# SURFACE WATER RUNOFF

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## Summary

Surface runoff, in a wide sense, is a natural phenomenon of free water movement within a land under the influence of gravity forces, which by all means sooner or later, appears in river channels and only in insignificant quantities directly flows into a sea. Runoff generation is a main process of the land part of hydrological cycle consisting of a lot of partial processes taking place in natural formations called river basins. Among the objects usually distinguished within basins, participating in formation of runoff and water accumulation and consumption are water divides, slopes with vegetation cover

and stratum of soil and weathered rocks, runoff elements, rivers and dry washes, lakes, bogs, glaciers and icings. The traditional division of the kinds of river feeding into pluvial, snow, glacier and underground is indefinite and incorrect. The idea of dismemberment of hydrographs by these kinds may provide some understanding of the runoff regime but is not admissible in the depth of rigor.

The physics of runoff generation processes in any place of land is the same, however the conditions in which these processes take place are extremely diverse. The spatial peculiarities of runoff generation are naturally considered in different scales - micro, meso, macro, mega and global. Natural phenomena accompanying runoff existence are numerous - erosion, inundations, outburst floods, debris flows, landslides, snow avalanches, contamination, etc.

The average annual water balance of the land of our planet is as follows: precipitation 760, evaporation 460, runoff 300 mm. The average perennial runoff modulus of world land is 10 l $s^{-1}km^{2}$.

Global hydrological observation network has nearly 64 000 stations. The most important type of water resources - renewable ones - is determined by the value of average annual runoff. Anthropogenic impact on runoff is exceptional by its negative consequences.

Runoff study is a basic and meaningful part of hydrology, the science of study of natural processes and phenomena on the Earth's land occurring with water, in water or with the participation of water. Hydrology of the new generation is basically connected with the prospects of earth modeling of runoff processes.

## 1. Introduction

Runoff is a natural phenomenon of free water movement within land under the influence of gravitational forces. Runoff is an indispensable element of the hydrological cycle and most important for human life.

The term "surface runoff" is unfortunately unequivocal. However, one should consider a dictionary of technical terms in hydrology, therefore, to avoid any discrepancy and discontinuity of the definition system of various types of runoff there are separate specifications and additions below. In a narrow sense "surface runoff" is a kind of runoff determined by the conditions of its formation. And in a wide sense it is all the water having got to the surface of land, non-evaporated and hasn't been taken from the cycle as a result of some natural or anthropogenic processes and under the influence of gravitational forces sooner or later having reached the world ocean or central water reservoir of an area without drain. Besides, the ways of its movement are not limited only by land surface at all. But there is one as important as formal condition: before getting into the ocean this water should appear at the surface of a land. Then "underground runoff" should be divided into underground river runoff (underground feeding of rivers) and underground sea runoff which leaks (flows out) directly into the sea below its level.

Surface runoff in a wide sense is almost a synonym to the term “river runoff”. But the latter doesn’t include non-channel runoff from the territory directly contiguous to a sea shore.

## 2. The Nature of the Phenomenon

### 2.1. Hydrological Cycle

“All the rivers flow into a sea but the sea is not overflown: rivers return to that place whence they flow in order to flow again”. These Ekkleziast’s words may be the first formulation of the hydrological cycle essence (see *Hydrological Cycle*).

Land and ocean existence and the flow of solar energy coming into the Earth predetermines planetary water circulation in the system of three classical geospheres - hydrosphere, atmosphere and lithosphere. The interaction of these three spheres created the conditions for the course of life on the Earth. There is no more important, grandiose and comprehensive phenomenon on this planet than water circulation. The ground part of this circulation finds its reflection in everything that happens on the surface and under the surface of the land: rivers flow, lakes lap, soil moisture feeds roots of plants, plants themselves grow and feed the animal kingdom and humanity, underground waters search their secret ways to rivers and seas, dissolve limestone and dolomites creating the magic world of karst caves...

### 2.2. Runoff Generation Process

Runoff generation is the main process of the ground part of the hydrological cycle (see *Runoff Generation and Storage in Watershed*). It is a complicated multi-factor process consisting of a large number of partial processes, localized within river basins. By the process of runoff generation one understands not only appearance of free and, therefore, able to flow down water but also its temporary accumulation and the following yield being called natural runoff regulation.

The main partial processes forming in the complex of the whole process of runoff generation are the following:

- Precipitation over the watershed surface and its partial interception by vegetation cover.
- Snow cover formation if precipitation is solid.
- Thermal energy dynamics in snow cover, its melting, water yield and destruction.
- Processes of infiltration and surface runoff generation if rain intensity or water yield from snow cover and hydro-physical soil properties allow that.
- Depression storage of a part of surface runoff in hollows of microrelief without drain.
- Surface runoff transformation by runoff elements.
- Dynamics of soil waters, their phase transformations, detention of part of water in suspended condition and its expenditure for evaporation and transpiration, soil and underground runoff generation.

- Soil and underground runoff and its transformation by runoff elements of various layers.
- Channel lag and channel runoff transformation.
- Runoff in the point of concentration as a result of interaction of all partial processes of runoff generation.

## 2.3. River Basin

River basin is a part of the surface layer of lithosphere

- formed as a natural united whole in the process of functioning of the surface part of hydrological cycle for a long enough period of geological time and, therefore, inherited from the climatic conditions of the past;
- connected with the system of relief forms and limited by divide line;
- including layer of weathered rocks and soil-vegetation cover;
- having own hydrographic network including river network and developed ways of surface and underground flowing down into it;
- limited by a mouth of the main river or any other point situated upstream (point of concentration).

The main characteristic of a basin is its area. For indication of sizes of river basins definitions - large, medium and small are widely used. Figures met in literature (such as the area of small basins is 2000 $km^2$ and smaller) are baseless and incomprehensible. One can't avoid conventions but can use some sufficiently logical public agreement, for instance:

- small basins are measured by ones, tens and hundred square kilometers;
- medium basins - by thousand and tens of thousand;
- large basins - by hundred thousand and million.

All the land consists of river basins of the widely varying sizes. Each larger basin is formed from smaller ones down to elementary watersheds. The latter make a great number of $10^9$ and their sizes depending on relief character and natural zone change in rather significant range (from 0.01 to 1 $km^2$). It is obvious that on the other end of the hierarchical sequence of river basins by their size figure $7\times10^6$ appears (Amazon basin).

The character of relief of any river basin and in the first turn its altitude and ruggedness are of exceptional significance. Many sides of runoff generation processes and some specific hydrological phenomena are directly determined by slope inclination (see *Hydrology of Sloping Terrain*).

Within river basins there are various hydrological objects and non-hydrological ones but of great hydrological importance. They all in different ways participate in the united process of runoff generation.

The main and local divides may be surface and underground ones of various layers.

**Slopes** are the surfaces limited from all directions by orographic lines - divides and channels. Within a slope during snow melt and rain falls non-channel flows may be formed. On formation of surface runoff water flows down over micro-brooklet network (erosion furrows). Sometimes during heavy rains overall flowing down is observed too, when almost the whole slope is covered with water though unevenly.

**Vegetation cover** intercepts precipitation and determines transpiration input into evapotranspiration.

**Soil-ground stratum on slopes** is the element of a basin of particularly great hydrological significance. It is an environment effectively accumulating water and playing the basic role in transformation of precipitation into runoff. Its important hydrological properties are related to filtration and water detention. On formation of soil and ground runoff water movement within the layers is caused by relatively impervious beds. Such movement is called throughflow or subsurface runoff. As water flows down, it accumulates in the underground drainage system. Soil regulates water consumption by plants and its losses by evaporation. Finally, it is an element basically determining the peculiarities of water-balance relations in the basin.

**Layer** of coherent, sandy, macrodetrital or chinked rocks forming near-surface part of the earth's crust and including aquifers, lenses and layers of underground waters of various levels.

**Runoff elements** are limited by micro-divides sites of surface and underground elementary slopes and watersheds exposed with their "overfall" part to slope non-channel or underground drainage system. Surface runoff elements depending on inclination and landscape may change from $10^{-3}$ to $10^{4}$ $m^{2}$. Underground runoff elements may be much larger. For each runoff element there is non-linear relation between outflow and water volume. The picture of functioning of a lot of runoff elements is quite unlike flowing down of a overall water depth, thickness of which is almost linearly grows from a divide to slope foot as it is described in the majority of the textbooks on hydrology. Runoff element is minimal limiting natural embodiment of watershed principle.

**Rivers** are constant water courses of various sizes flowing in developed channels.

**Dry washes** are ways of temporary water courses flowing in arid zone, in drought time precisely being observed over channel formations and deposits of bed load. Numerous local names of such objects are known: wadi (North America, Africa, Arabia), sai (Uzbekistan, Tadjikistan, Kirghizia), chai (Azerbaijan, Turkmenia), sair (Mongolia), cho (India, Pakistan), chaung (Burma), nullah (East Africa, Near-East), oshana (South Africa), omuramba (Namibia), arroyo (South-West of the USA, Latin America), coulee (West of Canada and USA), creek (South-West of USA, Australia).

**Lakes**. The latter may be perceived as elements of hydrographic system of river basins. Basically, lakes play a double role: on the one hand they actively evaporate water, on the other hand they are natural regulators of runoff, smoothing hydrographs of water outflow from their capacities. The more the dynamic volume of a lake (total water volume with the exception of “dead” storage ), the higher is its regulating influence on river runoff with the other equal conditions. Rivers flowing out of very large lakes are characterized by high constancy of runoffs. The best known examples are: the Saint Lawrence River flowing out of the system of the Great Lakes; the Neva River having in its basin such water reservoirs as Ladoga, Onega and Ilmen; Angara River and Baikal Lake.

The role of lakes as the elements of runoff “dissipation” is great especially in arid zones. Besides, the form of a laky pan is of great importance, for with level fluctuations the lake area may change very little or, on the contrary, greatly. During drought months and years areas of such lakes may decrease very much, sometimes in several times which finally leads to water evaporation reduction in the basin. But one should take into consideration that bared lake bottom remains a powerful evaporator during some time. In the future with the filling of the lake basin with water these water losses should be filled. The examples of such lakes are: Ilmen (Europe), Chad (Africa), Lake Eyre (Australia), Mar-Chicita (South America).
There are whole landscapes especially in tundra zone when small and not deep flowing lakes almost entirely cover large territories. In this case precipitation falling to the water surface leads to so called direct runoff generation, possessing great dynamics despite small inclinations.

**Swamps** are specific combined formations of water and vegetation

- with typical moisture-demanding biocoenoses where accumulations of dead non-decomposed remains gradually turn to peat;
- having the extreme variants of their expression depending on their location in a basin as flat and concave lowland (eutrophic) and convex high (oligotrophic) variants of their existence;
- having specific morphology (ridges, rises, hummocks) and hydrography (intraswamp streams, small rivers and lakes, mires, sloughs, pools);
- consisting of two basic layers: inert layer situated on the mineral bottom and an upper - active layer.

In the basic behavior of a a swamp as a hydrological object, properties of both active and inert layers are found. Inert layer thickness changes from zero to the first tens of meters. Slight water permeability, constancy of water amount, volumetric share of which makes from 90 to 97 per cent, absence of air and aerobic organisms are typical for it. Active layer thickness is from 0.4 to 1.0 m. Its filtration properties decrease with depth in $10^3$ - $10^4$ times.

Evaporation and transpiration from swamp surface are relatively great. They are especially significant in arid zone and in boggy tropical woods.

Water regime of swamps and their participation in runoff generation at any given time moment determines the position of the level of swamp waters. And the extreme lower and upper positions of this level lead the same swamp alternately to water accumulation stage and intensive water yield stage.

**Glaciers and icings**. If on some territory situated at high altitudes solid precipitation systematically prevails without melting, snow accumulation which turns to firn and ice consistently takes place. The latter having sticky-plastic properties can flow slowly and this flow occurs in different ways depending on relief peculiarities. Glacier tongues moving below snow-line make leakage in the area of chionosphere and create the conditions for thawed waters runoff generation. As a result, glacial high water supplements and at the end of summer after melting of seasonal snow cover entirely replaces the usual one. Here is hydrological role of glaciers bringing in certain specific features to the process of runoff generation in high-mountain regions. This described picture idealized in some way is sometimes broken by displays of glacier dynamics imbalance: their pulsations and outbursts of intraglacier dammed and moraine reservoirs.

In general there are two essentially different runoff types being formed within basins and determined by phase water state. In the point of concentration it is either liquid water or ice or both. If ice melts above the point of concentration glacial feeding of river takes place. If it flows over this border it is not a matter of “runoff” in the usual sense of the word. Some usual terms are replaced by others: watershed - iceshed, divide - ice divide, water runoff- ice runoff. The subtle distinction between two mentioned runoff types is in the units of rate of flow: it is m $s^{-1}$ - for water, m$\times$(year)$^{-1}$ - for ice.

In the regions with severe winters especially in the zone of permafrost another variant of “solid water” storage accumulation in river basins is widespread. These are icings. The basic process of their refilling is freezing of flowing out ground waters. Consequently, freezing of small rivers in winter and additional income of thawed waters in summer are observed.

The concept of river basin as the most acceptable and precisely outlined by the natural unit itself has been taken into consideration not only by hydrology but also by ecology (watershed as an ecosystem), landscape science (watershed as a landscape unit), geography (of all the units of division into districts a river basin is most convenient), soil science and geomorphology (watershed as a pedo-geomorphological unit). Actually, any borders between distinguished at the locality landscapes, biomes, biocoenoses, runoff-producing complexes, soil areas are conditional and unequivocally non-reproducible at the same territory even by persons of the same area of specialization. At the same time the system of divides partitions the Earth surface into many watersheds of different sizes in any hydrographic zone which is fifed on the topographical maps and at any moment can be used unequivocally.

## 2.4. River Feeding Kinds

In traditional hydrology the following basic variants of river feeding are distinguished: pluvial, snow, glacial and underground. Such a classification is rather coarse and cannot be precise, for it is conducted by dissimilar features: the first two feeding sources differ by phase state of precipitation with all the following consequences, and the latter two by form and the place of water storage accumulation. All four feeding sources are different by the rate of water cycle. Furthermore, underground feeding from various layers of saturated aquifers concerning response time can vary widely ranging from hundred to thousand times.

For many years in the past, the ways of decomposition of hydrographs into these four components of general runoff by feeding sources have been persistently worked out. Such procedure was important, as the influence of various river feeding variants tells on the shape of their runoff hydrographs.

Deep down, the task of hydrograph decomposition by feeding types is not correct for many reasons:

- there is an attempt to determine items by total even with the help of the most refined manipulations;
- pluvial and snow runoff seldom follow one after another consistently, often it is a mixed feeding with the unknown ratios;
- general thawed runoff where there are glaciers is often snow-glacial;
- the term ‘underground runoff’ is very conditional and vague in general (what distance should water pass or how long it should be under land’s surface, so that its getting into channel system could be associated with underground feeding?).

Therefore, the tables with runoff division by four feeding sources given in many publications are not beyond convention. The cases of change of these figures in two or three times are known. And it is connected not so much with the poor accuracy of measurements and calculations as with uncertainty of terms themselves. Modern mathematical modeling renders the determination of runoff types in a definitive manner: surface, soil and underground runoff of various layers. And the distinction between pluvial and snow runoff is impossible in principle, for snow and thawed waters often mix before getting into soil. Besides, the fractions of water undergoing evaporation and soil moisture formation in which underground runoff remain unknown. Of course, formalized decisions are possible here but they always remain defective.

## 2.5. Soil Waters and Evaporation

Moisture dynamics in soil or regolith (surface friable formations of diverse origins and character) both during income of thawed and pluvial waters and during the period of their loss is one of the most important elements of the land part of hydrological cycle (see *Evaporation*). Just the soil provides evaporating surface with moisture or promotes its getting to underground waters. Evaporation intensity is limited by the degree of soil moisture. When moisture exceeds maximum water retentiveness (effective or minimal water-holding capacity), evaporation is equal to evaporating capacity. Evaporation from soil surface and vegetation cover is equal to the total of water losses in all the soil layers. The lower is the soil layer the less is its input into the total evaporation.

Water yield from any soil layer is absent till its moisture content exceeds maximal water retentiveness. As soon as this level is reached all the additional water entirely leaves this depth and gets down into the next one. If low infiltrating capacity of some aquifers puts restrictions for free water penetration, soil flow will be formed. In particular, it occurs when frozen ice-cemented soil melts.

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**Biographical Sketch**

**Vinogradov Yury Borisovich** was born on 7 December 1932, Samarkand, USSR and is Head of Laboratory, State Hydrological Institute, St. Petersburg, Russia.

**Education:**

• Central Asiatic State University, Tashkent, Geographer-Hydrologist,1950-1955
• Postgraduate Study, Uzbek SSR Academy of Sciences, Tashkent, 1955-1958
• Candidate of Technical Sciences, 1960
• Doctor of Technical Sciences, 1972
• Professor of Hydraulics and Engineering Hydrology, 1990

**Professional Experience:**

• Institute of Water Problems and Hydraulic Engineering, Tashkent, USSR, 1958-1964
• Kazakh Research Hydrometeorological Institute, Alma-Ata, USSR, 1964-1978
• State Hydrological Institute, St. Petersburg, Russia, from 1978

**Community Activities:**

Chairman of Debris Flows Committee, Scientific Boards of the USSR Committee on Science and Technology, and of the Academy of Sciences on Engineering Geology and Hydrogeology, 1979-1991

**Publications:**

Papers and Monographs on Hydrological Mathematical Modelling, including:

• 1967. The Problem of Hydrology for Rainfall Floods at Small Watersheds of Central Asia and South Kazakhstan.
• 1977. Glacier Outburst Floods and Debris Flows
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**Range of Interests:**

Organized and conducted the expeditions on studying of runoff formation and debris flows in various mountain regions of the former USSR (1957-1991). In 1970-1977 he as the head of a group of specialists carried out a number of experiments on artificial reproduction of natural Debris Flows of high density (Zailiyskiy Alatau Range, near Alma-Ata).

At present Vinogradov is working on an important generalizing monograph, devoted to the original methods of mathematical modeling of runoff formation, its contamination and catastrophic hydrological phenomena, development of methods of hydrological calculations and predictions of the new generation, ecological understanding of hydrology, questions of interaction of physical and stochastic hydrology and in the whole to the problems of the necessary changes in approaches, conceptions and methods of fundamental hydrological science.