Ainsi la théorie du changement de niveau des lacs avec écoulement est la théorie tectonique-géocratique. Elle se distingue radicalement de la théorie climatique des fluctuations du niveau des lacs-mers sans écoulement et aussi de la théorie climatique-tectonique du changement du niveau de l'océan.

Les conclusions sont exposées dans le tableau IV.

TABLEAU IV

| Océan | Mers-lacs (sans écoulement) | Lacs (avec écoulement) |
|---|---|---|
| 1. Régression géocratique continuelle du niveau. | 1. Changements géocratiques du niveau ne sont pas établis. | 1. Changements géocratiques du niveau |
| 2. Fluctuations hydrocratiques du niveau. Transgressions aux époques chaudes et régressions aux époques froides. | 2. Fluctuations hydrocratiques du niveau. Trangressions aux époques froides et régression aux époques chaudes. | 2. Fluctuations géocratiques du niveau ne sont pas établies. |

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# THE METHODS OF DETERMINING GROUND WATER FLOW TO LAKES WITH SPECIAL REFERENCE TO LAKE LADOGA

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RÉSUMÉ

Dans les recherches sur les lacs, les quantités d'eaux souterraines intervenant dans le bilan des lacs constituent habituellement l'élément restant dans l'équation exprimant ce bilan à long terme. Cette étude présente une méthode de calcul des quantités d'eaux souterraines arrivant aux lacs dans les zones d'échanges notables, directement par des considérations hydrologiques et hydrogéologiques. Ce calcul est fait par l'analyse des conditions naturelles de la formation de décharge des eaux souterraines en procédant à la dissertion des hydrogrammes fluviaux. L'apport des eaux souterraines au lac est obtenu par la somme des modules moyens des apports souterrains (pour de longues périodes), calculés pour des surfaces partielles du bassin du lac en tenant compte des conditions hydrogéologiques pour chacune de ces surfaces partielles. Un exemple de calcul est présenté pour le lac Ladoga.

SUMMARY

In the research on lakes the amount of ground water is usually determinated as the remaining element in the equation of mean long term water balance. This report presents the method of calculating the amount of ground water discharge in the lakes from the zones of intensive water exchange directly by hydrology-hydrogeological facts. Mean long term amount calculation of underground water discharge in water bearing horizons is carried out by the analysis of nature conditions in the formation of ground water discharge as well as genetic dissection of river hydrographs. Ground water discharge into the lake is determined as the sum of products of average modules in the ground water discharge (for long term period), calculated for separate areas of the lake basin taking into consideration the local hydrogeological conditions for the corresponding areas, discharge of which is directed into the lake. The similar research is done for the Ladoga Lake.

The problem of quantitative estimating the amount of ground water flow to large lakes has been studied extremely insufficiently. At the same time the characteristics of ground water flow to natural reservoirs and rivers are of keen interest to hydrologists studying the base flow to streams and reservoirs and making the total water balance of territories as well as to hydrogeologists investigating the conditions of forming the movement and discharge of ground water regionally.

In water-balance studies of lakes, ground water flow is usually determined as the remainder term of the average long-term balance equation which cannot be considered satisfactory. Ground water inflow to a lake exerts considerable influence on the formation of the water balance of a lake as well as on the salt and temperature regime of a lake. Therefore, elucidating the conditions of the generation of ground water flow to a lake and its quantitative estimation is of essential practical value.

The essence of the technique of estimating ground water flow to a lake being proposed amounts to the following. On the basis of an analysis of the natural conditions of ground water flow generation in a lake drainage basin and genetic separation of stream hydrograph components, the average long-term values of ground water flow of principal aquifers are estimated. Ground water inflow to a lake is determined as the sum of the products of average long-term ground water flow modules (the ground water flow module is defined as a volume of ground water flow from a unit of subsurface drainage area in unit time) calculated for individual sites of a lake drainage basin with due regard for local hydrogeological conditions and corresponding areas of these sites, the flow from which directly goes to the lake. Therefore, in estimating ground water flow to a lake from the zone of intensive water exchange it is necessary to solve two problems: (1) to estimate quantitatively the ground water flow to the streams of a lake drainage basin using the complex hydrologo-hydrogeological method of genetic separation of stream hydrographs and (2) to determine the lake drainage basin area, the ground water flow from which directly goes to the lake.

The estimation of ground water flow by the hydrologo-hydrogeological method involves the following: the analysis of the hydrogeological and hydrological features of river watersheds, establishing the nature of the hydraulic connection of ground and surface waters and the regime of ground water flow to streams in different seasons of the year, genetic separation of stream hydrograph and calculation of the main parameters of ground water flow. The theoretical fundamentals of this method are described in detail by B. I. Kudelin (Куделин, 1949; Kudelin, 1958; Куделин, 1960). Therefore, not dwelling upon the procedure of separating the subsurface component of streamflow, it should be stressed that the method of separating stream hydrographs is dependent upon the specific hydrogeological conditions of a certain basin or its part and the character of the hydraulic connection of stream and ground waters governing the dynamics of ground water flow to streams in different seasons of the year. The dynamics of the flow from individual aquifers depends on the conditions of the occurrence and recharge of unconfined ground water and artesian water and the position of discharge areas in relation to the edge of stream water. Different patterns of stream hydrograph separation result from different types of the hydraulic connection of ground and stream waters determining the regime of the ground water flow from aquifers being drained.

As a result of stream hydrograph separation the values of ground water flow to the streams of a lake drainage basin and the main parameters of ground water flow are calculated. Calculation for a long-term period allows the regional characteristics of ground water flow to be obtained from average long-term data.

Then the areas of individual sites of the lake drainage basin are determined, the ground water flow from which directly goes to the lake passing streams. The ground water flow to the lake from the zone of intensive water exchange ($Q_{gr}$, m³/day) is determined from the formula

$$Q_{gr} = 86.4 (M_1F_1 + M_2F_2 + \dots + M_nF_n)$$

where $F_1$, $F_2$,... $F_n$ are the areas (in km²) of individual shore sites, the ground water flow from which directly goes to the lake; $M_1$, $M_2$,... $M_n$ are the average weighted values of average long-term ground water flow modules in litres/sec/km², which correspond to these sites and are calculated by separation of the stream hydrographs of the lake drainage basin and selected with due regard for local hydrogeological conditions.

It is often very difficult to estimate the deep ground water flow from the zone of poor water exchange to the lake. This value can be estimated more accurately by means of hydrogeological calculations of the discharge of deep ground water flow to the lake depression. However, the data required for such calculations are often unavailable. Therefore, the amount of the ground water flow from deep aquifers drained by the lake depression can be characterised as the remainder term of the equation for average long-term water balance of the lake, all other water-balance elements being calculated with high accuracy.

As an example, let us consider the estimation of the ground water flow to Lake Ladoga from the zone of intensive water exchange using hydrologo-hydrogeological data.

The total drainage area of Lake Ladoga amounts to 280,336 km², within the U.S.S.R. 212,556 km². The area of the lake surface with islands is 18,266 km² or 6.5 per cent of the total area of the lake drainage basin, without islands 17,836 km².

The territory of the Ladoga drainage basin is subdivided into three secondary large lake drainage basins: (1) the northern or Saima-Vuoksinskii basin, (2) the eastern or Onega-Svir basin, and (3) the southern or Ilmen-Volkhov basin. The area of the Saima-Vuoksinskii and Onega-Svir basins, comprising the propagation area of the crystalline rocks of the Baltic Shield, is characterised by a considerable ruggedness of the relief which is due to tectonic processes and subsequent glacier activity. A large number of fractures and cracks on the bedrock surface along with the smoothing and accumulating activity of the Quaternary Glaciation have led to formation of a hill-kame landscape. In the numerous depressions stretching largely in the direction of glacier movement (from north-west to south-east), many lakes of different shape formed.

The Ilmen-Volkhov basin is an area where Paleozoic deposits are developed and which noted for a plain relief with a wide occurrence of accumulative forms appeared as a result of fluvial and marine erosion. In the southern part of the Ladoga drainage basin, relief forms produced by the last glaciation are well preserved. Chains of ridges composed of bedrock with a Quaternary cover of small thickness usually trend in north-western, more rarely in latitudinal and north-eastern directions, which coinsides with the prevailing trend of the main geological structures.

In the Ladoga drainage basin there is a great number of lakes of different sizes. In the northern part of the basin, the majority of lakes are of glacial origin and are barrier reservoirs or relief depressions filled with water between morainic ridges and hills. The largest lakes (Ladoga, Onega, Syamozero, etc.) are of tectonic origin. They are situated in depressions formed by faults and have uneven bottoms and considerable depths.

The interaction of tectonic processes and ancient glaciation has led to formation of a peculiar drainage network mainly represented by small river basins. Many rivers in the northern part of the Ladoga drainage basin are streams connecting lakes. The valleys of the largest streams are confined to depressions of formely existing extensive glacial reservoirs. In the northern part of the Ladoga drainage basin a large number of lakes have essential influence on the regime of flow. The degree of lake influence on streamflow depends on the number of lakes and their distribution in stream basins. The lakes of the northern part of the Ladoga drainage basin which are usually situated near stream channels exert considerable controlling influence on the redistribution of flow within the year.

The southern part of the basin is characterised by existence of small lakes which are largely situated on upland and near watershed divides and do not strongly influence streamflow.

The precipitation amount increases from 500 to 700 mm from north to south in the Ladoga drainage basin.

As to the geological structure, the territory of the Ladoga drainage basin is distinctly divided into two sharply different parts. In the northern part, situated within the Baltic Shield, immediately under thin Quaternary deposits Pre-Cambrian rocks are developed which form the crystalline basement of the Eastern European Platform. In the southern part of the basin, the rocks of the crystalline basement are overlain by strata of Paleozoic marine and continental deposits composing the mantle of the Russian Platform.

The hydrogeological conditions of the basin area are greatly varied. In the northern part of the basin, fissure waters of the crystalline basement occur, in the central and southern parts ground waters are mainly confined to carbonate and Paleozoic sandy-clayey deposits. The ground water of Quaternary deposits occur almost everywhere.

The analysis of physico-geographical, geological and hydrogeological features of separate parts of the Ladoga basin shows the basin territory to be heterogeneous as to the conditions of formation of ground water flow to streams. The authors have made a zonation of the whole territory of the Ladoga basin and distinguished seven areas with different formation conditions of ground water flow: the drainage area of the ground water of Archean and Proterozoic rocks and Quaternary deposits (I); the drainage area of the ground water of Quaternary deposits (II); the drainage area of the ground water of the Karelian Series of the Upper Proterozoic and Quaternary deposits (III); the drainage area of the ground water of Ordovician and Quaternary deposits (IV); the drainage area of the ground water of Middle Devonian and Quaternary deposits (V); the drainage area of the ground water of Upper Devonian and Quaternary deposits (VI); the drainage area of the ground water of Carboniferous and Quaternary deposits (VII).

The quantitative ration of the contribution of individual aquifers (or aquifer complexes) to ground water flow is shown on the map in three gradations: "main" contribution (more than 50 per cent of the total discharge of the aquifers being drained), "considerable" contribution (from 50 to 10 per cent) and "poor" contribution (less than 10 per cent). The background hatching corresponds to the age of the aquifer (or aquifer complex) making the "main" contribution to ground water flow. The

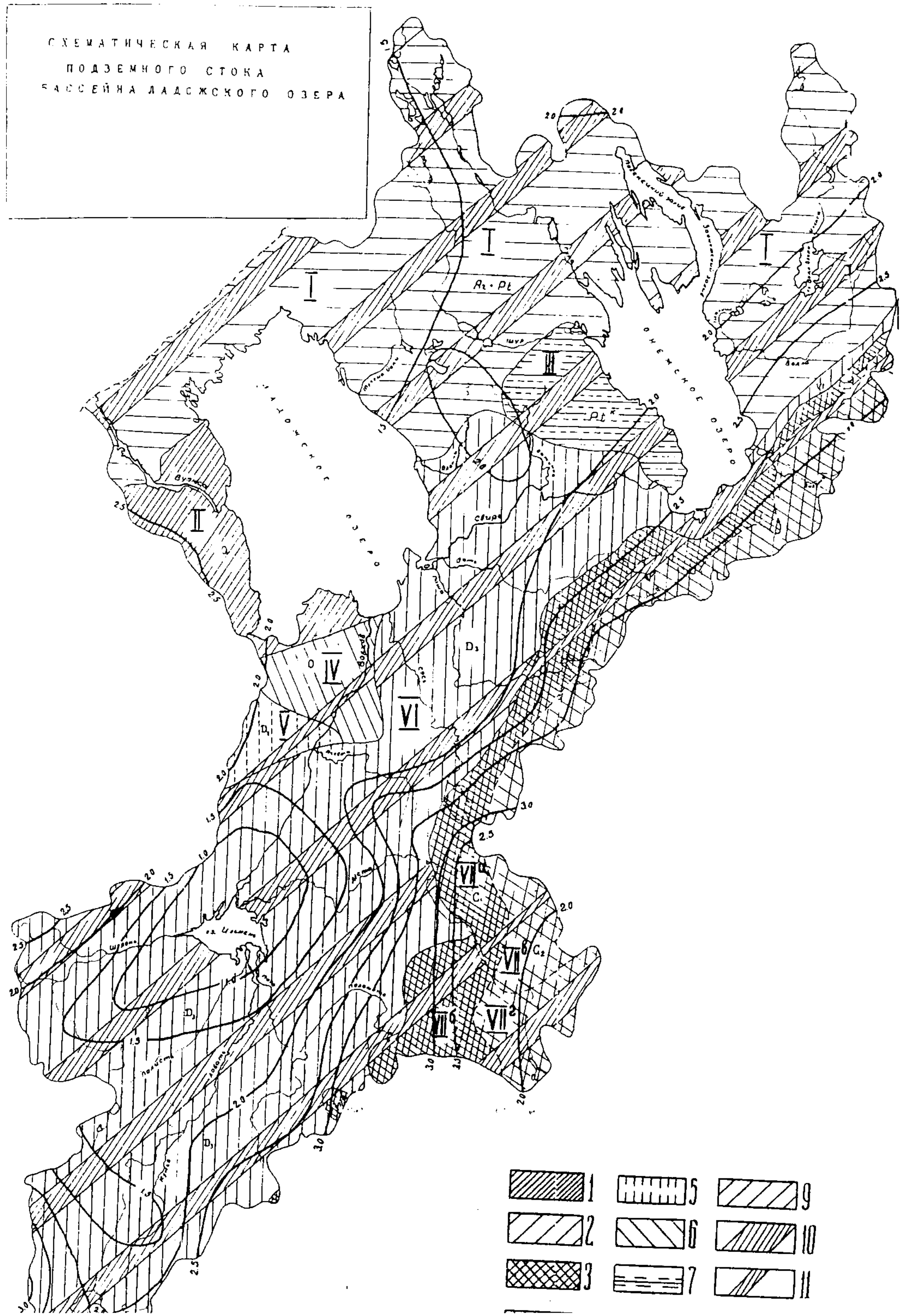


Fig. 1 — Schematic map of ground water flow to the Ladoga drainage basin:
— the drainage of the ground water of (1) Quaternary deposits; (2) Middle Carboniferous deposits; (3) Lower Carboniferous deposits; (4) Upper Devonian deposits; (5) Middle Devonian deposits; (6) Ordovician deposits; (7) the Proterozoic rocks of the Karelian Series; (8) Archean and Proterozoic rocks;
— the ground water flow contribution to streams: main (9); considerable (1); poor (11);
— the isolines of average annual ground water flow in litres/sec/km; (12);
— the boundaries and number of drainage area (a) and drainage subarea (b).

aquifers (or aquifer complexes) "considerably" or "poorly" contributing to the ground water flow to streams are shown by bands of corresponding width.

Within some areas, subareas are distinguished which differ in the degree of the contribution of the ground water of a certain aquifer (or aquifer complex) to stream base flow. For example, in area VI where the "main" contribution to ground water flow is made by waters of Carboniferous deposits, subareas with "poor" and "considerable" ground water flow from Quaternary deposits are distinguished.

For every area or subarea distinguished, the character of the hydraulic connection of ground and surface waters was established and the pattern of hydrograph separation was determined. For calculations long-term streamflow observation data from 6- gauging stations were used. The ground water flow records from the gauging stations with short-term observations (3 to 0 years) were extended by a detailed analysis of the obtained values and by establishing the connection of the ground water flow with the total flow and that of the ground water flow of the point, the short-term records of which were being extended, with the ground water flow of the long-term analogue point. From the normal long-term ground water flow of the selected analogue point the normal long-term ground water flow of the point, the data of which were being extended, was graphically determined. The obtained values were compared with the values analytically adjusted to normal values using the transitional coefficients of the total flow and ground water flow. The gauging stations data observed during periods of -3 years were used as additional information. Thus the ground water flow is characterised by average long-term values.

For the streams of the northern part of the Ladoga drainage basin noted for a large number of lakes, the quantitative estimation of the subsurface component of streamflow was made using the formula

$$M_{gr} = \frac{M_{min}}{3\sqrt{\alpha_1}}$$

where $M_{gr}$ is the ground water flow module in litres/sec/km$^2$; $M_{min}$ is the minimum total average monthly flow module in litres/sec/km$^2$; $\alpha_1$ is the lake occurrence coefficient of the basin in per cent.

The ground water flow to the streams of the Ladoga drainage basin was estimated by the above methods for each of the areas distinguished.
The calculation results are presented in Table I.

TABLE I

| Drainage area | Territory in km$^2$ | Average annual ground water flow in m$^3$/sec | Average ground water flow module in litres/sec/km$^2$ |
|---|---|---|---|
| I | 55,350 | 99.6 | 1.8 |
| II | 6,080 | 14.0 | 2.3 |
| III | 5,760 | 11.5 | 2.0 |
| IV | 3,950 | 7.9 | 2.0 |
| V | 2,000 | 3.8 | 1.9 |
| VI | 82,260 | 172.8 | 2.1 |
| VII | 27,900 | 75.4 | 2.7 |



The total value of ground water flow to the streams and lakes of the Ladoga basin amounts to about 385 m$^3$/sec or 12,140 · 10$^6$ m$^3$/year. The average ground water flow module is equal to 2.1 litres/sec/km$^2$.

The zonation and calculations allow some regularities of the generation of the ground water flow of the zone of intensive water exchange in the Ladoga basin to be revealed. The largest values of the average annual ground water flow module (about 3.0 litres/sec/km$^2$) are typical of the eastern margin of the basin which is a slope of the Valdai Upland and noted for favourable conditions of recharge and drainage of water-saturated Carboniferous rocks. The smallest values of the average annual ground water flow (about 1.0 litre/sec/km$^2$) are observed within the Ilmen Lowland characterised by the shallow erosional entrenchment of the drainage network, considerable surface distribution of morainic loams and lacustine-glacial clays impeding ground water recharge.

The ground water flow for the whole basin equals 10-15 to 30-40 per cent of the total streamflow.

The analysis of the formation conditions of ground water flow and maps of the ground water contours of principal aquifers and other hydrogeological data has shown that the ground water flow to Lake Ladoga goes from the mouth reaches of large streams and the watersheds of small streams which do not fully drain ground water flow. The area of the basin, the ground water flow from which directly goes to Lake Ladoga, is estimated by planimetering using hydrogeological and orographical maps and amounts to about 19,600 km$^2$, it comprises the southern-western part of area I (the average annual ground water flow module is equal to 1.8 litres/sec/km$^2$), the eastern and southern parts of area II (the ground water flow module is equal to 2.3 litres/sec/km$^2$), the northern part of area IV (the ground water flow module is equal to 2.0 litres/sec/km$^2$) and the northern-northern-western margin of area VI (the average ground water flow module is equal to 2.1 litres/sec/km$^2$). The total ground water flow that directly goes to Lake Ladoga from upper aquifer complexes equals 41.1 m$^3$/sec or 1296 · 10$^6$ m$^3$/year. If this value of ground water flow is divided by the surface area of Lake Ladoga, the obtained value is equal to 73 mm.

Thus, the direct water flow to Lake Ladoga is equal to 1296 · 10$^6$ m$^3$/year or about 10.7 per cent of the total ground water flow to the Ladoga basin equalling 12,140 · 10$^6$ m$^3$/year and approximately 10,844 · 10$^6$ m$^3$/year or 89.3 per cent are drained by streams and other lakes of the basin.

After considering the hydrogeological conditions of the Ladoga basin it seems that Lake Ladoga also drains the deep ground water of the zone of poor water exchange mainly confined to the Gdov sands and Lower Cambrian sandstones or to the zones of deep tectonic fractures of Archean and Proterozoic rocks. At the present time, the quantitative estimation of the value of deep ground water flow appears to be impossible due to lack of necessary data. However, the analysis of the general geostructural and hydrogeological conditions of the Ladoga basin as well as the comparison of the chemical composition of deep highly mineralized ground waters and Ladoga waters permits us to suppose that deep ground water flow to the lake constitutes a small portion of the incoming part of the water balance

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# ÉTUDE HYDROLOGIQUE DE LA LAGUNE DE SOMOLINOS (Guadalajara, Espagne)

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RÉSUMÉ

Considerations générales et études sur la geologie karstique qui est à la base de l'alimentation de ce lac.

On a effectué une étude géologique de la zone en vue de chercher à établir les rapports qui existent entre les variations de niveau des eaux du lac et les facteurs météorologiques.

SUMMARY

*Hydrologic study on the somolonos lagoon*

Some considerations and studies about geologie on the karstic zone supplying water to this lagoon.

An geological study of the zone was be done to intend to put in evidence the relationship between water level variation in this lagoon and the meteorologies factors.

## 1. INTRODUCTION

### 1.1. *Situation*

Dans le terme municipal du village de Somolinos à 400 m environ à l'est de la ville près de la route qui va de Atienza à Sepulveda.

### 1.2. *Caractéristiques*

Tectonique.

### 1.3. *Morphométrie*

Son périmètre est à peu près pentagonal avec les cotés apparemment convexes et une apparence circulaire.

La superficie est de 2 ha avec une longueur maximum de 500 m et une profondeur moyenne de 12 m d'eau permanente et un niveau pratiquement constant.

### 1.4. *Biologie*

Elle est habitée par des truches et des canards sauvages.

### 1.5. *Usage*

Principalement l'hydraulique qui produit le saut (10 m) du fleuve Bornova à la sortie de la lagune (petit lac).

### 1.6. *Folklore*

Il y a une tradition qui dit que la lagune n'a pas de fond. Elle se base sûrement sur le caractère abrupt et élevé de ses rivages.