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Title: "VERTICAL ZONALITY OF THE I TRA-A NUAL DRAINAGE DISTRIBUTION IN MOUNTAINOUS REGIONS OF GEORGIA" USSR

L. A. Vladimirov

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VERTICAL ZONALITY OF THE INTRA-ANNUAL DRAINAGE DISTRIBUTION IN MOUNTAINOUS REGIONS OF GEORGIA

Report made at the scientific session of the Tbilisi Geophysical Observatory on 15 May, 1948.

L.A. Vladimirov

Investigations of the intra-annual behavior of rivers in mountainous regions of USSR do not reflect sufficiently the effect of reservoir* height. [*Note: The word "reservoir" may be replaced by "basin" wherever it occurs in the following text.]

Usually the geographically-based portrayal of the intra-annual drainage distribution in mountainous conditions was made in the form of highly schematic isolines of seasonal drainage (1), or in the form of regions with typical annual drainage distribution. The establishment of these regions was based on various factors such as seasonal preponderance of drainage (2), maximum and minimum monthly drainage (3), seasons of maximum and minimum drainage (4), typical monthly drainage distribution (5). [Note: "drainage" is the same as "run-off".]

A common drawback of these subdivisions is their great schematism and the resultant limited possibility of practical application. Characteristics of the intra-annual distribution of drainage in mountainous regions become considerably clearer when they are related to the height of reservoirs(5).

The intra-annual drainage distribution is an integral characteristic of the entire reservoir, probably most dependent upon the average height of the reservoir instead of upon some other hypsometric factor.

The complex topography of the mountainous regions of Georgia, as well as the proximity of the sea, which effects sharp variations in climatic conditions within limited domains, must obviously determine the local interrelationship between annual distribution of drainage and average height of the reservoir.

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We have used calendar seasons to characterize drainage distribution since in mountainous regions it is impossible to distinguish such non-calendar seasons which would account for all types of phenomena encountered at the various altitude zones. At the same time establishment of identical seasons over the entire mountainous region of Georgia is necessary, in order to compare the aqueousness of the various regions.

In view of the non-availability of uniform hydrological observations for the entire territory of Georgia, dependence of seasonal drainage on the average height of reservoir can be studied only in the mountainous regions of Georgia. On the basis of analysis of the physico-geographic conditions and the nature of annual drainage distribution, the relationship between seasonal drainage (There and elsewhere seasonal drainage is expressed as a percentage of annual drainage) and the average height of reservoir evidenced itself in the following mountainous regions of Georgia.

1. Southern slopes of the western Great Caucasus
2. Southern slopes of the central Great Caucasus
3. Northern slopes of the western Great Caucasus
4. Northern slopes of the central Great Caucasus
5. Western part of the South-Georgian highlands
6. Akhalkalak highlands

The average heights of reservoirs are taken from the paper of B. D. Zaykov (5) and supplemented with new data obtained on large and small rivers. The period of observations at the majority of stations used in this study is between seven to ten years. The number of river reservoirs of each separate region, range of their average heights, and range of their areas are given in Table I.

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TABLE I

Name of Region	Number of Reservoirs	Range of Average Heights of Reservoirs, m.	Range of Reservoir [Basins] Areas km²
Southern slopes of the western Great Caucasus	30	880-2080	99-3040
Northern slopes of the western Great Caucasus	10	1700-2700	58-4350
Southern slopes of the central Great Caucasus	10	1455-2265	183-1900
Northern slopes of the central Great Caucasus	14	775-3175	59-1700
Western part of the South-Georgian highlands	7	750-1400	40-1100
Akhalkalak highlands	8	2075-2440	102-2280

In the case of spring and summer drainage in the Great Caucasus regions there is a correlative relationship; in all other instances there was established a graphical relationship.

Equations of direct regression of the spring and summer drainage for average height of reservoir are of the form shown in Table 2.

The most satisfactorily determined relationship (Drawing 1) is that between seasonal drainage and average height of reservoir in the western part of the southern slopes of the Great Caucasus (in order to save space, this article cites only a small portion of compiled graphical relationships). This is due to a large number of observation points; adequate length of observation; and, to what is especially significant, a large vertical gradient of seasonal drainage.

A sufficiently distinct relationship was determined in both regions of the northern slopes of the Great Caucasus and in the western part of the South-Georgian highlands.

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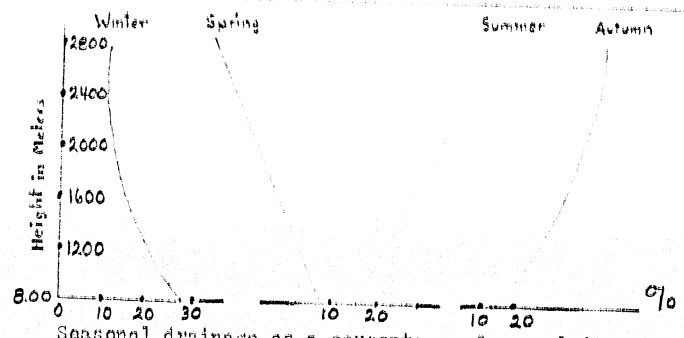
Considerably less satisfactory results were obtained in the eastern part of the southern slope of the Great Caucasus (with the exception of the spring season), evidently because of the small number of observation points and unequal lengths of observations.

In the Akhalkalak highlands, where the rivers are fed liberally by subterranean and lake waters, the relationship between seasonal drainages and the average height of reservoir is either barely pronounced or non-existent, which is to be expected. Only during spring seasons, when rivers are fed predominantly by surface water sources, does this relationship become pronounced.

In this short article, which represents a condensation of a more detailed paper, we cannot stop to analyse the reasons for deviations of the various points. Let us observe that all instances of deviation (excepting those determined by asynchronous observations of short duration) are explained satisfactorily by the physico-geographic peculiarities of the separate river reservoirs; that is, river basins.



Drawing 1. Graph of relationship between seasonal drainage and average height of river reservoir of the southern slope of the western Great Caucasus. [Note: Refer to the original document for an accurate figure.]

In order to compare seasonal drainage distributions of the various mountainous regions, graphs of such distributions versus average height of reservoir are shown in Table 2.

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TABLE 2

Name of Region	Season	Regression Equation	Correlation coefficient	% Error
Southern slope of the western Great Caucasus	spring	$S_B\% = -0.0160 H_{cp} + 62$	-0.94	±5
	summer	$S_{\Pi}\% = 0.0233 H_{cp} - 5$	0.96	±3
Northern slope of the western Great Caucasus	spring	$S_B\% = -0.0100 H_{cp} + 42.8$	-0.68	±1.9
	summer	$S_{\Pi}\% = 0.0102 H_{cp} - 33.4$	0.85	±2.2
Southern slope of the central Great Caucasus	spring	$S_B\% = -0.0210 H_{cp} + 80.7$	-0.87	±3.4
	summer	$S_{\Pi}\% = 0.0178 H_{cp} - 3$	0.80	±3.9
Northern slope of the central Great Caucasus	spring	$S_B\% = -0.0335 H_{cp} + 39.2$	-0.92	±3.3
	summer	$S_{\Pi}\% = 0.0111 H_{cp} + 26.4$	0.95	±2.7

[Note: S_B stands for S_{spring}; S_{Π}: S_{summer}. H_{cp} stands for H_{mean}.]

Winter drainage in the highest regions along both slopes of the Great Caucasus is approximately the same percentage (4-6 percent) of annual drainage. At lower heights, along the southern slope, there is a sharp increase in winter drainage, which is explained by the considerable vertical gradient of winter temperature; along the northern slope, on the other hand, there is observed a constant value, independent of reservoir height, of winter drainage, which is in good agreement with the negligible winter temperature gradient along that slope -- a slope which is the coldest part of the Great Caucasus within Georgia. Winter drainage in the upper zones (higher than 1600-1800 meters) of the central Great Caucasus (in Georgia) represents a considerable portion, compared with the western region, of the annual drainage: 8-10 percent. For a smaller annual drainage in this part of the Great Caucasus, as compared with the western part, the relative magnitude of the ground water component of river drainage is greater in this case. Winter drainage is also greater along the warmer southern slope of the central Great Caucasus than along the northern slope.

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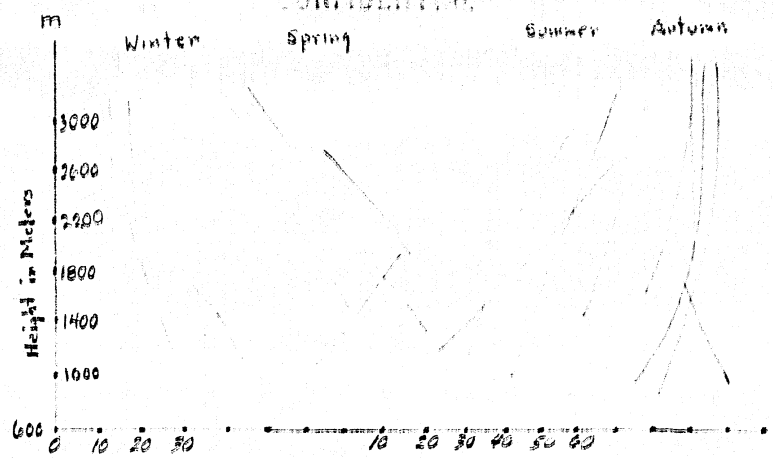

Seasonal drainage as a percentage of annual drainage.

Drawing 2. Superimposed graphs of relationships between seasonal drainage and the average height of reservoir.

—— Southern slope of the western Great Caucasus

···— Southern slope of the central Great Caucasus

-·-- Northern slope of the western Great Caucasus

--- Northern slope of the central Great Caucasus

-·-·- Western part of the South-Georgian highlands

[Note: Refer to the original document for an accurate figure.]

Below 1600-1800 meters, highest winter drainage is observed along the southern slope of the western Great Caucasus where an abundance of autumn precipitation, comparatively warm climate, and the regulating role of dense forest vegetation determine a relatively large winter drainage; this, for reservoirs averaging 1000 meters in height, comprises more than 20 percent of annual drainage. Even more considerable winter drainage (about 29 percent of the annual value) is observed at the same height along the warm, well-forested part of the South-Georgian highlands.

Spring drainage along the great Caucasus from reservoirs of average height in the order of 3,000 meters, independent of slope exposure and distance from sea, varies slightly: from 11.5 to 13 percent of annual drainage. With the decrease of the average reservoir height over the colder northern slope there is observed a comparatively

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slow increase in spring drainage, which at the height of 1,000 meters amounts to 30 percent of theannual value. Along the southern slope there is a faster increase of spring drainage as the reservoir height becomes lower. It amounts to 45 percent of the annual value in the western parts at the height of 1000 meters, and to about 50 percent of annual drainage in the central part at the height of 1,500 meters. Copious spring drainage along the southern slope is explained by an earlier, compared with the northern slope, commencement of thaw, and also by the abundance of winter precipitation in the western part and spring precipitation in the central part.

Reverse phenomena are observed in the western part of the South-Georgian highlands: spring drainage is increased with height, which is accompanied by a sharp increase, with height, of the quantity of spring precipitation and a comparatively short period of snow accumulation in lower zones.

During summer, at the height of 3,000 meters, largest drainage (up to 65 percent of the annual value) is observed in the western part of the Great Caucasus, which abounds in glaciers and snowfields; there the constant snow line is lower than in the central part.

In the central part of the Great Caucasus along its northern slope, at the height of 3,000 meters, summer drainage does not exceed 60 percent of its annual value; and along the southern slope, where rivers receive a negligible amount of glacier waters, it does not exceed 50 percent.

As the reservoir height is lowered, there is a rapid decrease in summer drainage along the southern slope; in the western part at the height of 1,500 meters this drainage amounts to 30 percent, and at 1,000 meters to only 18 percent. An equally sharp decrease in summer drainage is observed in the central part of the southern slope, where the second half of summer has little precipitation, the absolute

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amount of summer precipitation decreasing with height, being smaller than the amount of spring precipitation.

Along the northern slope of the Great Caucasus a cooler summer and its attendant maximum of precipitation determine the slow decrease in summer drainage, which at the height of 1,000 meters becomes 35-40 percent of annual drainage. In the western part of the South-Georgian highlands there is observed a slight increase of summer drainage with height. There is a decrease with height of the absolute as well as relative amount of summer precipitation; simultaneously, however, due to the increased steepness of the slope, evaporation losses are decreased. Moreover, at the upper zone reservoirs in the beginning of summer, rivers still receive thaw waters. [Note: reservoir = basin]

Autumn drainage of the Great Caucasus rivers is distinguished by its least spatial variation. In upper zones it constitutes 15-20 percent of annual drainage. As the reservoir height becomes lower, there is hardly any change in drainage along the northern slope, it is 15 percent of annual value in the western part of the southern slope, and less than that in the central part.

The large relative magnitude, as compared with that along the southern slope, of autumn drainage in lower zones of the northern slope is determined by the abundance of summer precipitation, a portion of which, once having saturated the top soil, continues to feed rivers quite copiously during autumn. Along the southern slope, especially in its central part , the second half of summer is comparatively dry, which causes a decrease of autumn drainage in lower zones; the rivers of the upper zones continue being fed in autumn by thawing glaciers and snow fields.

In the western part of the South-Georgian highlands, at lower reservoirs, autumn drainage constitutes about 27 percent of the annual

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value; as the reservoir height increases, autumn drainage decreases by as much as 20 percent, since in upper zones part of autumn precipitation is in the form of snow.

Percentage distribution of annual drainage for five mountainous regions of Georgia is given according to season in tables 3, 4, and 5.

These tables contain seasonal drainage characteristics determined over extensive mountainous regions, in view of which there is observed a considerable discrepancy in the relative values of drainage of the western and central parts of the southern slope of the Great Caucasus. An almost analogous distribution of drainage is obtained for both mountainous regions of the southern slope, if we displace the vertical zones of the central par downward by approximately 500 meters.

TABLE 3

Average height of reservoir (m)	Southern slope of western Great Caucasus				Northern slope of western Great Caucasus			
	DRAINAGE DISTRIBUTION IN %							
	WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
3000	4	13	63	20	5.5	11.5	64	19
2500	5.5	22	52.5	20	5.5	17.5	58	19
2000	8	30	42	20	5.5	22.5	53	19
1500	13	38	30	19	5.5	26.5	49	19
1000	20.5	46	18	15.5				

TABLE 4

Average height of reservoir (m)	Southern slope of central Great Caucasus				Northern slope of central Great Caucasus			
	DRAINAGE DISTRIBUTION IN %							
	WINTER	SPRING	SUMMER	AUTUMN	WINTER	SPRING	SUMMER	AUTUMN
3000	—	—	—	—	8.5	12.5	58	21
2500	10	28.5	42.5	19	9	17	53	21
2000	11	39	33	17	9.5	21.5	48	21
1500	12	49	24	15	11.5	26	42	20.5
1000	—	—	—	—	14	30.5	36.5	19

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TABLE 5

Western part of the South Georgian highlands

Average hei ht of reservoir (m)	DRAINAGE DISTRIBUTION IN % WINTER	SPRING	SUMMER	AUTUMN
1500	14	43	24	19
1000	23.5	33	19.5	24
800	27	29	18	26

The above tables and the superimposed graphs allow us to compare seasonal drainage distributions in various regions.

On the basis of graphs of seasonal drainage versus average height of reservoir it is possible to chart a sufficiently detailed map of isolines of seasonal drainage, as well as to determine seasonal drainage distribution for a non-investigated reservoir.

Also, we have investigated up to the present the relationship between the average monthly drainage over a long period (expressed as a percentage of annual drainage) and the average height of reservoir only along the southern slope of the western Great Caucasus.

These graphs of monthly drainage versus average height of reservoir were prepared separately for the western (from Kzymba to Gumista) and eastern (from Kodori to Pioni) regions.

For the western region this relationship is based on seven river reservoirs averaging between 1370 to 1930 meters in height (drawing 3), and for the eastern region it is based on the data of 20 river reservoirs with an average height of 1465 to 2660 meters. (Graph is given for the western region only.)

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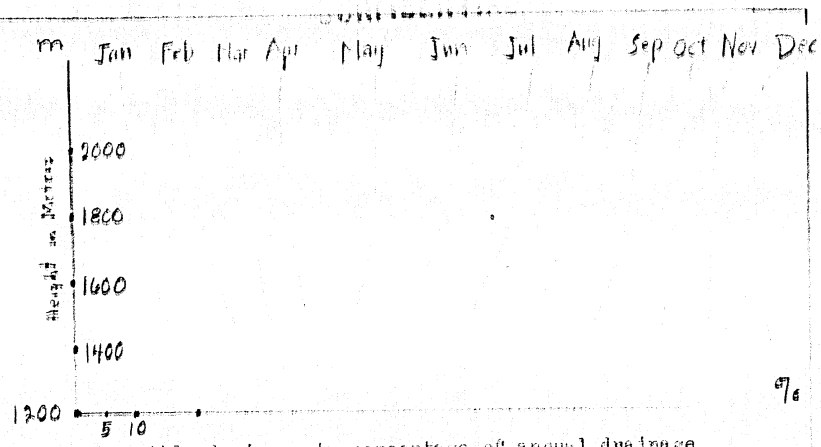

Monthly drainage in percentage of annual drainage

Drawing 3. Graph of relationship between monthly drainage and the average height of river reservoir in the western region along the western part of the southern slope of the Great Caucasus.

[Note: See original document for an accurate figure.]

In the western region, in zones below 1800 meters, the January and February drainage increases considerably with the decrease in reservoir height, due to thaws. An analogous phenomenon is observed in November and December. In March, and to a large degree in April, thaw spreads to low altitude reservoirs, where, in the main, there is observed increased drainage. In May, thaw takes place in reservoirs of greater height, monthly drainage reaching a relative maximum in reservoirs of average height in the order of 1800 meters. In June through August there is a constant increase in drainage with height (within the limits of the studied average height of reservoirs, of the western region); the rate of drainage increase with height, diminishes between June and August due to the exhaustion of snow reserves. In September and October constancy of monthly drainage independent of average reservoir height is observed; its magnitude is determined by the topsoil water supply and rains.

In the eastern region the nature of the graph is in general analogous to that of the western region; however, the eastern region has reservoirs of greater heights, and at the height of 2000-2600 meters, therefore, there takes place a decrease in June drainage with

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height and an increase during July and August.

A rather considerable increase in monthly drainage with height is observed in September for reservoirs not exceeding an average height of 2000 meters. Generally more uniform increases and decreases of monthly drainages are observed in the eastern region.

Table 6 gives percentagewise monthly drainage distributions for both regions.

TABLE 6

Average Height of Reservoir (m)	Monthly Drainage in % of Annual Drainage I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
Western region of the southern slope of the western Great Caucasus												
2000	2	2	3	10.5	20	18.5	14	8	5	8	5.5	4.
1800	3.5	2	5	11	21	17.5	12	7	5	7	6	4
1500	4	4	6.5	12.5	19	14	9	5.5	5	7	6.5	6
1370	5	6	9.5	14.5	17	11.5	7	4.5	5	7	7	6.5
Eastern region of the southern slope of the western Great Caucasus												
2500	1.5	1.5	2	5	14.5	15	21	13	10.5	6.5	3.5	2.5
2000	2	2	3.5	9.5	16	17	15	11.5	6.5	7	5	4
1500	3.5	4	8	14.5	16	14	9.5	5.5	5.5	6	6	6

[Note: "I" stands for January, etc.]

The annual course of precipitation in both mountainous regions is characterized by a rather uniform seasonal and monthly distribution. As we go eastward the amount of winter precipitation is somewhat decreased; however, everywhere within the limit of the mountainous zone along the southern slope of the western Great Caucasus, it amounts to

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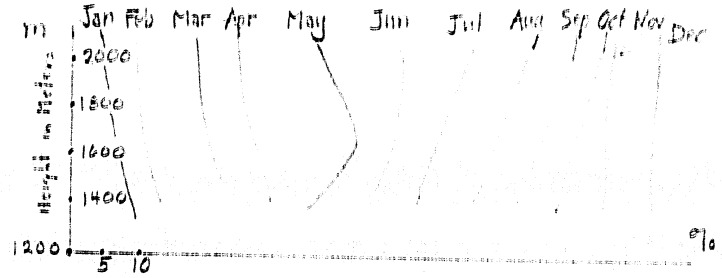
more than 20 percent of annual drainage. Consequently, the difference in the intra-annual drainage distribution in these regions is determined primarily by the differences in temperature and topography of each region.

We have investigated the possibility of establishing a relationship between the average reservoir height and monthly drainage (as a percentage of annual drainage) for a given year in the western region along the southern slope of the western Great Caucasus.



Monthly drainage as a percentage of annual drainage.

Drawing 4. Graph of monthly drainage for 1935 versus average height of river reservoir in the western region of the southern slope of the western Great Caucasus. [Note: See original document for accurate figure.]

The graphs of Drawing 4 illustrate rather convincingly the relationship between the average height of reservoir and monthly drainage for 1935 (an arbitrary year for which data is available for six reservoirs of the region)

Percentagewise monthly distribution of annual drainage for 1935 on the basis of the graphs is given in table 7.

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TABLE 7

Average Height of Reservoir (m)	Monthly Drainage in % of Annual Drainage I	II	III	IV	V	VI	VII	VIII	IX	X	XI	XII
2000	1.5	3.5	5	9	24	23	13.5	0.5	4	4	2.5	3
1800	3	4	5	12	20.5	19	11	8	4	4	2.5	3
1500	5	7	8	15.5	24.5	15	7	4.5	3.5	3.5	2.5	3.5
1370	7	12	11.5	17.5	20	9.5	5	3	2.5	3.5	3.5	4.5

[Note: "I" stands for January, etc.]

From the relationship between monthly drainage over a year and the average height of reservoir, taken in conjunction with the relationship between the average annual drainage and the height of reservoir, there follow most rational methods of restoration of monthly drainages (in the absence of observations at hydrological stations), as well as determination of the intra-annual drainage distribution for an uninvestigated river during a given year.

Further studies of the intra-annual distribution of drainage in the mountainous regions of Georgia, and evaluation of recently accumulated data by the hydro-meteorological department of the government of Georgia will permit the inclusion of a greater number of mountainous regions, as well as increase the accuracy of results of this study through the utilization of data pertaining to local relationships.

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E N D

Abbreviations:

NIU : Scientific-Research Institution.
GUGMS : Main Administration of the Hydrometeorological Service.
GGI : State Hydrological Institute.
AN : Academy of Sciences.

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