of hydrologic substantiation of newly made reservoirs and more detailed study is required for more accurate computation (forecasts) of the elements of the hydrologic regime. Our knowledge of the problem in question is of special importance for the developing countries that do not have sufficient experience in designing and establishing reservoirs.

WATER BALANCE OF RESERVOIRS

Computation of water balance is one of the major tasks of hydrologic and economic substantiation of projected reservoirs. Computation of water balance for short periods of time (months) is usually made by the following equation:

$$Q_{in} + Q_p - Q_d - Q_e \pm Q_s \pm Q_{ic} = A \qquad (1)$$

where Q_{in} is the surface inflow, Q_p is precipitation on the water surface of the reservoir, Q_d is the discharge through the hydroelectric power plant or the discharge of the river flowing out of the lake, Q_e is evaporation from the water surface and from the surface of the temporarily drained shore zone, Q_s is temporal loss of water due to saturation of the shores, Q_{ic} is temporal loss of water due to ice left on the shores during the decline of the reservoir level, and A is the accumulation in the reservoir.

The reliability and validity of the projected water balance computations depend on the knowledge of the hydrology of the water body and on the development of hydrologic science. If the hydrology of the water body and of the whole country is sufficiently studied, the computation of water balance components of the projected reservoir is not difficult. The methods used for determination of the balance components are shown by a number of authors, such as Z. A. Vikulina (USSR), D. R. Dawdy (United States), H. S. Riggs (United States), J. A. Cole (United Kingdom), Z. Kos and V. Souček (Czechoslovakia), M. Melentijevich (Yugoslavia), S. Dyck and M. Schramm (German Democratic Republic), and others. When the data are insufficient or absent, the computation is very complicated, though appropriate methods are available.

From the great number of problems concerning the computation of water balance of reservoirs, we shall discuss the most important from our point of view. When we compute the water balance of reservoirs and determine their guaranteed water yield during dry periods, it is important to determine long-range variations of water inflow, particularly in arid regions where the variations are great and rather extensive observations are required for reliable evaluation of statistical parameters of variable discharge and inflow. Evaluation of possible grouping of wet and dry years is of great interest. Along with common statistical methods, numerical models of long-term observation series composed by the Monte Carlo method are widely used in computations of water and water economy balances of reservoirs.

One of the important problems is the computation of runoff losses by evaporation from reservoirs. If sufficiently substantiated formulas for the computation of evaporation and field observational data are available, the value of evaporation from the water surface can be estimated with rather high accuracy, provided initial values of vapor pressure differences and meteorological characteristics above the evaporating surface are reliable. On the basis of generalization of the long-term experience obtained in the USSR, standard guidance materials for computing evaporation from a water surface have been developed. Studies on the radiation balance of reservoirs are being carried out to check these guides by the heat balance method. Similar methods for computing evaporation are used in other countries where comprehensive studies on evaporation are also being carried out.

A measuring system for computing evaporation from a water surface for short periods of time is being established. For this purpose, evaporation from Godivelle Lake computed by the method of water and heat balances is being compared with direct measurements (J. Jaquet and L. Mandelbrot, France).

When he was evaluating the accuracy of evaporation computations on the basis of reliable data on all the components of water balance of a reservoir with a capacity of 2 million m^3, P. Dubreuil (France) showed that even under the most favorable conditions, evaporation could be rather accurately estimated for time intervals no shorter than 5 days (in rain periods the interval for reliable estimation increases up to 15 days). A close relationship has been found between direct measurements of evaporation (by level variations of several reservoirs, provided there is no inflow, outflow, and precipitation) and data obtained by floating evaporimeters (G. Girard, France).

The analysis of variability of annual evaporation and influencing factors (G. E. Harbeck, United States) has confirmed previous conclusions and studies made in the USSR; i.e., obtaining valid average annual evaporation values requires a much shorter series of observations than obtaining the same characteristics of precipitation and runoff.

Studies on evaporation by different methods were made on a small lake in the United States (J. Ficke); these methods included accurate records of water balance components and estimation of energy (heat) balance and mass transfer (method of turbulent diffusion). These studies showed that water and heat balances ensure the best results for a considerable period of averaging and for great intensity of evaporation whereas methods based on mass transfer equations are preferable for evaluating evaporation for short periods (and for periods with comparatively small evaporation).

However, computing the water balance of a projected reservoir requires not only the value of evaporation from the water surface of the reservoir but also the runoff losses that are computed by the difference of evaporation from the water surface Z_b and the evaporation from the land area occupied by the reservoir Z_c. An approximate method for computing such losses was presented by the author at the International Symposium on Hydrology of Lakes and Reservoirs at Garda in 1966.

Unfortunately, evaporation from certain types of land areas is not yet sufficiently studied. The present methods give only average values for large territories with various features.

Therefore one of the most important tasks connected with the increase of accuracy in computing the water balance of reservoirs is the improvement of methods for computing evaporation from different types of land areas, particularly from floodplains as well as from reservoirs partly covered by aquatic plants and from parts of the shore periodically drained during the fall of the water stage. In this respect the study of the effect of the aquatic vegetation on evaporation is of interest (V. S. Eisenlohr, United States).

The estimation of underground inflow to a reservoir, as well as filtration and bank storage, is rather complicated; these elements are not sufficiently studied and therefore are often not taken into account in water balance computation. At any rate, underground inflow to reservoirs on the plains, as shown by special studies, is not great, i.e., not more than 1–3% of the surface inflow. Temporary losses by soil saturation in the shore zone are usually computed by the backwater curves and by the difference between water content and porosity of the shore rocks. Their role in the water balance depends on the size of the periodically drained area and the water capacity of the rocks forming the reservoir.

Z. A. Vikulina has shown that subsequent checking and computing of so-called current water balances of existing reservoirs during their operation allowed the conclusion that discrepancies in the monthly balances are, on the average, ±5% and those in the annual balances are 1–3%. In a number of reservoirs for which the components of water balance are computed without sufficient accuracy the discrepancies may be very great, and they may equal ±15–20% in some months and ±5–10% for the year.

Accurate determinations of the mean water level of the reservoir and its morphologically homogeneous parts are of great importance for the increase of accuracy in water balance computations during reservoir planning and are more important during reservoir operation. Accuracy is particularly important if we consider water balance for short periods of time (10 days or 1 day). Computation of water balance with allowable accuracy for diurnal time intervals is a very difficult task at the present level of accuracy of computing water balance components.

COMPUTATION OF WATER AND SALT BALANCE OF RESERVOIRS

The hydrochemical regime of reservoirs is due to annual variability of the volume and chemical composition of inflow (river discharge and local runoff), the volume of precipitation on the water surface, outflow, water use, infiltration, evaporation, and processes of ice formation and ice melting. The following factors have practically no influence on the salt balance of a reservoir: sedimentation and solution of salts as a result of physical, chemical, and biological processes and reactions of exchange and adsorption; salt transfer by wind; and salt losses or gains with changes of the flood zone boundaries.

Practical requirements concerning the salt content in water and the composition of dissolved salts for projected man-made lakes can be met with computations made by the water and salt balance method. Studies on the problem of water and salt balance forecasting for planned reservoirs were made by N. M. Bochkov and P. P. Voronkov (USSR), K. W. Prophet (United States), and others. The estimation of the average mineralization of the reservoir M_a for the definite period n could be made by

$$M_a = M_{e(n-1)} + M_{en}/2 \tag{2}$$

In (2) the average weighted mineralization of water for the end of the estimated period M_e is determined by the following ratio, in which the main components of the water and salt balance for separate periods are presented:

$$M_e = \frac{M_b V_b + M_{if} V_{if} + M_{ic} V_{icm} - M_{ic} V_{icf} - 0.5 M_b V_{of}}{V_b + V_{if} + V_p + V_{icm} - V_{ev} - V_{icf} - 0.5 V_{of}} \tag{3}$$

where M_b and V_b are the mineralization and the volume of water in the reservoir at the beginning of the design period, M_{if} and V_{if} are the average weighted mineralization of the inflow and the volume of inflow, M_{ic} and V_{icf} are the average mineralization of ice and the volume of water lost by ice formation, V_{icm} is the volume of water resulting from melting of ice, V_p is the volume of precipitation on the water surface, V_{of} is the volume of outflow, and V_{ev} is the volume of evaporation. This method produces satisfactory results when the hydrodynamic conditions of the reservoir provide sufficient mixing within the total water mass.

Formula 3 computes the ultimate mineralization of water in the reservoir for a design period M_u, and then formula 2 computes the mean mineralization for any given time interval M_m.

For small reservoirs in which alimentation is contributed by local runoff the duration of design periods (duration of the predominance of interflow, subsurface flow, and groundwater flow in the channels) and the volume of the flow under question are estimated by a hydrograph. The latter is plotted for river reaches located upstream from the backwater zone. The hydrograph separation is made according to a scheme based on the peculiarities of formation of the flow in the basin. Since an intensive interflow coming into the channel results in a sudden rise in the water level, groundwater inflow into the channel practically ceases. Therefore, if the lag time of the interflow for a given basin is known, it is possible to make a graphic estimation of the period of its predominance in the channel and of its volume, respectively. The same method may be used to estimate the volume of subsurface and groundwater flow.

Since it is necessary to take into account the drainage area when man-made lakes are projected, the necessity may arise to establish such lakes without considering some salinization of the water. In such cases the water and salt balance method can be used to estimate the possible increase in mineralization of the projected reservoir and to envisage the removal of highly mineralized water from the reservoir prior to the spring flood if necessary.

If no water removal occurs, the mean weighted mineralization of a man-made lake at the end of the spring flood M_{ls} (mineralization late in spring) should be estimated by the following equation:

$$M_{ls} = \frac{M_b V_b + M_{ss} V_{ss} + M_{ic} V_{icm}}{V_b + V_{ss} + V_{icm}} \quad (4)$$

where M_{ss} and V_{ss} are mean weighted mineralization and the volume of water in the soil and surface water (genetic category), respectively; these serve as the main source of alimentation of lakes and reservoirs during the spring flood. According to (3), mean weighted mineralization of water in a lake or reservoir for subsequent periods (i.e., late in summer and late in winter) may be computed in a similar way by the use of appropriate (for the given period) components of the water and salt balance.

If some portion of spring floodwater is removed from the reservoir, the computation for the end of the total period of filling of the reservoir should be made in two steps. Moreover, it is necessary to take into account only the important components of water and salt balance for a specific time interval. The computation may be made more strictly when the change of water mineralization is taken into account by the exponential curve.

If the spring period results in the water removal of more than twice the reservoir volume late in winter, the reservoir will be 'washed' in such a way (if mixing of different water layers is sufficient) that it will be possible to accept the mineralization of the reservoir at the end of the spring flood as being equal to the mineralization of inflow.

DYNAMIC PHENOMENA

The development of research on waves, currents, and water level fluctuations due to wind effect, as well as the improvement of methods for their computation, has been demanded by a constant increase in the requirements of hydraulic engineering, river transport, flotage, and so on. As a result of the study of wind waves on inland lakes and reservoirs a theoretical background has been developed for the computation of wind waves on the basis of the equation of wave energy balance.

For the substantiation and development of practical methods of computing the wave regime on lakes and reservoirs, field observational data on waves have been collected. The measuring technique has been modified, and methods of observation and data processing have been improved. By citing this improvement, we refer to the creation of mechanical and electrical wave-recording gages, the development of methods for wave stereophotography, and the application of methods of mathematical statistics for data processing.

Summarization of observational data on lakes and reservoirs made it possible for A. P. Braslavskii to develop a method for the computation of wind waves on the basis of data on wind velocity, the length of wave fetch, and the depth of the reservoir. By this method it is possible to compute wave elements all over the water area of the lake or reservoir and to obtain charts (collation maps) of waves for different directions and velocities of wind. The charts, prepared prior to the establishment of reservoirs, are used in operational practice for navigation and flotage.

The most significant difficulties in the research on the mechanism of waves are connected with the lack of reliable methods to fix the processes characterizing this phenomenon. Wave-recording gages used at present make it possible to obtain the characteristics of water level fluctuations at particular points in the lake, and this capability makes possible the calculation of the height and the period of waves of a given frequency after an appropriate processing. But it is impossible to judge the space and time variability of wave distribution.

Until recently, the study of currents in the open part of inland lakes and reservoirs has been usually confined to the evaluation of the general circulation on the basis of indirect indications and sporadic measurements of currents from ships. Such information has been obtained only for a few reservoirs and does not give a complete notion of the character and peculiarities of currents on reservoirs.

More comprehensive information from field observations has been obtained for coastal areas of some reservoirs in connection with the study of sediment transport and shore transformation; but even in this case the amount of information is rather limited. As for the indirect methods of current determination, it is reasonable to mention the dynamic method for the computation of density circulation in deep lakes, which may be considered a modification of the widespread dynamic method relative to seas. This method has been applied for the computation of currents of some large lakes, e.g., Baikal and Ladoga.

Recently, investigations of currents in lakes and reservoirs have been intensively developed for the study of water pollution. Long-term observations of currents in the open parts of lakes and reservoirs by autonomous instruments are being organized, and use of aerial photography for the simultaneous study of currents over a large water area is being enlarged. Observations of currents in the coastal area are being increased as well.

Direct methods of measurement of currents include (1) measurements of direction and velocity of a current at a point from a ship or on an autonomous device by current meters of different types and (2) observations of the trajectory of objects in suspension (floats) over a certain part of the water area. According to which method is used, the observations may embrace more or less of the water area. The lack of an automatic instrument for reliable recording of slow currents is the most substantial hindrance to the development of observations of low-velocity currents that are characteristic of numerous inland reservoirs.

The collection of a great amount of observational data has led to the improvement of methods of data processing. During the last few years, statistical methods of data processing have made it possible to obtain numerical characteristics of prevailing currents in some areas of particular reservoirs, and some attempts have been made to evaluate quantitatively the contribution of individual factors in the total transfer of water masses.

The existing computation methods give only the idea of individual current types, which usually are not observed in a pure form. Such computations for lakes and reservoirs, however, have not yet been widely accepted.

The study of wind effect on water level fluctuations in reservoirs is of particular interest. A. V. Karaushev has developed a method of computation according to wind velocity, direction, and duration.

PROBLEMS OF ICE REGIME OF RESERVOIRS

Theoretical investigations and analysis of observational data on reservoirs located in different climatic zones have been made to obtain quantitative characteristics and to establish general regularities of freezing processes, formation, and breakup of ice cover on the reservoirs, as well as to evaluate the character of ice regime variations on river reaches after the construction of hydraulic structures that cause a backwater effect.

The variety of ice phenomena, dates and duration of freezing, ice cover, and ice breakup are determined by the combination of meteorological and hydrologic conditions, morphometric peculiarities, and the operational regime of the reservoir.

Investigations of freezing processes based on the study of heat balance and water mixing conditions, as well as on the analysis of data on the characteristics, dates, and duration of the freezing period, showed three types of freezing typical of reservoirs. They differ by the intensity and the location of ice formation (on the surface or at a depth), type of ice (surface ice or frazil ice), and the duration of the freezing period (1–3 or 10–15 days).

Methods of computing freezing of reservoirs developed by V. V. Piotrovich, K. I. Rossinski, L. G. Shuliakovski, B. V. Proskuriakov, and R. V. Donchenko (USSR) and Z. Litynska (Poland) make it possible to solve the practical problem of the expected character and duration of freezing by means of a consecutive computation of principal characteristics of freeze-up processes and use of their interrelations.

After the freeze-up a new phase in the regime of a reservoir begins. In this period the ice cover is subject to further development due to the increase of ice thickness caused by crystallization of water at the lower surface of the ice pack, freezing of frazil ice under the ice cover, and congealing of snow saturated with water covering the ice. The intensity of the increase of ice thickness in winter is determined by the changes of heat balance and heat conductivity of the ice cover. On the basis of observational data, characteristics of the intensity of increase of ice thickness in winter have been obtained.

The destruction of ice cover on reservoirs occurs under the influence of heat and dynamic factors. The processes of ice destruction are described in detail by V. V. Piotrovich and B. M. Ginzburg, who have suggested a method for the computation of ice breakup on reservoirs.

The operational regime of a reservoir has a great influence on the formation and breakup of the ice cover. When the reservoir is freezing, increased discharges of hydroelectric power plants demand the acceleration of water mixing and consequently contribute to the increase of the freezing period. The operational regime of hydroelectric power plants located upstream determines the duration and dates of freezing in upstream reaches of corresponding reservoirs.

Because of a considerable lowering of water level in the reservoir, the ice cover is broken, and much of it remains on the shores, islands, and shoals (about 40%). These complex problems have not been properly investigated.

The existing methods of computation of ice regime elements of reservoirs are mainly based on the heat balance method and do not solve the problems of dynamics of ice cover on reservoirs. Special investigations on reservoirs are needed to study ice drift, ice cover deformation, formation of ice jams and ice dams in the backwater zone and in lower pools of hydroelectric power plants, change of radiation, and characteristics of ice during the melting period.

The study of these important problems of ice regime of reservoirs is essential to solve problems on the increase of the navigation period, evaluation of ice load on hydraulic structures, and water intake arrangements.

FORMATION OF SHORES AND BOTTOMS OF RESERVOIRS

The problem of formation of shores and bottoms of man-made lakes has become greatly important from a practical viewpoint during the last 2 decades, particularly in connection with the establishment of large reservoirs on great lowland rivers of the USSR and some other countries. Up to 2 decades ago the process of shoreline formation of man-made lakes had not been observed, and in fact there was no process in nature that could be treated as an analog. Thus there were great difficulties in estimating and forecasting shoreline deformations, which turned out to be many times greater than was expected. Further field observations on a number of reservoirs showed that the shifting of a shoreline consisting of soft ground is very intensive and sometimes may reach 50–100 m/yr. In some cases it may become necessary to move large populated areas and other costly objects situated on the shores of new reservoirs.

A method of estimating (forecasting) shoreline deformation in reservoirs was developed in the USSR and published in 1953. This method avoids large errors that may have serious aftereffects. At first the method was used only for estimating the final stage of shoreline deformation, but later improvement made it possible to estimate shoreline deformation for any time interval.

Laboratory studies of wave transformation in shallow water gave a qualitative scheme of bottom velocities. On the basis of the analysis of this material a theoretical scheme of energy losses in shallow water and the formula of extreme stability of bed sediments were developed. Thus, in particular, it was proved theoretically and confirmed by experiments that energy losses of the wave are caused by bottom filtration capacity rather than by bottom roughness. Using this theoretical basis, N. E. Kondratiev deducted the formula of the profile of a stable shore shoal and the formula for determination of depth near the shoal edge.

The relation between the depth at the outward edge of the shoal H, the wave height h, wavelength index $k = 2\pi/\lambda$, the depth of filtrating layer P, and the size of bed sediment particles d is expressed by the equation

$$h = \frac{2d \sinh kH}{\eta}\left[-\tanh kP \pm \left(\tanh kP + \frac{3.4\eta}{kd \tanh kH}\right)^{1/2}\right] \quad (5)$$

which can be simplified as follows:

$$H = 0.64h \sinh^{-1} 8.1h \quad (6)$$

The stable profile (the final stage) is compared with the initial shore profile (nondeformed) by graphic superposition of these profiles, and the balance between the volume of eroded material and accumulated material is taken into account.

The development of the process in time is described theoretically by the assumption that this process fades asymptotically according to the exponential law. Other methods have been suggested that would allow estimating, with different degrees of accuracy, and forecasting possible deformations of reservoir shores. To check and improve the existing methods, special field investigations are being carried out at present on some reservoirs.

RESERVOIR SILTING

One of the most important aspects of the hydrologic regime of large reservoirs is the sediment regime that depends on erosion, sediment transport, and sedimentation. The main source of sediments in a reservoir is the sediment load of inflowing rivers. In some cases a considerable portion of sediments may result from bank collapse, lateral inflow, and transport by wind.

Sedimentation is caused by the decrease of the transport capacity of the stream along the longitudinal axis of the reservoir, which tends toward 0 in the widest part of the reservoir. The transport capacity decreases with an increase in depth and a decrease in stream velocity.

The regularities of sedimentation in reservoirs are reflected by the equation of balance of the transported sediments. This equation takes into account the sediment income through the inlet cross section, sedimentation, and uplifting of particles due to turbulent exchange processes and bottom eddies. On the basis of this equation an exponential expression of the longitudinal distribution of sediment concentration was obtained. It is most expedient to apply this expression to individual sediment fractions. The value of the total sediment concentration and of the total sedimentation of the fractions is estimated by a summation of the individual fractions.

The equation of the distribution of sediment concentration along the longitudinal axis x of the reservoir and the formula of the transport capacity of the stream are the methodological basis for the computation of reservoir silting. Computation shows what part of sediment is deposited in the reservoir and what part is carried away through the outlet. It is also possible to estimate sediment distribution along the reservoir. For this purpose the computation is carried out for the design reaches into which the reservoir is divided.

The change of the partial sediment concentration for the i fraction of sediments on a reach of the reservoir of Δx length is expressed by the equation

$$S_{i_{end}} = S_{i_{tr}} + (S_{i_{beg}} - S_{i_{tr}}) \cdot \exp\{[-B(u_i + k_i)/Q]\Delta x\} \quad (7)$$

where u_i is the fall velocity of sediment particles of the i fraction; B is the reservoir width; Q is the discharge; k is the parameter of sediments of the i fraction, the value of u_i and the hydraulic characteristics of the stream being taken into account; $S_{i_{beg}}$ and $S_{i_{end}}$ refer to the sediment concentration at the beginning and at the end of the reach, respectively; and $S_{i_{tr}}$ is the partial transport capacity of the stream for the i fraction on the Δx reach.

Detailed estimates of reservoir silting are supplemented by hydraulic computations that account for morphometric changes of the reservoir bed due to silting. Hydraulic computations are based on plotting the curves of the free surface of the reservoir.

Approximate estimates of reservoir silting, as well as practical methods of estimating pond silting, are based on the estimation of the relative capacity of a reservoir expressed by the ratio of reservoir capacity to the volume of annual streamflow. For these methods only the data on long-term average annual sediment discharge are used. The above methods also include extrapolations that allow estimates of reservoir silting by the end of any future year on the basis of the data on reservoir silting by the end of the first year of reservoir operation by means of the exponential equation. The problems of sedimentation and the technique for computation of reservoir silting are described in a number of articles and monographs. One of the first monographs on reservoir silting, published in 1939, was written by G. I. Shamov, who suggested an interesting extrapolation method for the estimation of reservoir silting. Various points related to the same problem are described in the works by S. T. Altunin (1952), V. S. Lapshenkov (1961), I. A. Shneer (1964), and K. I. Rossinski and I. A. Kusmin (1964, USSR); C. W. Farnham, C. E. Beer, H. G. Heinemann, J. W. Roehl, and M. Elliott (1966, United States); J. P. Carbonnel (1966, France); L. Cyberski (1966, Poland); and B. Djordjevic (1966, Yugoslavia). The works by A. V. Karaushev present theoretical methods for the estimation of silting of large (1965) and small (1966) reservoirs based on a general scheme.

The data on sedimentation in a number of reservoirs in India, the United States, and some other countries are given in a 1960 paper by D. V. Goglekar. This work also contains some empirical relations for the estimation of reservoir silting. A guide for the computation of the silting of large and small reservoirs that describes both well-known and new methods has been published in the USSR. The available observational data, though scarce, show the sufficient reliability of the existing computation methods and indicate certain drawbacks at the same time.

In future, various aspects of the problem of reservoir silting should be studied. It is most important to collect field data not only on the total volume of sedimentation but also on sediment distribution over a reservoir as well. It is quite obvious that it is impossible to estimate sediment distribution and the ways of sediment transportation without adequate information and a study of currents. Special attention should be paid to field observations of alongshore sediment transportation during wind waves.

Theoretical work should be aimed at the improvement of the methods for computation of the transport capacity of streams and at the development of the theory of sediment movement under complex conditions of currents. It is very important also to carry out experimental investigations of the parameters of sediments (fall velocity, volumetric weight of sediments, and so on).

The use of electronic computers for the estimation of reservoir silting is very promising. Unfortunately there are several difficulties in this respect, particularly due to multistage schemes of detailed computations of silting.

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