Problems and significance of water balance calculations

Utilization of water resources in the general framework of the economy requires comprehensive analysis and the solution of many problems depends on the availability of data on surface and groundwater regimes. The water resources of an area are determined by complex physiographic processes, so quantitative estimation of these resources and forecasting of changes is inevitably associated with the establishment of patterns of behaviour of the individual components of the water balance. Amongst the numerous interrelated parameters affecting water balance we may distinguish the zonal features of a certain area, which are developed under the influence of global heat and moisture exchange, which determine the main natural patterns of water resources of a given area. Local factors (soils, geology, geomorphology, vegetation, etc.) introduce substantial variations into the general zonal process. They cause the natural differences of the hydrological regime within comparatively small regions. However, in spite of the high stochastic variability of water resources, and considerable differences in the moisture regime over the area, in the long-term, there can still be distinguished typical features and more stabilised characteristics of the moisture content for a certain natural zone. Examples might be: a definite relationship between the input and output components of the water budget; a characteristic combination in the intra-seasonal variation of individual components; patterns of formation and transformation of the water balance elements, etc. In this connection it is always possible to identify these patterns and to study the quantitative characteristics both of individual elements of the water balance and of water resources as a whole.

The methods used to investigate the water budget depend on the aim, but in all cases, practical problems of management of
the hydrological regime are solved by taking into account the natural conditions of formation of input and output components of the water budget of the area. Economic activity mainly consists of distribution of individual components of the water budget in time and in space, in changing the ratios between individual elements over a certain time interval, in rational utilization of water resources and reasonable control of the water regime, etc. All these measures affecting the moisture regime should be appropriate to the natural formation of components of the water budget and to the interrelationship between intake and discharge components.

The possibilities of controlling the hydrological regime for more effective productivity are considerably limited. In the present state of knowledge, many input elements (precipitation, condensation, moisture exchange, etc.) cannot be controlled, and the extent to which the main output component of the water budget (evapotranspiration) can be influenced is determined by solar radiation and moisture regime. The study of the water balance of an area is thus an important hydrological and reclamation activity.

Water balance investigations are of great methodological significance, since in the simultaneous study of all input and output components, and of the laws of transfer and transformation of water over the area, whilst combining the components into a single budget, the accuracy and reliability of results is considerably improved. More accurate evaluation of water resources of an area and its hydrometeorological characteristics gives many scientific activities and practical measures a sounder basis. By studying components of the water balance, the effect of different aspects of economic activity (including water reclamation of waterlogged lands) on the moisture regime and water resources of an area can be more reliably determined and quantitatively estimated. The rational use of water resources and their development requires well-founded water economy budgets that determine available resources for use in a given region and evaluate the possibility of satisfying different national water consumption requirements. In many cases engineering problems are solved on the basis of water budget calculations; hydraulic engineering measures are designed for the regulation of runoff and of the moisture regime and the soil moisture regime of agricultural areas.

Significant results have been obtained in the USSR regarding the components of the water budget of a territory. Water balance methods are used to solve various problems, from small-scale investigations to establish patterns of moisture transfer in different layers of the unsaturated zone and rooting layer of the soil, etc., to water balances of catchments, large basins and regions. The methods used vary according to the aim of the investigation and the problems to be solved, but they are all based on the law of mass conservation.

Short description of papers

The following papers presented in Topic 2 throw light on various problems involved in the investigation, both of individual ele-
ments and of the whole water balance of marsh-ridden areas. Some of the papers discuss results of experimental investigations on the formation of elements of the water budget of bogs and marsh-ridden lands under different natural conditions, some papers give results of extensive investigations into the water and heat balance of swamped forests, while certain papers deal with hydrological investigations concerning elements of the water balance of marsh-ridden lands.

In the paper 'Water regime of the unsaturated zone in drained lands under irrigation' by S F Averianov, Yu N Nikolsky, N P Bunina, A I Uzunyan (USSR) an analysis is made of the water balance of the unsaturated zone of drained peat soils in a bog area in Byelorussia which are periodically moistened by sprinkling. The relationship between elements of the water balance in the unsaturated zone is established on the basis of the designed drainage rate, and the most useful drainage rate is determined.

Experimental data on the components of the water budget of undrained upland and lowland bogs in the forest zone of the European part of the USSR is discussed in the paper 'Water balance of swamps in the forest zone of the European part of the USSR' by L G Bavina (USSR). A comparison is made of the components of the water budget of bogs and adjacent river catchment areas, which has not revealed any significant differences between the long-term mean annual characteristics in water balances. Certain differences in the runoff are found for years with either heavy or light precipitation.

In the paper 'The water balance of lowland areas in northwest coastal regions of the FRG' by R Eggelsmann (FRG) results are given of investigations on the hydrological regime of peat beds in the north-west of the FRG. Characteristics of the water balance components are given and the effects of drainage and development on individual elements of the hydrological regime are determined.

The results of an experimental study of the components of the water balance of swamps in West Siberia drained by plastic drainage, are presented in the paper 'Hydrological regime and water balance of drained lands of the forest zone of West Siberia' by K D Vvedenskaya, I F Rusinov (USSR). The evaporation regime and drainage runoff are presented as tentative qualitative characteristics for the conditions of West Siberia.

The results of detailed investigations of elements of the water and heat balance in swamp forests of Byelorussian Polessie are given in the paper 'The water and heat balance of the forests of Byelorussian Polessie' by O A Belotserkovskaya (BSSR). These investigations are based on simultaneous observations in which the newest remote-control electrical measuring instruments were used. All the components of the radiation regime were studies, as well as those of temperature and moisture distribution along the vertical profile of the active forest layer to the upper limit of the displacement layer in the atmospheric strata nearest the earth and in the rooting zone of the soil. Observations were made of the runoff from afforested catchment areas and of groundwater regimes and precipitation. These observations have made it possible to characterize the heat and water balance of different types of...
forests and to draw conclusions regarding their hydrological role.

In the paper 'Mathematical simulation of runoff from small plots of undrained and drained peat at Glenamoy, Ireland' by J Dooge and R Keane (Ireland) it is suggested that use be made of mathematical models for investigation of the effect of bog drainage on runoff. Schematic models for simulating runoff from peat bogs in Glenamoy are considered, and the model parameters are determined on the basis that this method may be used for forecasting changes in the runoff after peaty areas have been drained.

In the second paper by the same authors entitled 'The effect of initial moisture content on infiltration into peat' the process of infiltration is shown to obey hydrogeological laws in general and conditions of the formation of the soil moisture regime in particular. Parameters entering into the Philip infiltration equation are determined in terms of initial moisture content and hydraulic conductivity of unsaturated peat soil. The moisture content distribution in the unsaturated zone and the process of infiltration in typical cases for different values of initial moisture content are predicted.

Some problems concerned with infiltration of precipitation water are treated in the paper 'A mathematical model of subsurface drainage in heavy soils' by F Feher (Hungary). A method is suggested for reclamation of heavy, periodically overmoistened soils using a system of compound drainage, and the hydraulic parameters of this system are presented. The system of drainage depends on the stage of percolation of precipitation water through the arable layer, on further seepage into mole drains located in the subsurface layer, then on the flow to the drainage ditch through filling filter to the drainage collectors.

In the paper 'Hydrological stability criteria and preservation of bogs and bog/lake systems' by K E Ivanov (USSR) the conditions, possibility of existence and stability of various forms of bog/lake systems are considered from the point of view of adaption of complex organogenous natural formations to changes in the environment, the main components of which are the intake of solar energy and the systems contributing to water recharge. An example is given of computation of the limiting values of morphological coefficients of external and internal drainage of systems depending on climatic factors, which for different latitudes make a limit for areas of steady-state systems when possible internal transformations take place in their structure. In the steady-state regions a rate of drainage may be found that does not cause degradation and decay of the system.

The methods used for investigating swamps and for organization of experimental work, hydrological and hydrophysical observations on swamps are considered in the paper 'Methods employed in the investigation of swamps with fixed stations and mobile surveys' by S M Novikov (USSR). Theoretical principles are discussed on which the methods of investigation are based.

Hydrological characteristics of a large marsh-ridden area are given in the paper entitled 'Distribution of annual natural stream flow in the Polessie lowland' by I M Livshits (BSSR), which presents results of investigations and estimation of natural uniformity of stream flow of the Polessie lowland, where
catchments are generally waterlogged. Characteristics of the natural uniformity of the annual water regime of rivers of the investigated area are established and a particular method for determining parameters of frequency curves and uniformity values are given, both for investigated rivers and for those which are not investigated as yet.

The papers discussed at the Symposium cover only some of the water balance investigations of marsh-ridden areas in the USSR. This report also generalizes on other published methods and results of water balance investigations and their practical application to the reclamation of marsh-ridden lands.

**Methods and results of water budget investigations**

Calculations of the water balance of marsh-ridden areas may be made for various specific purposes, the data required and the method of calculation depending on the problem to be solved.

The main questions whose answers depend on water balance calculations are the following:

1. evaluation of total water resources and determination of possible rates of water consumption in complex use of water resources;
2. evaluation of the role of swamps and marsh-ridden lands as a natural factor in recharging of rivers, in the water balance of river catchment areas and stream flow;
3. evaluation of the effect of drainage and transformation of the water regime of marsh-ridden areas on runoff and moisture regimes, including their effect on the groundwater regime;
4. calculations and forecasting of the moisture regime of the area and moisture reserves in the rooting layer and in the plant nourishment layer on drained lands, to find an optimum drainage and irrigation rate for typical periods of an annual cycle and for years with average, light and heavy precipitation, also, to find sources of water supply and in the design of modern engineering methods of water reclamation;
5. control of the moisture content in drainage and irrigation systems and forecasts of the moisture content depending on expected meteorological conditions;
6. calculation of the moisture content in the surface layers and in the unsaturated zone of peat deposits and of marsh-ridden lands used for peat production and various types of construction, e.g. for roads, laying transport piping, erecting transmission lines, industrial and civil construction.

Calculations of the water balance have to be made for various types of bogs, and marsh-ridden lands with topography, vegetation, structure of peat deposits and, mainly with different rates of water flow and water exchange with the underlying ground and surrounding areas. Therefore, the structure of water balance equations and the values used should correspond to the features of the objects considered and to the solution of the problems stated for every particular case. In view of this it is more convenient to consider methods of calculation, and the data required, separately for each of the above problems.
Depending on the size of the swamps and marsh-ridden areas and the conditions of their formation in river catchment areas, three main types may be distinguished:

1. Units where swamps and marsh-ridden lands are located entirely within the catchment area, and have a concave or level surface sloping towards the beds of the hydrographic network. They are typical terrace or flood-plain type which in the zone of unstable moisture supply are, as a rule, represented by different types of bog facies.

2. Swamp systems that are located entirely within the river catchment area, but have a convex surface, so that the runoff from the swamp first reaches non-marshy parts of the catchment, before passing along the river network to the outlet section.

3. The system of swamps and marsh-ridden lands which are divides for adjacent river catchments.

In each of the above three cases we must distinguish catchments (with their marsh-ridden areas) which are completely drained by the river network from those which are incompletely drained. In the former case stream flow measured at the outlet of the catchment is the total runoff from marsh-ridden and non-marsh-ridden areas of the catchment. In the latter case, part of the runoff from marsh-ridden and non-marsh-ridden areas of the catchment areas is lost in infiltration to underlying deeper strata from which the groundwater flow reaches the river network downstream of the outlet from the catchment.

The latter case is most common and may be expressed as:

\[ x = \beta + y_1 + y_2 + \Delta W \]  
\[ x = \beta + y_{1\beta} + y_{2\beta} + \Delta W_{\beta} \]

where:
- \( x \) is the precipitation;
- \( \beta \) is the evaporation from the whole river catchment area;
- \( y_1 \) is the runoff from the catchment area measured at the outlet;
- \( y_2 \) is the loss to deep, underdrained layers of ground or groundwater recharge;
- \( \Delta W \) is the change in moisture storage in the catchment area;
- \( \beta \) is the evaporation;
- \( y_{1\beta} \) is the runoff;
- \( y_{2\beta} \) is loss to deep aquifers;
- \( \Delta W_{\beta} \) is the change in moisture storage for the marsh-ridden part of the catchment area.

Equations in this form make it possible to solve the problems listed earlier in items 1, 2 and 3, with regard to calculation of the water budget of large regions: individual marshy river basins, territories embracing several river basins, marsh systems of the watershed type and bog systems lying within river basins.
lation is then made on the basis of measurements and determination of individual components of the water budget.

Precipitation is determined on the basis of the observation data of the hydrometeorological network and their treatment in accordance with instructions of the Hydrometeorological Service; the runoff $y_2$ from the catchment area is the discharge measured at the outlet. Direct determination of component $y_2$ of the groundwater exchange for the whole catchment area presents great difficulties. This component must be calculated either as the residual term of the water balance equation, or it must be combined with the value $\Delta W$; the sum $(y_2 + W)$ is also to be found as a residual term of the water balance equation (1). However, as groundwater exchange of marshy, unclosed river basins varies only slightly, it may be found from the balance equation composed for mean annual values, for which the change in moisture is $\Delta W + 0$. Then

$$y_2 = x - y_1 - W$$

(3)

where bars over the terms denote a mean annual value.

With this approach the term $\Delta W$ may be determined separately as a residue of the equation:

$$\Delta W = x - y_1 - W - y_2$$

(4)

In a number of cases, especially for small marshy catchments, the change in moisture storage may be determined directly from groundwater level measurements and the data on moisture reserves in the unsaturated zone for individual physiographic facies composing the catchment area in sections free of bogs and for bog facies (micro-landscapes) in the marshy section. The change in moisture storage in the catchment area in this case should include the change in groundwater volumes and also in volumes of moisture in the unsaturated zone on the non-marshy and marshy parts of the catchment.

Calculation of evapotranspiration from the catchment area presents considerable difficulties. However, a great deal of experimental and theoretical investigations of this component of the water balance have now been made, (Konstantinov, 1968; Romanov, 1962; Shebeko, 1965). It should be noted that little work has been done on investigation of moisture exchange in swamps and marsh-ridden lands with the adjacent areas. This problem should be investigated not only by hydrologists but also by hydrogeologists.

The independent solution of the water balance equation (2) for the marshy part of the catchment area, for which modern methods of calculating its components (worked out for undrained and drained swamps and marshy lands and determined by hydrophysical methods) may be used, facilitates considerably the calculation of the components of the water balance for the catchment area as a whole. In this case we may solve for any pair of values if we have a system of two equations with these components as unknowns.
In addition, when the marsh-ridden region for which the water balance is being calculated or investigated is a river catchment area (for example, in cases of watershed bog systems), the determination of the components of the water balance may be based on the methods in which determination of the stream flow at the outlet by hydrometric means is unnecessary. At the present time a number of hydrophysical methods of determining the stream flow and the water balance of natural (undrained) swamps have been developed. Runoff from bog systems may then be calculated from filtration characteristics of the bog facies, from observation data on the groundwater levels on the bog and water yield coefficients, (Ivanov, 1957; Romanov, 1961), from hydrometeorological relationships from which the level of bog waters may be calculated on the basis of meteorological data, (Anon., 1971; Novikov, 1965), with subsequent use either of the filtration characteristics or of the water yield method.

Evaporation from swamps is currently determined on the basis of a number of proposed methods and relations sufficiently reliable for calculations both of undrained and drained swamps. Calculation of the change in moisture storage is made either on the basis of direct changes in moisture content in the unsaturated zone or changes in the groundwater level, or on the basis of data on changes in the groundwater level and coefficients of water discharge for each layer (for undrained swamps).

The value most difficult to determine is water exchange of peat deposits in bog systems with underlying horizons. This term in the budget is determined either as the residue of the water balance equation or (for undrained swamps) from the relations used for groundwater exchange in accordance with the theory of hydromorphological relations. In this case, knowledge of types of bog facies and form of network of flow-lines obtained from aerial surveys is required to find the initial infiltration in undrained marsh-ridden lands, (Ivanov, 1965; 1967).

For estimates of the water balance a study is required of all the components. Any simplification of equations relating input and output moisture components, made for particular cases, should retain the physical meaning. In determining the unknown element as a residue of the water balance equation, an estimate of errors and reliability of results is essential. Only then can investigations on the water balance have the required scientific and practical value.

Water balance calculations acquire special practical significance in the development of marsh-ridden areas. They are necessary as a basis for reclamation methods, control of the water regime in soil horizons of the unsaturated zone, specification of required runoff in construction projects for drainage and irrigation systems, for forecasting moisture from expected meteorological conditions, and also for estimating changes in hydrological conditions on drained and adjacent areas in the transformation of the moisture regime as a result of water management works, (Anon., 1971; Globus, 1969). In this case wide use is made of the methods and results of calculations based on hydrophysical methods of determination of water balance components and the study of water exchange patterns in the unsaturated zone as a whole and on its
boundaries (earth-soil surface, groundwater level).

Many calculations of moisture movement on drained areas are based on the potential theory of moisture transfer, using the measured potential and physical potential characteristics of the environment, (Globus, 1969; Luikov, 1954, 1969; Nerpin and Chudnovsky, 1967; Rode, 1965; Korchunov, 1960; Afanasik and Finskii, 1970; Afanaskii, 1971). A number of authors have proposed modifications of this method, (Romanov, 1961; 1962; Vorobiev, 1969), based on the determination of capillary potential, which finds application in the case of large-pore media in the zone of complete and partial capillary saturation. These methods of calculation may be used in narrow unsaturated zones when the distribution of capillary moisture is close to equilibrium.

In studying and calculating the soil moisture balance in given layers of soil, including the whole unsaturated zone, the moisture exchange procedure based on the potential theory is mainly used. A particular case of this is the potential movement of groundwater according to Darcy’s law.

Investigations of the components of the water balance using evaporators, lysimeters, and other soil profile monoliths have become widespread in the USSR and elsewhere. Under such circumstances, water balance equations become considerably simplified, since the impermeable walls of the unit eliminate moisture exchange of the monolith with the surrounding layers of soil. In the general case

\[ \zeta + \Delta W - E + d = 0 \]  

where:  
\( \zeta \) is the precipitation on the surface of the monolith;  
\( E \) is the evaporation from the monolith;  
\( \Delta W \) is the increase or decrease in moisture storage in the monolith;  
\( d \) is the discharge outside the monolith or inflow from the outside through special holes.

In solving practical problems of the water budget and water resources of waterlogged marsh-ridden areas, investigations on individual elements of the moisture regime and water balance of large river catchment areas in certain marshy regions is of great importance, since water management includes the comprehensive use of water resources. The results of important investigations along these lines have been published as follows: Voskresenskii, 1962; Bulavk, 1971; Ivanov, 1953; Kostyakov, 1951, 1961a, 1961b; Shebeko, 1965, 1970.

The use of water balance calculations in designing drainage irrigation systems

Waterlogged territories are little studied from a hydrological point of view. The effective use of such territories for agriculture requires a radical transformation of moisture conditions, thus engineering methods of controlling the water regime on such lands are vital.
The main task of reclamation is to ensure the dynamics of moisture reserves, water-air and heat regimes in the rooting layer of the soil within the optimum range and during the whole growing period of the crop instead of permanent superfluous moisture. For this purpose, drainage systems are constructed which remove the surplus water in periods of excess and make up the deficiency in soil moisture during dry periods. The direction and degree of influence on natural conditions of marsh-ridden areas depends on the hydrological regime, hydrological standards are thus the starting point in designing drainage-irrigation systems and estimating the water regime created under their influence. Among such standards may be chosen the conditions of formation and values of input and output elements of the water budget, maximum and minimum values and process parameters of particular categories of runoff, patterns of moisture exchange between the soil and the lower layers of the atmosphere and with the groundwater table. The laws of groundwater migration in the saturation zone have a dominating influence, (Averiyanov, 1956, 1957, 1960; Verigin, 1969; Aleinik and Nasikovskii, 1970; Polubarinova-Kochina, 1969; Vasiliev, 1970; Averiyanov, 1971)

Design of drainage-irrigation systems for marsh-ridden areas is constantly being improved as the science and practice of reclamation develop. In view of the high stochastic variability of factors controlling the moisture regime, the creation of optimum conditions is a complex problem, and dependence on the calculation methods in the planning of reclamation measures is increasing. At the present time the moisture regime is estimated and planned according to the hydrological situation for periods of maximum or fixed discharges on certain dates and for process characteristics of the water balance elements. Such planning makes it possible to forecast in detail the water level in canals and rivers as well as variations of the water table on a drained area and of the moisture storage in the rooting layer on waterlogged lands.

Often moisture conditions of an area are evaluated according to the position of the water table, about which there is ample information. This information is important; the water level is however a derivative of certain combined effects of the water balance elements and the groundwater dynamics, including the reclamation methods. Groundwater levels and levels of water in the drainage network are the outcome of the whole complex of elements of the water balance and the effect of engineering and agronomic measures. Therefore, the forecasting of the water balance requires detailed calculations. In addition, the moisture regime after reclamation measures have been carried out cannot be completely characterized by the water level alone. Reclamation provides for the optimal moisture content in the rooting layer of the soil. In this case detailed calculations are necessary of moisture exchange in the unsaturated zone and at the boundaries of the zone and of water exchange of swamps with the surrounding area, which have to be made on the basis of specific conditions of formation of input and output elements of the water budget. Water balance equations are also used to solve water reclamation problems. The design of a drainage-irrigation network and irrigation regime for agricultural areas should be based on relations
and values of input and output elements in the water balance of the area considered, on moisture transfer in the unsaturated zone, on moisture exchange with groundwater tables and in the atmospheric layer just above the soil. Hydrogeological investigations are also essential for the underground recharge of swamps. When this data is incomplete problems of designing the moisture regime by reclamation measures may be solved only in particular cases or can be solved only partially. In many cases the suggested procedures of water balance calculations remain unfulfilled because initial hydrological, hydrophysical and agrophysical relations and standards have been incompletely studied.

The design of drainage-irrigation systems for swamps and marsh-ridden lands, is, in the USSR, based on data from water balance investigations. Design methods and water balance standards applicable to different regions have been worked out. Their application promotes improvement of water reclamation measures and has the following advantages.

If drainage systems are calculated only for particular extreme discharges in stream cross-sections, the water regime will be characterized for short time intervals only. Hydrological conditions in the network and moisture regime of the area for the main vegetative period remain unknown. The application of water balance calculations makes it possible to complete hydrological calculations in the network of canals and culverts by calculation of the water regime of fields under agricultural crops for the whole vegetative period.

Water balance calculations have made it possible to forecast the moisture regime and to design rationally all necessary reclamation layouts to ensure optimum conditions. In addition to extreme values of hydrological standards, the moisture regime on drained bogs and marsh-ridden lands should be based on process characteristics of input and output elements of the moisture balance, namely, intraseasonal runoff in years with typical moisture content or in calculated years; the precipitation regime, intraseasonal distribution of evapotranspiration by agricultural crops in years in which rainfall is not the same; standard values of moisture exchange in the unsaturated zone; infiltration and underground recharging of swamps and marsh-ridden areas.

As a result of designing drainage-irrigation systems and forecasting the moisture regime on the basis of water balance and hydraulic calculations, we establish with specified frequency the water reserves in the rooting layer of the soil for the years in question, the role of the water table regime in water flows and on fields under agricultural crops, deficiencies in soil moisture in the dry periods and necessary water discharges to provide the minimum allowable drainage rates during periods of excess moisture. These are subsequently used to find and design water sources for irrigation-drainage systems.

Specific methods of designing and estimating the irrigation regime may differ depending on the required accuracy, extent to which the initial data have been studied, features of natural conditions, methods and calculation procedures. Designs may be made for specific areas subject to typical natural conditions.

The general approach to designing irrigation regimes may be
demonstrated by using one of the accepted water balance methods for an evaluation of the level regime on fields under agricultural crops, internal specific discharges and moisture reserve regime in the rooting layer, (Shebeko, 1970).

In calculating the groundwater regime it should be remembered that in warm periods of the year this regime depends on moisture exchange at the soil surface and in the unsaturated zone, on precipitation seepage to the water table, flow of moisture from the water table to higher strata of the soil of the unsaturated zone, drainage by ditches and drains. Calculations are made for the whole unsaturated zone over successive intervals from any initial moment (from the end of the snowmelt, beginning of planting) with known initial conditions. The groundwater level \( H_k \) at the end of the interval will be found from:

\[
H_k = H_{n-1} + \Delta H + \Delta H_2
\]  

where:
- \( H_{n-1} \) is the groundwater level at the beginning of the interval considered, cm;
- \( \Delta H \) is the increase (+) or decrease (-) in the groundwater level under the influence of moisture exchange with the unsaturated zone;
- \( \Delta H_2 \) is the decrease in the groundwater level due to runoff and moisture exchange with adjoining catchments.

Moisture exchange with the unsaturated zone causes either an increase in the groundwater level \( \Delta H \) during precipitation seepage \((C, \text{mm})\) or a decrease \((-\Delta H)\) as a result of percolation of groundwater into the unsaturated zone \((V, \text{mm})\):

\[
\Delta H = C \frac{K}{10}
\]

\[
\Delta H = -V \frac{K}{10}
\]

where: \( K \) is the water rise coefficient.

Infiltration of precipitation to the water table will take place when, according to conditions of input and output, the accumulation of water approaches the maximum equilibrium moisture content (field capacity) \( W_v \) or exceeds it. In this case the difference between the maximum equilibrium moisture content in the unsaturated zone \( W_v \) and the actual moisture reserves \( W_a \) (or the accumulating capacity of this zone \( W_{ak} = W_v - W_a \)) is equal to zero, and as a consequence percolation of water from the groundwater table \( V = 0 \). Calculations are made according to the water balance equation:

\[
C = W_{n-1} + \gamma_n - E + V - W_v \geq 0
\]
If infiltration also takes place with a moisture content less than the maximum equilibrium moisture content $W_v$, when precipitation penetrates through larger pores and cracks but does not saturate the soil critically, then the term $f_2W_v$ is introduced to the equation. This describes infiltration for a moisture content less than $W_v$. Then

$$C = W_{n-1} + \zeta_n - E + V - f_2W_v \geq 0 \quad (10)$$

Here $W_{n-1}$ is the water accumulation in the unsaturated zone at the beginning of the time interval considered, mm; $E$, $\zeta_n$ is the evapotranspiration and absorption of precipitation on the soil surface, mm:

$$\zeta_n = \zeta - \zeta_{nc}$$

$\zeta$ is the rainfall, mm; $\zeta_{nc}$ is the part of the precipitation which is discharged as surface runoff.

From equations (9) and (10) values of $C < 0$ and $C > 0$ may be obtained. The value $C = 0$ must be assumed. When $C < 0$, percolation $V$ occurs. In the general case the value $V$ is found from the following expressions:

$$D - E > V \leq V_{max} \quad (12)$$

where: $V_{max}$ is the maximum possible percolation to the water table for a maximum accumulating capacity of the unsaturated zone and the given groundwater situation.

From such calculations the moisture regime in the unsaturated zone for an area with a given system of ditches and in years of normal precipitation can be characterized in detail. For individual particular cases calculations may be considerably simplified. For example, on developed bogs surface flow during the warm period of the year is zero, and $\zeta_n = \zeta$. Then $f_2 = 1$ may be assumed with a small error.

If, during seasonal variations in levels for certain periods, unfavourable conditions are created with higher water tables, it becomes necessary to discharge excess water to ensure the minimum drainage rate $H_{min}$ for this period. The value of discharge $h_c$, mm for the considered time interval may be calculated from:

$$h_c = (H_{min} - H_k) \frac{10}{K} \quad (13)$$

The value $h_c$ determines the rational arrangement of drains and designed specific discharges which should be provided.

Water balance calculations may be made without calculating.
drainage of groundwater by the designed network of ditches (without calculating $\Delta h_2$). Then the required discharge $h_c$, which is somewhat overestimated, shows the specific discharge rates for the whole network of the drained area. The distribution of the total discharge of drainage systems for a particular season is obtained by adding groundwater flow components or the total lateral inflow.

Separate analysis of the components of the total discharge (internal and lateral inflows) is reasonable for the improvement of hydraulic engineering reclamation methods. The internal specific discharges mainly determine the necessary parameters of the regulating network (drainage), and the total runoff and intermediate inflow make up the design discharges for field canals and the peripheral network.

Water balance calculations for the whole unsaturated zone, as shown above, allow the water storage regime in this zone, the dynamics of groundwater and necessary internal specific discharges from the drained area to be determined provided that the maximum groundwater level is not exceeded. Such characteristics permit the rational designing of drainage systems, a more detailed estimation of conditions for controlling the moisture regime to prevent overmoistening in wet years, or for controlling the groundwater levels in designing additional irrigation by sluices in dry years. But the water regime in the whole unsaturated zone alone does not completely describe the conditions for plants to be supplied with adequate moisture. For this purpose an analysis of moisture storage in the rooting layer is necessary. Moisture stored in the rooting layer on any date during the vegetative period can be determined from the water balance equation for this layer:

$$B = W_{spr} + \sum \Delta W + \sum (\xi + \Pi) - \sum E$$  \hspace{1cm} (14)

where: $W_{spr}$ is the design spring water stored in the rooting layer of initial thickness and at the beginning of the growing period;
$\Delta W$ is the change in water accumulation in the rooting layer with its depth from the previous to the subsequent time interval considered;
$E$ is the evapotranspiration of crops;
$\sum$ is the sum for the time from the beginning of the calculated period to the interval under consideration;
$\xi, \Pi$ are design precipitation and groundwater flow from the lower layers.

The deficit ($d$) or excess ($-d$) of soil moisture in the rooting layer for a certain crop on any date of the warm period is found from the relation with the optimum moisture storage $W_{op}$:

$$d = W_{op} - B$$  \hspace{1cm} (15)

Thus, the water balance calculations for various combinations of input and output element of the water budget for a particular
season characterize in detail the water regime in years with typical moisture conditions. This makes it possible to forecast the moisture regime when designing drainage-irrigation systems and to provide for rational reclamation measures, to use differential approaches to designing individual elements of the drainage network.

Reclamation methods used on marsh-ridden lands and engineering procedures depend on particular natural conditions of the moisture regime, formation of individual components of the water balance, seasonal and yearly distribution and combination of input and output elements and general characteristics of the water resources of the area. The division of the territory into reclamation regions is based on the water balance characteristics, geology of soils and climate. For these purposes results of investigations of the water balance of individual catchments of both small and large rivers, of bog and forest systems are used. Water balance investigations are also applicable for water management designs on redistribution and comprehensive use of water resources.

However, a number of problems have not as yet been sufficiently investigated for the great variety of natural conditions of marsh-ridden areas. This retards considerably the wide introduction of promising water balance methods. These problems are as follows:

1. Inadequate study of patterns of formation and magnitude of the individual water balance components, their interrelations and interdependence.
2. Conditions of water exchange between groundwater and the unsaturated zone, and also between different layers of the soil above the water table for various hydrogeological conditions.
3. Moisture extraction from the rooting layer plants under different soil, botanical and hydrophysical conditions, and for different soil moisture contents.
4. Water exchange of marsh-ridden areas with adjacent catchments, groundwater recharge of swamps and marsh-ridden lands.
5. Patterns of formation of individual components of the runoff from small marsh-ridden and reclaimed catchments, conditions of transformation of the runoff regime and its components, etc.
6. Improvement of investigation methods, development of physical and mathematical simulation procedures, etc.

In view of all these problems, more extensive and profound scientific investigations should be carried out for a better evaluation of water resources of marsh-ridden areas, the components of the water balance, and patterns of its formation for the purpose of adequate transformation of the water regime, finding the most effective engineering methods and construction and the rational use of water.

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