4. Studies of the morphological activity of rivers as illustrated by the River Fyris.

By

Filip Hjulström.

Preface.

The present paper may be considered to be a study of physio-geographical and geological dynamics. It has been written with the conviction that the knowledge of the forces at work on the land-surfaces of the earth is quite as important in geomorphology and physiography as the results brought about by these forces. A complete knowledge of the most important of these forces — a knowledge in which much is lacking -- presumes a co-operation between almost every branch of natural science. This is to a great degree dependant upon the results of other scientific branches, and as these branches are developed, a further extension of the now existing theory of erosion will be possible. This does not concern in the least the theory of erosion by running water, which still has many shortcomings and gaps. Several of these gaps cannot yet be filled.

The investigation which will here be described, is intended to give a determination of the degradation of the Fyris river-basin in Central Sweden. At almost every stage of such an investigation problems of principle import are encountered concerning the dynamics of streams and different fluvial processes. Therefore, it was necessary to include several investigations concerning special details as a preamble for the methods used as well as for the interpretation of the results obtained. They have been included in an account of some important results in hydraulics, mainly, such as are of interest for the understanding of the nature of erosion and the transportation of matter, but which have not been fully observed within geography and geology.

Two chapters for which the writer has gathered material for several years are not ready in a definite state at the printing of this paper, but will — perhaps — be published later on. The first of these may be considered to give a description of the investigations, hitherto carried out, concerning the degradation of different river-basins with a graphical representation of the mechanical erosion. The other chapter deals with the question of the origin of meanders in rivers, from the several standpoints which have been developed in this paper.

In recent years many investigations of almost the same kind have been started in other countries, and many new and important results may be expected from these.

The present investigation was suggested by Prof. Dr. HANS W:SON AHLMANN, Stockholm, who first awoke the writer's interest for the study of geography with his lectures as deputy professor in geography at the University of Uppsala. The writer wishes to thank him also for his kind interest in the further progress of the investigation after his transfer to Stockholm.

Prof. Dr. JOHN FRÖDIN has, as the writer's teacher and as the head of the Geographical Institute of Uppsala during the writer's employment as assistant there, shown an especially great personal interest for the writer's work and has actively facilitated this work in many ways. The writer is highly indebted to him for his active assistance, without which the investigation possibly might not have been carried through.

The writer is also highly indebted to Prof. Dr. HELGE BACKLUND who allowed the writer to use the chemical laboratory of the Geological Institute of the University for the analysis-work, and provided a large portion of the necessary apparatuses and material. Finally, he has been kind enough to publish this paper in the Bulletin of his institute.

For very valuable advice and reference the writer wishes to thank his teacher and friend Docent Dr. HILDING KÖHLER.

Among the many other persons who have been helpful to the writer in different ways during the progress of the work, the following may be named. Prof. HJALMAR O. DAHL has permitted the writer to carry out an experimental investigation at the Hydraulic Laboratory of the Royal Technical University of Stockholm; Geheimerat, Prof. Dr.-Ing. TH. REHBOCK has given the writer permission to stay at the River Hydraulics Laboratory of the Technical University of Karlsruhe and has facilitated his work there, Docent Dr. YNGVE BJÖRNSTÅHL has permitted the writer to carry out measurements of the viscosity and the electrical conductivity at the Institute of Physical Chemistry of the University of Uppsala; Dr. O. FALK, Oslo, has lent the writer an apparatus for the measuring of the velocity of a stream and Dr. O. DEVIK, Bergen, an apparatus for measurements of the scattering of light. Prof. Dr. WILH. SCHMIDT, Vienna, has kindly given advice and reference; Docent Dr. ERIK LJUNGNER picture, Prof. Dr. SANTE MATTSON, Fil. Dr. R. MELIN, Docent Dr. G. FRÖDIN, Docent Dr. N. G. HÖRNER and Fil. Mag. A. B. ULLSTRAND references.

Mr GÖSTA ROOS has attended to the sampling, Mr ERIK KARLSSON to some of the analyses, my wife to a portion of the filtrations 1931—1932, Miss E. ÖHRWALL to the drawing of some figures and diagrams, Fil. lic. GERD ENEQUIST has attended to the alphabetical arranging of the bibliography, and the English lecturer at the University, FREDERICK A. L. CHARLESWORTH has been responsible for the whole translation from the Swedish manuscript. The writer here wishes to thank all who have been of assistance to him.

The accomplishment of the investigation was made possible by grants and scolarships, received, 1930—1932, from the Lennander and Liljewalch foundations at the University of Uppsala, the State's Meteorological-Hydrographic Institute, the Swedish Association of Antropology and Geography, and the Geographic Association in Uppsala.

Introduction.

The most important factors which determine the form-system of a land-surface without tectonic movements are the climate, and the geological nature of the land-surface. According to EMM. DE MARTONNE (1913) »le relief dépends du climat au moins autant que du sous-sol». The climate determines the kind of the exogenous forces and to a certain extent their intensity, while the geological nature determines the resistance power of the land-surface against the influence of the former.

Within the humid region the erosion work by running water is more important than that by other agencies. This mode of erosion may be briefly described in the following manner. The streams erode their bed and banks and remove the material eroded or supplied. By these processes the beds are lowered and form the lowest points within the area considered. But only a very small per cent of this area consists of river bed. The areas between the different branches of a river are uneffected by river erosion. There prevails instead interfluvial degradation by rainwash, or sheet flood erosion, creep and solution. In districts, where the precipitation is great, the rainwash is the most important factor. »Although rainwash dominates the time particularly before and during initiation (of drainage systems), most of the land surface of the earth never leaves the rainwash stage. It is the task of a drainage system during extension to reduce the horizontal distance of rainwash travel to as small an amount as possible. From an areal standpoint, therefore, rainwash possesses far more importance than the streams to which the water is contributed». (W. S. GLOCK, 1931, p. 313). It should be noticed here that the beds of the rivers furnish a base to which the interfluvial agencies work (RICH 1933). Thus the erosion work which the river itself effects becomes a deciding factor. The main river in a river basin becomes the great principal line also for the erosion within the basin.

However, it is often difficult to determine the boundary between stream and water sheet. The concentration of the run-off to definite paths takes place gradually at many places. It is influenced by the nature of the ground, by the slope, and by the discharge.

The erosion by running water is considered to be the best known of the different kinds of erosion. Perhaps it is somewhat better investigated than, for example, glacial erosion. But also many important problems concerning the nature and course of the erosion process itself remain unsolved as the following description will show. Also the question of the rate of erosion pertains to the knowledge of the nature of erosion; without that, the erosion problem is incompletely investigated.

Investigations concerning the rate of erosion within different river basins are from a scientific and practical viewpoint equally desirable.

From the scientific point of view the greatest interest is perhaps attached to the gaining of a knowledge of the degradation of the land area of the earth. The land surface is lowered by means of this degradation; the matter is carried to the sea, whereby the sea surface is raised until finally a state of equilibrium is reached when the land is lowered to the sea surface's level. This surface of equilibrium, the goal for all erosion and denudation, lies according to A. PENCK (1934) at a height of 250 m. above the present sea-level. How fast does this process take place? How quickly does the denudation proceed at different latitudes? How is it affected by the height above the sea, by the climate and its variations? Many other such questions could be asked but cannot be answered other than through direct measurements.

From a practical point of view it is of great importance, for example, for hydraulic engineers to know the amount of sediments transported by the river. The bed-load and parts of the material in suspension will be deposited in dams and perhaps fill them up in a few years time. It is important also for irrigation engineers to know the quantity of sediment. A certain percentage is useful and desirable for the enrichment of the soil but if the quantity is too large the irrigation channels will silt up. It is of interest for agricultural engineers to know the erosion of the fields. The soil erosion is in some countries »a national menace». Above all this applies to accelerated erosion, but it is even of interest to know the normal erosion. It influences the soil conditions and thereby also the availability of land. For the supply of water from rivers to cities its clearness is of interest. In the case of vigorous erosion a risk lies for the undermining of the shore and consequently for its caving-in.

A calculation of the rate of erosion and of the degradation of a river basin can be carried out in two different ways:

1) *The sampling method,* which implies a calculation of the amount of matter carried by a stream through a selected profile. The calculation must then be extended to all three ways of transportation: the amount of material carried in suspension and in solution as well as of the bed-load.

2) *The plot method,* that is to say, a calculation of the amount of material carried away by rainwash from selected plots. The run-off must be desilted and the amount of silt determined. The plots should be chosen so that the loss of soil is obtained from representative types of soil, slope, vegetation etc. From that the total loss of soil from the river basin can be calculated. The methods for such investigations have been very carefully worked out, see for instance LOWDERMILK (1929), FORSLING (1931), and DULEY and MILLER (1923).

However, only the amount of the rainwash erosion is obtained through the latter method. This is in itself of very great interest. Also in countries where the soil erosion has been accelerated by human influence (deforestation, cultivation etc.), by fires, overgrazing, etc. such investigations have been carried out on an immense scale. BENNETT calculates (1928) that 40—50 per cent of the land now in tilled crops in the United States has suffered in some degree from soil erosion. The United States Department of Agriculture has also started an investigation of this kind in accordance with an extensive program (BENNETT, 1933) which has already given very interesting results. (BENNETT, 1934).

The method of determining the degradation by means of measuring the loss of soil due to rainwash erosion has from a geographical and geological viewpoint a very great defect. The erosion which takes place in the river bed itself does not appear in the result. In many cases it is of importance and therefore should not be lacking in the final value for degradation.

Furthermore, this method naturally demands access to plots and the establishment of the experiment stations is rather expensive. It has also been used, for the most part, in the extensive investigations supported by different states.

On the other hand, an investigation of this kind can give very detailed information concerning the effect of different factors on the rate of erosion. Above all, the influence of the nature of the soil can be worked out in detail; different soils and different vegetations have, according to the American investigations, shown different resistance against the soil erosion.

The method first mentioned — that is, determination of the material carried by a stream through a selected profile — has the great advantage that the influence of the river itself is observed. On the whole, the morphologically important work of a river becomes more easily surveyable by an examination following this method. However, it gives only an average of the degradation within that part of a river basin which is situated above the selected profile. The analysis of, for example, the importance of the nature of the soil on erosion cannot be carried so much in detail as with the other more expensive method.

Another difference between the two methods is that the plot method shows the erosion only for small areas and does not give the final figures for erosion and deposition as does the sampling method. If a deposition takes place within one part of the area as, for example, close to the river or in its bed, this method gives no information about it.

From the geographical and geological standpoint a combination of these two methods is therefore most suitable if one wishes to determine the rate of river erosion.

The investigation which will now be described, has been mainly carried out according to the sampling method. From the geographical and geological point of view it was desirable to obtain information about the work of a river, the Fyris river in Central Sweden. This method is less expensive but requires much time and work. It has been combined with a few calculations of the matter-transport from small areas which are drained by small streamlets.

The sampling method requires, however, a very well prepared proceeding; at the different stages during the course of the investigation problems of principle significance are encountered. This is also the case when interpreting the obtained results. Therefore, it is necessary to first deal with those questions concerning dynamics of streams which bear upon erosion, deposition and transportation of sediment.

CHAPTER I.

The dynamics of streams.

The mechanical influence of flowing water on a surface clearly depends on the nature of the water and of the surface and — what is very important — on the nature of the movement itself. Flowing water can pass through a series of various kinds of movement, each of which has its special characteristics which distinguish it sharply from the others. In this way, peculiarities of the movement itself may bring about mechanical reactions that are morphologically so characteristic and important that sometimes the kind of movement can be said to have greater significance than the composition of the solid matter upon which it works.

As regards the water-movement there are, however, a number of important problems which are still to be solved. The knowledge about the most important kinds of movement which change the earth's surface is still very incomplete, and a general explanation of the mechanical influence of flowing water on the earth's surface can certainly not be given in the near future.

Physical geography and geology have therefore to wait for further progress in hydromechanics and hydraulics. But very intensive research is being carried out in this field both on theoretical and experimental lines. In the last decades results have been obtained which are very important for this study, though they have only partly been recognized in physiogeographic dynamics. Many of the numerous hydraulic laboratories that have been built in recent times are intended for purely practical experiments but the collected information may well provide the solution of many problems that are of special interest at the moment.

A mass of water changes its position under the influence of gravity and its own kinetic energy either by falling or by flowing.

Falling.

The characteristic of »falling» is that the liquid does not come into contact with restricting walls or with a river-bed but can move freely, its course being influenced only by the natural forces at work. This sort of motion is not in itself of such great significance for physio-geography, because water when it falls, does not produce any morphological effect. But such an effect may well be expected as the result of such a falling action especially when the falling water hits solid rock instead of a water-filled pool.

It may therefore be of interest to examine more closely some characteristics of falling streams of water which play an important part in erosion, especially as this subject has not been treated. (A description by CORNISH, 1926, of Niagara deals with the phenomena of rhytm).

As the air-friction is rather negligible, a large unbroken mass of water gains a considerable velocity when it falls from a great height. The acceleration causes the stream of water to grow thinner as it falls; when the velocity increases the cross-section is diminished. But a stream of water always tends to fall into smaller units; and these in turn split up further and finally become drops. »The sheet of clear water holds together for a few feet only of the decent, then breaks up in frothy masses which falling far below in irregular succession send up sound of drumming thunder» (CORNISCH, Niagara, 1926). Now the important fact should be noted that drops falling through the air have a maximum size of about 7 mm. in diameter and a maximum falling velocity of 8 met. per sec. (LENARD, 1904). This only applies to stationary air. At a big waterfall the mass of water causes the air to follow it downwards and the maximum velocity therefore naturally increases correspondingly. In any case, however, the eroding power of the water after it has been dispersed is rather negligible when compared with its original force.

According to OEHLER (1930) the formation of drops depends on the air-resistance, the degree of penetrative rotation (Durchwirbelungsgrad) and on several other factors. Capillary forces also play an important part in the dispersing process. A detailed description of the action can not be given as the complicated stages of the process are still rather inadequately known.

It is clear, however, that the stream of water remains unbroken over a longer stretch of its fall if the mass of water is big and the stream thick. *This leads to the obvious conclusion that the height of a waterfall increases its eroding power only when its mass is great.* It is, however, impossible to state definitely what minimum water-mass is necessary for the maintainance of a homogeneous stream of water falling from a certain height. It may, however, be pointed out that in many waterfalls the stream of water is dispersed into drops during low-water-periods and remains homogeneous during high-water-periods. At the transition from one state to another a very noticeable change in the eroding power of the water takes place. When the stream of water is unbroken a considerable amount of erosion follows. (Concerning the mechanical processes see the chapter on erosion of solid rock). On the other hand, there is in this case relatively little erosion when the water mass has been split up into drops unless the sediment-content is considerable. It has, of course, been found out in modern engineering that even pure drops of water can exert a very great eroding power when their velocity is great.

According to ACKERET (1931 and 1932) and COOK (1928) a hard metallic surface may be attacked and made to look as if it had been »sand-blasted», when the velocity of the drops relative to the metal surface reaches 40 met. per sec. Such an erosion of solid rock may therefore be expected at the sea-coast when during storms waterdrops are hurled against the land. But in the case of falling water the maximum velocity is, as has been stated, the same as that of rain, namely 8 met. per sec., unless the air is not moved by the water-mass.

And here, too, we see that a slight change in velocity causes a violent variation in eroding power — a usual phenomenon in nearly all forms of erosion by wind or flowing water.

The process of flowing.

Flowing water has long been regarded as one of the most important — if not the most important — of those exogenous forces which combine to change the earth's surface. The washing-power of rain-water which is especially great on high mountains when it lies in large sheets or when forming small torrents it makes its way down a slope to streams and rivers, the tremendous power of rivers especially in periods of high water to amass and disperse, all these phenomena are clearly so significant that they must be taken into account even outside the sphere of science.

On a closer study of the character of these phenomena it was soon found, however, that the dynamics of flowing water were extremely complicated. The morphological action is equally complicated. An explanation of the processes has, of course, had to take into account all new developments in the dynamics of streams. Although there is — as has been said before — much research still to be done on this subject the last decades have seen considerable advances.

It has now for instance been proved that flowing water passes through several different states of motion[1] when its velocity is gradually increased from 0 and that it reaches a definite maximum velocity which is never exceeded in nature.

[1] Viz. i.g. REHBOCK (1917).

In the case of very small velocities a sliding or parallel movement takes place which is generally called *laminar*. This movement then changes, however, to the *turbulent* state when a certain critical velocity, which is very low in natural water-courses, is reached. These two kinds of movement are the most important. The turbulent state is the most common in natural water-courses, it is in fact almost the only one. This denomination, however, covers two different types of movement, namely streaming and shooting (schiessend). Below a certain degree of velocity which is relatively easy to determine, the movement is streaming and at higher velocities shooting. When afterwards the velocity rises above this point cavitation occurs in the state of shooting movement, and when this increases the water finally reaches its maximum velocity which has been found to be about 23.5 met. per sec.

When the velocity rises from 0 up to 23.5 met. per sec. the water therefore passes through the following states of movement: laminar, streaming and shooting.

This then is the order:

laminar
streaming } turbulent motion
shooting }

But it should be pointed out that future research on the question of turbulence may possibly cause a further division of the turbulent stage to be made. And furthermore, movement where cavitation is present might possibly be regarded as a special state of movement at greater velocities than the state of turbulence.

This classification can be applied in all cases. In the case of a single river several further marginal velocities may naturally be postulated according to the various phenomena that are taken into account. From the physiographic point of view the most important marginal velocity should, in such a case, be that one at which erosion sets in and at which a loose surface is set in motion. It should generally lie somewhere within the »streaming» range. Other similar marginal velocities will be mentioned subsequently.

The three above-mentioned states of movement are, however, so important from the physiographic point of view that they are worth examining more closely.

Laminar movement.

The characteristic quality of laminar movement is that the water particles move along parallel courses, which may be imagined to be arranged in layers that do not intersect or mix. If a coloured fluid is introduced into water in laminar motion by means of a capillary tube a sharply defined narrow band of colour is produced indicating the course of the movement. This band fades only gradually by diffusion. (See illustrations by SCHOKLITSCH, 1920).

Experimental investigation has shown that the NEWTONIAN friction-laws are valid for laminar movement. At an early stage satisfactory mathematical formula was obtained for this kind of movement. Starting from NAVIER-STOKES' hydrodynamic equations (e.g. LAMB p. 577, KAUFMANN p. 198), EXNER (1931, p. 376) found the velocity in a semicircular cross-section to be

$$v=(R^2-r^2)\frac{g \sin i}{4\nu}$$

where $R =$ the radius in the semi-circular cross-section
$r =$ the distance from the central line of the surface of the water
$g =$ acceleration by gravity
$i =$ the angle between the water surface and the horizontal plane
$\nu =$ kinematic viscosity.

In this case, therefore, the various velocities when plotted will form a parabola. Particles which at a certain moment are situated in the centre of a vertical line are to be found in a parabola after a unit of time with a horizontal axis and with the top at the distance

$$\frac{R^2 g \sin i}{4\nu}$$

from the mentioned vertical line and the distance from the focus to the apex $= \frac{v}{g \sin i}$.

The average velocity $U_m = \frac{g \sin i \,.\, R^2}{8\nu}$.

For an open channel the average velocity according to HOPF (quoted from SCHOKLITSCH 1920, p. 902 with different signs) is

$$U_m = \frac{g \sin i \,.\, d^2}{3\nu}\left(1-0.315\frac{d}{B}\right)$$

where $d =$ the depth of the channel and
$B =$ the width » » » .

It is in the nature of laminar movement to be without cross-currents. In a canal with smooth sides where the movement is expected to be laminar the water only moves in the prescribed direction; there is for instance no vertical movement. The presence of such currents is, as will be demonstrated later, necessary for the carrying of suspended matter, and therefore laminar movement is without this carrying power. — This naturally does not mean that absolute clarity of the water should be regarded as characteristic of this state of movement. If the suspended matter is carried in the water in such a highly disperse state that the very small particles have a very low falling velocity, then the water may have a muddy appearance. The fact, however, should not be overlooked that the particles fall even if slowly; sedimentation takes place and the water clarifies gradually, first of all in the upper layers.

And now the question arises as to whether the other kind of transportation namely along the bed itself can occur with laminar movement. According to the above parabola of plotted velocities the velocity at the bed is nil. There is then not any friction against the bed and the walls; the action of gravity helps to overcome the very slight friction within the water. But the last mentioned kind of transportation is however, possible. As will be explained in greater detail in Ch. II a solid body lying on the bottom or in suspension just above the bottom is forced upwards. This upward force is rather insignificant but small light particles lying loosely on the bottom may, however, be set in motion by it. But this movement becomes very irregular. The force diminishes when the particles have reached a certain slight height above the bottom and then diminishes further when the difference in velocity between the particles and the water decreases. A particle which is raised from its position by this force, the *upthrust* or *lift*, does not rise more than a very slight distance from the bottom, as the force is not sustained. When the particle no longer touches the bottom it is driven onwards by the water; the relative velocity of the particle within the water and the force at work decrease in the same degree. When the particle is set in motion it then sinks again.

From this it can be seen that this kind of transportation is confined to the immediate proximity of the bottom. It can at most take place for some centimeters from the bottom and it is in the form of *saltation*.

E. G. RICHARDSON (1934) has recently published an account of an experimental investigation concerning the transportation of silt by streams and here he treats among others the question of transportation at low velocity. For the purpose he took fuller's earth with a specific gravity of 1.6 and a mean average diameter of 0.05 mm. »It was necessary to choose a light fine material of this nature if measurements of the erosion and transport under streamline conditions in the channel were to be made» (op. cit. p. 774). The material was moreover suspended and settled before use so that it might have a uniform composition and it may be assumed to be considerably easier to move in this state than when it is natural compact clay. It could therefore flow along in the water almost as easily as the water particles themselves at low velocities.

RICHARDSON's experiment showed, however, that the erosion and the transportation even of this extremely easily moved material was quite negligible at low velocities »where the notion is streamline, or nearly so» (p. 777).

From the physiographical point of view the influence of flowing water in regular movement is as follows: — very small and light particles which rest loosely on a surface can be set in motion and transported by saltation or simple rolling and sliding, to use GILBERT's terminology. But this kind of transportation is confined to the immediate proximity of the river-bed. No transportation of suspended matter can take place. If for example a mass of suspended matter is brought in by a tributary it immediately begins to settle and sedimentation takes place over a short or long distance; this will depend on the velocity of the water, the falling velocity of the particles and the depth of the river.

But this kind of laminar movement is extraordinarily rare in natural water-courses on the earth's surface. In a thin layer of water where the movement is predominantly laminar isolated eddies and disturbances can sometimes be observed and here the movement of large grains of sand can take place. The presence of eddies makes circulation possible and may cause hydrodynamic upthrust, and the particles which remain at rest in laminar movement are transported.

And various kinds of flowing may occur side by side. SCHOKLITSCH (1920) took a channel in an oblique position and studied the appearance of the surface where the laminar movement at the shallow side changed to turbulent movement where the channel was deeper. Waves occur running in the same direction as the current and varying in appearance according to the prevailing velocity.

Critical velocity.

Laminar movement changes, as has been stated, to disturbed, eddying, turbulent movement at a certain critical velocity, a transition which will now be described in more detail.

The most important characteristics of both the states of movement were observed at an early period by French and German physicists. But the theoretical background and the term »critical velocity» date from OSBORNE REYNOLDS (1883 and 1895). REYNOLDS introduced a coloured fluid into glass tubes of different diameter by means of a capillary tube and then studied the movement of this coloured fluid at various velocities. He found that when the velocity in a tube was increased what was previously laminar movement changed to turbulent at a certain »critical velocity». The transition was clearly evident because the straight colour-band became irregular and moved in a cork-screw or scrawl manner. REYNOLDS obtained different values for this critical velocity in tubes of different dimensions.

It was found that the state of movement in a viscous fluid could be expressed by a formula which REYNOLDS obtained by studying the nature of dynamical similarity, namely

$$R = \frac{v \cdot m}{\nu}$$

where v = the average velocity for a given cross-section,
m = the hydraulic mean depth at a given cross-section (i.e. area of cross-section divided by wetted perimeter).
ν = the cinematic viscosity of the fluid (i.e. viscosity divided by density).

This number which will be represented in the following treatise by R is called REYNOLDS' number. If R, which refers to the relation between the forces of inertia and friction, is applicable to, for example, two geometrially similar river-beds of different size, then the flow is similar. The law of similarity is naturally also applicable to the critical velocity; this will be represented by a certain value of R, $R_{\text{crit.}}$ Great difficulties have, however, been encountered when trying to determine this value. It was for instance found that an upper limit for laminar velocities was obtained and also a lower limiting velocity for turbulent flowing which can lie almost 10 times lower. Between these two velocities there is a field of transition in which both states of flowing may occur. Accidental disturbances etc. determine largely which kind shall prevail.

According to the latest experiments carried out by ALLEN (1934), the lower critical velocity is reached in the region of $R = 1400$ — a value which is, however, between 2 and 3 times higher than that found by previous authors. In a natural river the disturbances due to the uneven bed are so numerous that a low value for $R_{\text{crit.}}$ may be regarded as probable.

The kinematic viscosity, ν, has according to POISSEUILLE (quoted from KAUFMANN 1931) the value

$$\nu = \frac{0.0178}{1 + 0.0337 \cdot T + 0.00022 \cdot T^2} \left(\frac{\text{cm}^2}{\text{sec.}}\right)$$

where T=the temperature in Celsius

and therefore ν at $0^\circ = 0.0178$ cm² per sec.
ν at $10^\circ = 0.0131$ » » »
ν at $20^\circ = 0.0101$ » » »

The temperature has, therefore, a very important influence on the degree of cinematic viscosity ν. At 0° ν is twice as great as at 25°. Consequently in one and the same river the critical velocity at 25° is only half that at 0°.

And apart from the temperature the content of loose and suspended matter may also be expected to have some influence. Water containing much clay might perhaps become sluggish to a very high degree. There is a formula by EINSTEIN for estimating the viscosity of a colloid by means of its concentration:

(See for instance ERK, p. 575).

$$\nu = \nu_0 \, (1 + k \, . \, \varphi)$$

where ν = the viscosity of the sol

ν_0 = the viscosity of the solvent

φ = the total volume of the dispersed matter, expressed in the colloidal solution as a unit of volume

k = a constant factor, which EINSTEIN estimates as 2,5.

This formula only applies to small concentration and to spherical particles. The size of the particles should be unimportant. According to this formula the concentrations of suspended matter, which generally occur in rivers only increase the viscosity to an extraordinarily slight degree.

When measuring viscosity of clay-suspensions and other suspensions previous investigators have, however, found that there is much divergence from EINSTEIN's formula. It has been found, among other things, that the coagulation of clay increases the viscosity.

From RENÉ GALLAY's report (1924 and 1926) it can for instance be estimated that a suspension of colloidal clay from the loess at Aarau with a maximum grain-dimension of 50 μ and a concentration of 94.40 gr. pr litre at a temperature of 25° show a viscosity of 0.01108. After coagulation caused by the addition of $\frac{n}{1000}$ $CaCl_2$ the viscosity rises after 2 minutes to 0.01281 (EINSTEIN's formula gives this value as 0.00979).

According to GALLAY the change depends on the increase in volume. »L'augmentation de volume que subit le sol lors de la coagulation est la seule raison que l'on puisse invoquer pour expliquer, d'accord avec la théorie l'accroissement de la viscosité» (1924, p. 21). According to E. PETERSON's experiments, quoted by H. GORKA (1927), the viscosity in at least one case was greater in a suspension where the grains were small than in one where the grains were coarser for the same concentration. The increase in viscosity after coagulation is so characteristic that it has been used when estimating the changes in degree of dispersity; GORKA, for instance, used it when estimating the aggregative influence of frost. But frost can even cause dispersion, and according to E. JUNG (1931) viscosity experiments cannot give consistant results. An increase in viscosity actually depends on the hydration of the dispersive phase.

As the possibilities of calculating or estimating viscosity in clayey river-water are rather limited it seemed most advisable to carry out some viscosity-tests with water from the Fyris. The measurements were made in accordance with the experiences published by WOLFGANG OSTWALD and F. PIEKENBROCK (1924).

For the measurements a viscosimeter of the OSTWALD type was used. In the viscosity-tests water from the Fyris was used; samples were taken on the 20th of Sept. 1934; the content of suspended matter was 9.5 mg. per litre, the ignition loss 2.5 mg., the content of dissolved matter 224.0 mg. with an ignition loss of 56.8 mg. The temperature of the water when the samples were taken was 14°. The viscosity was taken both of this water and of suspensions with gradually increased mud-content. The latter were obtained by adding mud taken from the river-bed among the vegetation near the bank. The silt was first of all passed through a sieve with a 0.1 mm mesh in order to eliminate the larger parts of plants etc.; the substance is to be considered to correspond nearly to that carried by the river in suspension at high-water. Two different fractions were tested, and it was found, that in the sample with greater grain-dimension a sedimentation set in in the capillary tube of the viscosimeter and had some influence on the results.

Table 1 gives the results of the tests which were carried out at a constant temperature of 20°.5 Celsius. They represent the following:

Sample 1: Water from the Fyris according to the above description
2: 100 cc. Fyris-water and 2 cc. of sample 5
3: 100 » » and 5 cc. of sample 5
4: 100 » » and 20 cc. of sample 5
5: Silt suspension obtained by adding silt from the river-bed to Fyris-water (sample 1) after removing a fraction with a grain-dimension greater than about 2 μ.
6: 100 cc. Fyris-water and 20 cc. of the coarse highly concentrated fraction of silt, removed from sample 5.

The specific gravity was measured by a pycnometer.

Table 1. Measurement of viscosity in mud-suspensions in Fyris-water by means of the OSTWALD viscosimeter.

Test	Conc. in mg per litre	Sp. grav.	Viscosity calculated (EINSTEIN)	Time in sec.	Viscosity (kinematic)
1	9.5	0.99854	(0.0102)	52.4	0.0102
2	354.8	0.99877	0.0102	53.3	0.0104
3	848.1	0.99909	0.0102	53.7	0.0105
4	2945.8	1.00044	0.0102	53.7	0.0105
5	17620.0	1.00993	0.0104	57.4	0.0113
6	36679.3	1.02524	0.0105	61.4	0.0123

As will be seen the viscosity increases as the silt-concentration rises. The increase is considerably greater than EINSTEIN's formula implies. This fact may be explained by the deviation from the spherical form and by the presence of a water-envelope which follows the particles in their movement. But, although the increase in viscosity, concurrent with a rising silt-content, is greater than the formula implies, it is, however, very small. It is evident, from the table, that even with a silt-content, exceeding the highest considered in these measurements with Fyris-water, *the increase in viscosity is so small that it corresponds to a decrease in temperature of only 1°*. Even with such a high silt-content that the suspension at 20° seems almost like a paste the viscosity is no greater than that of pure water with a temperature of 13 to 14°.

From this it may therefore be concluded that the influence of temperature on viscosity is so much greater than that of the silt-content, that it is in most cases justifiable to overlook it altogether.

If the critical velocity is computated according to the formula

$$V_{\text{crit.}} = \frac{\nu \, . \, R_{\text{crit.}}}{m}$$

a critical velocity 0.7 mm per sec. is obtained when $R_{\text{crit.}} = 1400$, $\nu = 0.0131$ cm^2 per sec. and $m = 230$ cm (which roughly corresponds to the value for Fyris-water at the place where the samples were taken); when $R_{\text{crit.}} = 600$, which in this case is a more probable value, $V_{\text{crit.}} = \frac{1}{3}$ mm. per sec.

In the large rivers of the earth the critical velocity is only to be reckoned in fractions of mm. per sec. which means practically speaking that the water is motionless.

It is therefore evident that laminar movement hardly occurs in natural water-courses of reasonable dimensions.

Sheetflood.

But, on the other hand, laminar movement is not rare in small shallow water-courses. A canal with a rectangular cross-section of 1 m. breadth, 2 dm. depth ($m = 14.3$ cm.) has a critical velocity of 5.5 mm. per sec.; the same canal with 5 cm. depth ($m = 4.5$ cm.) has a $V_{\text{crit.}} = 17.5$ mm. per sec. Rain-water flows away partially in large thin sheets and it is important, when studying sheetflood erosion to know in what way the water then moves. The formula indicates relatively high values for the critical velocity when $R_{\text{crit.}} = 600$ and $V = 0.0131$ they are unreasonably high, when the sheet became thinner. In a sheet of flowing rainwater, for example, which is so extensive that the influence of restricting walls can be disregarded, such a high critical velocity (19.7 cm. per sec.) is registered, where the sheet has a thickness of 4 mm., that it coincides with the marginal velocity between streaming and shooting movement. The water will pass direct from laminar to shooting movement without passing through the intermediate of streaming. In still thinner sheets the shooting state of movement commences at a velocity which is lower than the critical; with a thickness of 1 mm. shooting begins at a velocity of 31.3 cm. per sec. whereas the critical velocity is 78.6 cm. per sec. The explanation of this peculiarity is that the usual formula for determining the limit of streaming and shooting movement ($=\sqrt{g \cdot h}$, where $h=$ the depth of water) is not valid here, since no account is taken of the part played by *cohesion* which in this case is very important. The formula gives much too low values here.

But a highly contributive reason is that the value used for $R_{\text{crit.}}$ is too high. Values of the same size have also been obtained by H. JEFFREYS (1925) and by HORTON, LEACH and VAN VLIET (1934). The former found $R_{\text{crit.}}=310$ and the latter found it to be 548—773, in experiments with a painted wooden trough, 10.2 cm. wide, respectively a wooden trough, 5.64 inches wide, finished smooth with sandpaper. From ALLEN's investigations it is found that $R_{\text{crit.}}$ has a lower value at small water-depths. According to ALLEN this should be due to the fact that »the stabilizing influence of the approach channel, indeed, increases with increasing depth of the stream» (op. cit. p. 1093).

HORTON, LEACH and VAN VLIET consider that REYNOLDS' number, taken by itself, is not a reliable criterion for the point at which flow changes from a laminar to a turbulent regime or vice versa. »There is some question as to the applicability of REYNOLDS' criteria for pipes in the case of open channels. Furthermore, the pipes on which REYNOLDS' experimented were relatively smooth and there is a question as to the validity of his results with reference to flow over rougher surfaces». The authors consider that »for a given channel-roughness, temperature, and slope there is always some depth at which the velocities of laminar and turbulent flow would be equal. For smaller depths the velocity of laminar flow is less than would be the velocity for turbulent flow if the latter could occur ... The point of equal velocities apparently fixes the lower limit of turbulent flow in a channel». The position of this point is determined by the HORTON criterion; that is the following formula using C. G. S.-units:

$$V_{\text{H}} = 0.021 \cdot \frac{\nu}{n^2 \cdot D^{\frac{1}{3}}}$$

where ν = the kinematic viscosity,
n = the coefficient of roughness of the channel,
D = the depth from the water-surface to the bottom.

Unfortunately the experiments upon which these conclusions are based have not as yet been published.

Experiment.

Since all the available investigations of the transition between laminar and turbulent regime with water in thin layers have been carried out in not especially wide troughs of smooth material, and since the knowledge of this transition is of great importance for the determining of the nature of the rain-wash, the following experimental investigations were carried out in the laboratory of the Geographical Institution at the University of Uppsala in Sept. 1934.

A thin water-layer was made to flow, with a velocity that could be regulated, over a sand-covered surface, whereby the movement was observed by means of colour introduced into the water through a capillary tube. The thickness, velocity and temperature of the water-layer were measured, and from this data $R_{\text{crit.}}$ could then be calculated.

In order to obtain a uniform water-layer the water was led from the water-pipe into a container with a row of circular holes with a diameter of about 1.5 mm., placed 5 mm. from each other. The outpouring water was regulated by the water-pipe to the container.

The surface, over which the water-layer ran, consisted of a sheet of glass, 37×75 cm., to which a layer of sand was held fast by means of varnish. The sand had a rather uniform consistency with a grain-dimension of about 0.5 mm. It was taken from the sandpit at Tunåsen close to the tile-works, a short distance north of Uppsala. The colour used was a solution of $KMnO_4$ introduced into the water by means of a capillary tube at a safe distance from the influx container so that the movement would be uniform.

The outstanding difficulty in taking measurements was, of course, to calculate the thickness of the water layer over the sand-covered surface. The determination of the depth was carried out in the following manner; two pins fastened in a piece of cork, $^1/_2$—1 mm. from each other, were emersed in the water at right angles to the surface. One of the pins was made to touch the sand and the position of the other was fixed so that it just touched the free water-surface. This was easy to determine through the arrangement of suitable illumination so that reflection was effected. For the acquirement of a reliable average the pins were placed in such a middle position that, with a large number of measurements the water at different points, the upper pin-points in half the cases were found above, and in the other half below the free water-surface. The depth of the water-layer was obtained by measurement of the difference of length of the pins with a minute micrometer. One must be satisfied, of course, with quite a rough estimation of the layer-thickness, but it proved nevertheless, that the acquired values at different measurements of the same layer did not vary with more than 0.1—0.15 mm.

The velocity was determined by measuring the time (by means of a stop-watch) which an irregularity in the coloured water required, to pass a distance between two marked points.

The determination of the velocity which should be considered as the critical could be produced quite easily. At low velocities, when the free water-surface was completely smooth, the colour band was quite regular, and there was no doubt that the movement was laminar. When a narrow colour-ribbon curved aside from a grain of sand and then regained its course, it did so evenly and without forming eddies of any kind. If then, the velocity was increased over a certain value the movement became irregular, forming eddies and changing the colour-bands into irregular cork-screw-formations and dissolving the colour-bands into small clouds. The turbulent state of movement had appeared. The determination proved easier if one took the opposite course and decreased the velocity so that the movement changed from turbulent to laminar, since the depth of the water-layer could more easily be determined with the absence of wave-formations. This method was therefore used at all the experiments.

It was shown during the experiment that in the case of thin, outspread layers the entrance of the turbulence was associated with the occurrence of *waves* upon the surface, at least for the gradients 25 to 35 per cent as in this experiment.

For depths rising above $^1/_3$ cm. these waves have, through the combined effect of gravity and capillary, a minimum velocity of 23.2 cm. per sec. with a corresponding wave-length of 1.73 cm. (viz., for instance, LAMB, 1932, p. 460; ERIC LINDQUIST, 1927; and HOPF, 1910, p. 32). At the experiments, however, the thickness of the layers amounted to only 1 mm. and lower velocities than the mentioned minimum velocity seemed to occur.

In the laminar stage of movement no waves occur in the above-mentioned water-layer. The appearance of the critical velocity was shown by the fact that waves occurred; they were always accompanied by a mixing of the water. The objection may perhaps be made here that this is not what is generally known as turbulence; one might object that this state of movement may, at first sight, seem to be somewhat too regular. From the present point of view, namely erosion and transportation of solid matter, this mixing must, however, be termed turbulence. NIKURADSE (1933) has also, through an experiment, obtained a »turbulenzerzeugende» wave-formation by »irgendeine Oberwelle».

The mixing appeared, in the experiment, first and foremost in the spreading of the colour-band along the line of the wave crest, that is to say, at right angles to the direction of the movement. At certain wave-lengths this phenomenon was especially apparent. In the vicinity of the capillary tube which introduces the coloured liquid, the colour-band was very distinctly formed as a narrow ribbon between the wave ridges, but in these ridges it was especially irregular and widely spread out. One can picture a band with marked expansions. This applies, however, only to a very short distance. Since the wave ridges have greater velocity than the water, they attack and expend a larger part of the narrow band. After a certain distance, therefore, nothing remains of this. It has been transformed into a broad band with turbulent movement. Because of the increasing dilution the movement becomes less clearly observable after a longer distance.

The distance, l, to the place where the coloured band had changed into a turbulent broad band is, as one may easily understand,

$$l=\lambda \cdot \frac{v+c}{c}$$

where λ = the distance between the above-mentioned wave ridges
v = the velocity of the water
c = the velocity of the waves as compared to that of the water.

By determining three of these units it would be possible to determine the fourth. From this for instance, it would be possible to determine the wave velocity.

When the speed was increased from low velocities with laminar movement so that turbulence appeared, very small waves occurred, capillary waves; these have a rather high velocity. The colour band then almost immediately changed into a band showing turbulent movement, in full agreement with the above given formula which for small λ and high values for c gives a low value for l. At high water-velocities large wave-lengths appeared causing the above-mentioned appearance of the colour-band. A closer study of the waves above the critical velocity lies, however, outside the field of this investigation and, furthermore, requires other equipment.

An attempt was made to photograph the appearance of the colour band. The picture, Fig. 1, shows, however, very incompletely the rapidly changing appearance. Under existing arrangements for illumination and photographing a faster exposure could not be obtained, and to the eye the picture appears as much more complicated.

At the sides the stationary waves also appeared, as mentioned by HOPF and JEFFREYS, and which, as the former observed, were entirely independent of the entrance of turbulence. Because of the breadth of the sanded experiment surface, these waves did not have any effect upon that part where the experiment was carried out. In that part only transversal waves were found which were transmitted in the direction of the water-movement.

This kind of wave-formation also appears in natural water-courses and an attempt to moderate it was therefore not made. The sand-covered surface had the same consistency as a sandy ground surface. The only deviation from natural circumstances was that the surface was impermeable to water. No connection was here found with a groundwater surface — a circumstance which, however, cannot play any important part for the nature of the current and for the result of the experiment.

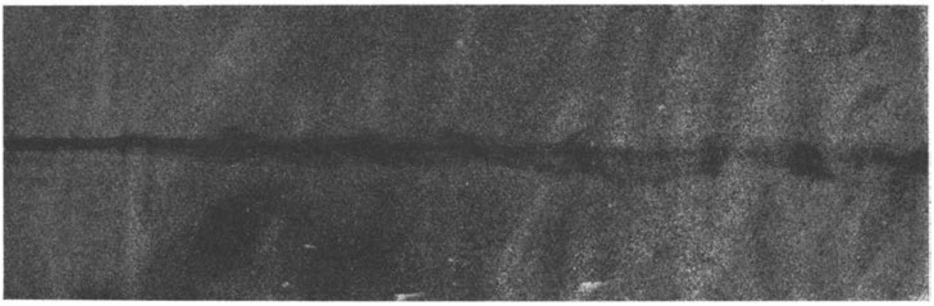


Foto FILIP HJULSTRÖM sept. 1934.

Fig. 1. A colour band in a thin water sheet. The swells indicate the waves. The colour is entered into the water by a capillary tube at the left margin of the picture and the water flows from left to right.

The values obtained through the determination of the critical velocity are found in table 2. As will be seen, three determinations were carried out for each of the two layer-thicknesses, namely 0.8 and 1.0 mm. corresponding to the gradients, 25 and 35 cm. resp. per 100 cm., as used with the glass-sheet above mentioned.

Table 2.

Measurements in determining values for $R_{crit.}$ in thin water-layers.

Water-layer's thickness: 0.8 mm.				Water-layer's thickness: 1 mm.			
Temp.	Velocity	$R_{crit.}$	n	Temp.	Velocity	$R_{crit.}$	n
11°	8.1 cm/sec.	38	0.052	11°	7.8 cm/sec.	61	0.050
11°	7.4 »	45	0.055	13°	6.7 »	56	0.052
11°	7.0 »	44	0.056	13°	7.2 »	60	0.050
Average: $R_{crit.} = 42$				Average: $R_{crit.} = 59$			
n (from HORTON's criterion): 0.054				n (from HORTON's criterion): 0.051			

The low values of REYNOLDS' critical number are especially noteworthy. HOPF's result for $R_{crit.}$, namely 330, seems to be the minimum for water in open channels. His experiment, however, was carried out in a carefully smoothed brass-channel with a water-depth of 1—3 mm. When the brass surface was slightly roughened by means of a file, Hopf obtained (1910, p. 24) a somewhat lower value for $R_{crit.}$

A natural sand surface must, even if it appears quite even, have an especially great friction resistance on a thin water-layer. For a thin water-sheet which hardly covers the projecting grains of the surface, the projections must be relatively very large, and the low values for $R_{crit.}$ are therefore hardly apt to surprise.

REYNOLD's critical number, which is larger for increased layer-thickness, also agrees with what could be expected. But since the hydrodynamic theoretical basis as well as the experimental investigations concerning wave formation in such thin layers are missing, this variation $R_{crit.}$ cannot be submitted at the present time to theoretical explanation.

Table 2 also has a column for the friction-coefficient n. This has been calculated from HORTON's criterion in order to determine its applicability in this case. The friction-coefficient should, of course, in such a case be constant. That is also the case; n is 0.054 and 0.051 resp. for the two examined water-layers. The correctness of HORTON's criterion has, therefore, in the present case been proved. Water, which at 10° Celsius flows over a surface with the same roughness as in the experiment, therefore, cannot flow other than laminarly if the velocity is lower than

$$V_H = \frac{1}{10 \cdot D^{\frac{2}{3}}}.$$

The performed experiment is of importance in deciding the question of the value of the limit between laminar and turbulent movement in water flowing in layers, as is often the case, for example, with rain-water. From this it is evident that the movement is *almost always turbulent* and causes matter-transportation. Laminar movement really prevails only when the water supply decreases and the water at last is about to cease flowing. In the then greatly thinned out layer a regular movement, may for a shorter time unit, take place before it ceases entirely. At the movement's incipient over a dry surface or one dampened by raindrops the water-layer becomes quite thick because of the surface tension and the movement becomes turbulent — a state of movement which prevails from the very beginning until the movement is just about to cease.

Disperse flowing.

A liquid, which contains solid particles in suspension or in colloidal form, shows many deviations from the pure liquid from the physical-chemical point of view. WOLFGANG OSTWALD[1] has shown that in colloidal systems with structure-viscosity, turbulence appears much earlier than what is indicated by the corresponding REYNOLD's number for the pure liquid. He has named this phenomenon *structure-turbulence*.

OSTWALD (1934) has even questioned if suspensions and colloidal systems on the whole can assume laminar movement. The physical condition for the laminar state of movement is such a fineness and similarity in the structure of the liquid that the mathematical differentiation in extremely thin layers may be thought of as being contrary to the actual structure. Deviations from the spherical form may be able to cause cross movements.

OSTWALD has gathered extensive material for his conception that colloidal systems are predestined for turbulence, or at least a sort of disperse movement, which is more like turbulent than the laminar movement.

How silt and clay suspended in river-water conduct themselves in this respect, has not been investigated. Since the shape of the particles have effect, it seems probable that natural water exists with such an anomalous turbulence. Perhaps it is a customary phenomenon.

Turbulent flow.

Whereas marked regularity is typical of laminar motion, turbulence is characterized by a variety of mixed movements which produce an aspect of disturbed, eddying motion. »Das durch Bestreuung kenntlich gemachte Stromlinienbild wechselt von Moment zu Moment und die Stromfäden liegen nicht mehr schlicht nebeneinander sondern scheinen sich zu verflechten (Flechtströmung)». (TOLLMIEN 1931 p. 291). Every observer of the movement of water in a river will be struck by its turbulent nature and will realize that doubt must be felt concerning the possibility of obtaining more detailed knowledge about it. The continually changing aspect of the current which can be seen on the river-surface denotes a very complex state of movement underneath.

The nature of turbulence must still be regarded as an open question. An exact integration of NAVIER-STOKE's hydrodynamic differential equations has not led to any result (OSEEN, 1931) and OSEEN proposes moreover the following definition of the term turbulence:

»A water-movement is turbulent, when it is so complex, that we do not attempt to obtain an explanation of it but are satisfied with an explanation of the average movement» (op. cit., p. 4).

[1] Kolloid-Zeitschrift, Bd 38, 1926, p. 261.

Distribution of the velocity.

The mixing of water, characteristic of turbulent movement, tends to equalize the different velocities at different depths. At the transition from laminar to turbulent movement a mixing-process begins, whereby the water-particles from various levels and with very different velocities are brought together and then move with a medium velocity. The whole water-mass thus becomes, so to speak, interlinked (BEYERHAUS, 1916). If the velocity is shown on a diagram a parabola is obtained in the first case, and in the second a much gentler curve which only towards the bottom and the sides gives values considerably below the average. See Fig. 128. The velocities immediately above the bottom certainly differ greatly according to the composition of the latter. If the bottom is composed of loose matter which is carried along by the water, the 0-point on the curve will lie slightly below what, to the eye, would appear to be the river-bed. As will be explained more in detail later the transition from solid stationary bottom to siltladen water may also be regarded as more or less continuous; in this case the 0-point on the velocity-curve should be taken as lying on the plane above which the loose matter happens to be moving at the time. The pulsations, which occur continually in the movement of the water and the matter on the bottom, change the position of the 0-point and of the distribution of the velocity. What is needed for practical purposes is, however, an average curve of the distribution of the velocity. But it is evident, that we have here a water-movement with highly fluctuating velocity on the bottom and at the restricting walls; this is in marked contrast with laminar movement in which the velocity is nil at the restricting walls. (BEYERHAUS 1916).

If the bottom is stationary, as for instance in the case of solid rock, the composition of the surface is the deciding factor. Even surfaces certainly hardly ever occur in a natural river, but unevenness and roughness can be more or less marked. In this case the 0-point on the curve will, as KREY (1927) showed, lie *below* the upper points of the projections in the bottom's surface. In the case of a bottom of large stationary blocks difficulties may perhaps occur, when fixing the 0-point.

On the question of the distribution of the velocity here the abundant relevant literature must be referred to. A great number of different formulae have been suggested and it is difficult to point to anyone of them as being superior to the others, because there is not one which can be suitably applied to all the phenomena which occur in natural water-courses. The earlier suggestion, that the maximum velocity is found slightly below the surface is, according to REHBOCK (1930, p. 514), erroneous and applicable only to narrow canals.

It seems to the writer, as if two of the existing formulae are more useful than the others; these were the potential and the logarithmic formulae, because these two by their simplicity facilitate in some measure the calculations for which they will be used later. They can moreover be deduced to a certain extent from comparatively few hypotheses (see KREY, 1927).

KREY gives the following formula for the velocity distribution in broad rivers with a uniform depth, H:

$$v = v_{max.} \cdot \frac{\log \cdot \left(1 + \frac{z}{a}\right)}{\log \cdot \left(1 + \frac{H}{a}\right)}$$

In the formula z = the height over the bottom

a = the distance between the bottom and the point where the velocity becomes equal to 0.

This latter term has a very low value if the roughness of the bed is not great. — PRANDTL (1932) obtains a similar logarithmic formula.

However, in the following a potential formula will be used for giving the distribution of the velocities. For the sake of simplicity it is thereby assumed that the 0-point of the curve coincides with the bottom. In the formula:

$$v = v_0 \cdot (a + z)^{\frac{1}{p}}$$

the constant a is usually placed at 0. v_0 indicates the velocity at the height, $z = 1$ cm. The formula is therefore $v = v_0 \, . \, z^{\frac{1}{p}}$.

For high values for the constant »p» in the formula, the formula becomes more similar to logarithmic formulae. Rather varying values have been found for p. KREY gives values between 8 and 20. According to measurements by NIKURADSE (1931) »p» increases when REYNOLDS' number increases, and decreases with increasing roughness.

Characteristics of turbulence.

It is impossible to deduce from what has been stated, at any rate for the present, any laws governing all the details of the turbulent movement. But on the other hand average movement has been the object of intensive study during the last two decades; it has been approached from the meteorological, hydrodynamic and technical point-of-view. This study has been carried out partly on theoretical, partly on experimental lines, theoretically by, for instance, TAYLOR, RICHARDSON, PRANDTL, V. KARMAN,

W. SCHMIDT, HILDING KÖHLER and many others, experimentally, especially in Germany and England.

All these studies started with the primary supposition that, apart from the main movement in the normal direction of the current, isolated water-particles have a secundary movement. These water-particles may comprise large or small masses but they are always larger than single water-molecules. It may be supposed that they exist separately only for a certain and not very great distance because they then mix with the new surrounding fluid (see for instance RUDEN 1933 and SUTTON 1934). Thus new balls of water are formed and they, in their turn, only exist for a short time and so on.

This theory naturally leads to an analogy with the conception of the kinetic gas-theory. Just as, in that case, the quantity »mixing path» is used as being characteristic of a gas at a certain pressure in order to indicate the distance travelled by a molecule between two successive collisions, so here has a distance been introduced to characterize turbulent movement. The term was first introduced by I. G. TAYLOR and was later expanded by L. PRANDTL who also introduced the name »Mischungsweg» (mixing path). The term can be interpreted as denoting the diameter of the water-balls in question. (PRANDTL, 1931). But usually it means — as the name implies — the distance which a water-particle in uniform movement relative to the surrounding water or air covers before mixing and losing its peculiar features (PRANDTL, 1932).

The individual water-portions are, of course, of different sizes and move in different ways; little is known about them. It is very difficult to examine them experimentally although good results have been obtained in isolated cases, especially when dealing with aircurrents (see for instance WILHELM SCHMIDT's investigation into the structure of wind). It would, of course, also be of the greatest interest to know about those statistical *average* values for the characteristic features of movement, values that are perhaps easier to ascertain; this has, therefore, been the main objective of research on turbulence. For many reasons and not least for an understanding of the power of running water to erode and transport solid matter it would be highly desirable to have a clear conception of the size of these water-particles, their frequency, velocity, direction and mixing path; it would be well to be aquainted with the changes in these elements caused by various things such as changes in velocity, in the composition of the bottom and dimensions of the stream.

Many of the results of experiments along these lines have been reached in meteorology and apply to air. But these results generally hold good for river-water at least in so far as they are of a qualitative kind.

The experiments of W. SCHMIDT (1930) and A. BÜDEL (1933) and others have proved the separate moveable air-masses to be of quite different sizes. A BÜDEL has tried to classify them. He carried out the following experiment; a rocket was shot up to a distance of 40 met.; as it fell it left a strip of smoke which was photographed. BÜDEL could then distinguish a series of small airquanta (Luftquanten) which had a vertical length of 1 to 2 meters. Taken over a secund, for instance, these »quanta» move in the main direction of the current but over a smaller unit of time, for instance $\frac{1}{20}$ sec. they are found to have a rapidly changing movement backwards and forwards. Owing to the superposition of the movements in these air-quanta or current-elements units of a higher order are formed which are 10 meters in size; BÜDEL gives them the name »Geschosse». Unlike the air-quanta these »Geschosse» show no tendency to form eddies. The above measurements naturally vary according to conditions; the velocity of the wind, the temperature and the composition of the earth's surface have an influence. But BÜDEL points out that the formation of »Geschosse» presupposes the existance of the smaller units and that there is no continuous transition between these current-elements. He developes the idea further and suggests that there may be units greater in size than »Geschosse»; he also suggests that »Turbulenzkörperchen» smaller than air-quanta exist.

BÜDEL's results agree quite well with those of W. SCHMIDT's and MILDNER's. SCHMIDT's experiment points to the presence of »Geschosse» and air-quanta, the former with a cross-section of 5 to 10 meters and a duration of $\frac{1}{2}$ sec. The separate »Geschosse» do not touch one another but are divided by inactive strata of air-quanta; BÜDEL reached the same conclusion.

It is easy to imagine that similar conditions are present in the flowing water of a river, that is with a reduction of the dimensions. The irregular and erratic pulsation in the movement of the water points to be presence of such units. Not much is known about their dimensions and the possible presence of a scale of sizes. FAGE and TOWNEND (1932) have in their examination of turbulent flow of water in pipes with an ultramicroscope observed that the field of view (1.75 mm. diameter) generally moved together. The above-mentioned authors have carried out observations up to distance of $\frac{1}{1600}$ mm. from the boundary of a square brass pipe of 22.25 mm. »and the whole appearance suggested that the violent motion in the faster moving fluid dragged the whole surface layer bodily sideways» (l. c. p. 670). TOWNEND (1934) points out that if in turbulent motion the fluid near the surface moves in relatively large masses, »it seems still more likely to occur in the main body of the fluid».

Some information about the size of these units of turbulence can be obtained by studying the rapid changes from moment to moment in the velocity-values. Cf. RÜMELIN, 1913.

The scale of the mixing path, l, to use PRANDTL's term has been calculated by NIKURADSE, in connection with his remarkable experimental tests concerning the flow of water in tubes (1930, 1932, 1933) and canals (1929). NIKURADSE has computed the mixing path from measured values of velocity and pressure. It was found that l increases towards the centre, that is as the distance from the wall of the tube and the canal respectively increases. Near the wall l rises linearly that is to say it is proportionate to the distance from the wall.

v. KÁRMÁN's equation (1930)

$$l=\varkappa \,.\, y.$$

where y=the distance from the wall

$\varkappa$=a constant, unconnected with REYNOLDS' number (with a value $\varkappa=0.36$—0.40)

only applies up to distance of $0.07 \,.\, r$, where r=the distance to the centre of the tube. Beyond this distance l rises gradually and at the axis of the tube reaches a value of $0.14 \,.\, r$—$0.16\, r$. In convergent canals the maximum value is lower.

The question of the direction taken by these individual water-units is of very special interest when considering erosion. What form does it take in the immediate proximity of the bottom and higher up? Is the turbulence directed, that is to say specially clearly marked in certain planes? Are the axes of the small eddies present, pointing in the main direction of the current or are they at right angles to it? In order to understand the process of erosion it is of fundamental importance to know whether the irregular turbulent movements occur chiefly on a plane at right angles to the direction of the main movement or whether they take place principally in that direction. In the second case erosion occurs, when the particles are able to overcome resistance and are set in motion for a high value of the continually varying velocity in the main direction of the movement. If, on the other hand, the oblique pulsations are of importance, then the eroding process can be explained mainly by the fact, that the particles are forced on to both sides of obstacles, for instance similar particles, that impede them, and are then carried on more easily. It is to be expected that in the case of one kind of bed-surface the one form of turbulence will erode more powerfully, whereas the other form will be more effective on another surface. In the case of inhomogeneous matter, where various grain-dimensions are represented, a movement with strong oblique pulsations must be more effective than the other type of turbulent movement.

It is possible that the conditions may be different at different velocities (and for different values of REYNOLDS' number) but published experimental tests show that the components causing divergence from the avarage velocity-value are as marked in the main direction of the movement as at right angles to it. FAGE and TOWNEND (1932) found that, at the centre of the pipe, all three components were approximately equal. As the wall was approached the velocity-disturbance normal to the wall of the brass-pipe, passing a maximum at about $\frac{8}{10}$ of the distance from the centre to the wall, decreased to zero, whilst the other two components increased. At the wall itself, it was found that whilst the flow tended to the laminar type, the movement of the particles in the lamina was sinuous. No particle was seen to move in a rectilinear path. These experiments are validy when REYNOLDS' number = 1280 and the mean rate of flow through the pipe = 25.6 cm per sec. These results were strongly corroborated by TOWNEND (1934) when he carried out an experiment concerning the flow of the air through a pipe of square-section at the REYNOLDS' numbers 3,000 and 9,300. He produced and filmed a series of sparks which heated up small elements of air, the motions of which were made visible. In this case, however, the experiment could not be carried out very near the wall. TOWNEND did not find any important differences in the state of turbulence at the different REYNOLDS' numbers except that the central region of equality of the three velocity-components extended to a greater distance from the axis at the higher REYNOLDS' number.

These experimental tests only apply, however, to smooth surfaces whereas in a natural river the bed and the sides are always rather uneven. A remarkably important theoretical investigation into the three-dimensional movements in the atmosphere, carried out by KÖHLER (1933) shed some light upon the conditions of turbulence in this case. By applying the results obtainend from observations of wind-movement KÖHLER has been able to draw important conclusions as to the vectors of turbulence. »Den Unterschied des Turbulenzzustandes, der entsteht, wenn eine Flüssigkeit von einer rauhen Unterlage über eine glatte Unterlage hineinfliesst, kann man wörtlich in etwa folgende Weise beschreiben. An der rauhen Unterlage wird die Flüssigkeit kräftig festgehalten. Die KORIOLIkräfte können dabei eine Ablenkung hervorrufen, die je kleiner ist desto rauher die Unterlage ist. Die Turbulenzbewegung wird dagegen wegen dieser Kräfte in eine horizontale Kreiselbewegung verwandelt. Der natürliche Zustand wird also sowohl von der rauhen Unterlage wie von der Erddrehung verursacht. Über der glatten Unterlage »gleitet» die Flüssigkeit nach rechts und α wird so gross, dass die Coriolikräfte nicht mehr imstande sind die turbulente Kreiselbewegung zu erhalten». (L. c. p. 37). α is the angle between the resulting direction of the movement and the direction of the gradient.

Even in the case of rough surfaces the characteristics of turbulence observed by FAGE and TOWNEND are, therefore, to be found and the divergence from the average movements is as great in the main direction of the movement as at right angles to it. Therefore erosion is greater than if the turbulence occured only in one direction.

The pulsations.

By means of turbulence rapid variations in the velocity around its average value are called forth, as has been pointed out previously. These velocity-variations at one point, the pulsations, are noticeable in many ways. They are visible on the surface, and at velocity measurements make themselves noticeable through the difficulty to reach a constant result. As has been mentioned in more detail on p. 252 the time interval which marks 50 rotations of the propeller in an OTT-meter will vary. The pulsations are also registered by means of pressure measurements.

Quantitative measurements have hitherto caused great difficulties and the pulsations are not yet very well known. By the investigations of BAZIN, SCHOKLITSCH and others (see FORCHHEIMER, 1930, p. 185—187) it has been made known that the intensity of the pulsations is greatest at the bottom and sides and most notable with low velocities. According to FORCHHEIMER (1930) at a measurement by SCHOKLITSCH in the Danube canal the expression

$$\frac{u^2_{\text{max.}} - u^2_{\text{min.}}}{u^2}$$

where $u =$ the velocity varies between 0.15 at the surface and 0.40 at the bottom. The measurements by RÜMELIN (1913, p. 15 and 20) reworked according to the above formula give the values between 0.12 and 0.59. In a case where the low average velocity was 8 cm per sec. the velocity varied between 0 and 16 cm. per sec., that is to say the above formula became equal to 4. The value was obtained in a canal close to the bottom, near one of the sides. According to MURPHY (1904) measurements of the velocity in the Thames have given the values 0.14, 0.22 and 0.45 for the depths 0, 3 and 6 meters respective, and in the Mississippi 0.21 and 0.42 for the depths 0.3 and 3 meters.

It is seen without further explanation that the pulsations must have a very great importance for the erosion of the water. A direct proof-example can be advanced from the Fyris river-basin. The largest tributary of the Fyris, the Säfja river, which was investigated during a short period concerning its silt-transportation, has for some years been dredged. On one occasion, at the end of August, 1929, an insignificant slide of the dredged matter had taken place south of Fundbo, so that such easy erosible silt was obtainable from one side of the river towards the middle. The place was somewhat exposed to currents because of the above placed dredging machine. This was not working at the time in question. It was now shown that the increase in the silt-percentage below the place of the slide was quite important. An increase in the muddying could be seen at the water surface itself about 10 m. below. A closer examination showed, however, that this muddying was not of constant strength but varied. Because of this some measurements of the water velocity were made in connection with sampling, both at a depth of 1 m. and at a distance of about 3 m. behind the slide. The depth of the river was here 1.5 m. The measurements were carried out in such a way that the time was noted for every signal which indicated 50 revolutions of the propeller on the OTT-meter. Meanwhile water was pumped unceasingly with a pump and conducted into bottles by means of a rubber tube. At every signal the tube was moved over into a new bottle. Table 3 gives the obtained values.

Table 3.

Influence of the pulsations on the erosion.

	Time for 50 revolutions of the propeller, sec.	Velocity cm/sec.	Silt-content mg/litre
Series I	13.1	0.58	139
	12.4	0.61	152
	13.7	0.56	137
	11.5	0.65	198
	12.4	0.61	161
Series II	11.0	0.56	187
	13.0	0.58	163
	13.7	0.56	153
	12.1	0.62	181
	13.8	0.65	159

As is seen there is a very close connection between the velocity and the silt-percentage. (For the velocity the formula:

$$V = 0.103 + 0.126\ n$$

is applicable, when $n =$ the number of revolutions of the propeller per sec.) The table shows how, in such a case, the erosion is to a great degree dependent upon the velocity. It shows of course a special case with a loosened and soaked fine matter, but the erosion takes place here in the same way as under normal circumstances.

The variations in velocity are, as is seen, quite large; the above mentioned expression, used by SCHOKLITSCH, has a value of 0.30.

The periodic quality of the variations is difficult to determine by means of common OTT-meters, as these register only the average. The values of the table seem to indicate vaguely a somewhat irregular period of about 12 sec. In such a case this should be a very high value. RÜMELIN has found that the pulsation-time oscillates round a constant average value, p, that it is the same for different depths on a vertical and has the value

$$p = \frac{H_m}{v_m}$$

where H_m = the average depth
v_m = the average velocity.
In the example just mentioned p should therefore equal 3 sec. POEBING (1922) has with an exact instrument, which registered the momentary values, also found deviations from RÜMELIN's value, but in the other direction. It is possible, therefore, that several periodic values are found.

Such a periodic value is also indicated, even if vaguely, by other pulsation measurements which the writer carried out for the determination of the variations in the silt-mass (Ch. IV). A velocity-meter was here used, constructed by Dr OLOF FALK, Oslo. This FALK meter seems to be especially suitable for measurements of small velocities and can be used for measurements of the momentary values of the velocity. Measurements of low current velocities cause indeed many difficulties. Common OTT- or WOLTMANN-meters do not register such velocities and rafts must be used which indicate the surface velocity, or measurements of the mean velocity by salt methods or by air bubbles, as indicated by MIYAGI (1929). The FALK meter seems to signify an important step forward, and because of this it will be described in detail. An older type has been described by FALK (1926—1927).

The apparatus is very simple in principle; its use is based upon the twisting of a thin metal torsion thread when the current tries to operate upon a vane fastened to the thread. The twisting of the other end of the thread which is required for the retension of the vane is measured, and the prevailing velocity is read on a calibrating curve. Fig. 2 shows in more detail the construction, highly simplified; *a* is the thread bent into a spring, to which the vane *b* is fastened. This vane is balanced by the metal ball *c*. The spring *a* is fastened partly to the tube *d*, which is held in place by the thread *d* at the outer iron tube *f*, and partly, at the upper end, by the adjusting screw *g* which can be turned by a handle. The twisting is read off partly at *h* (whole revolutions) and partly at *i* (parts of revolutions). When the vane *b* is met at right angles by the flowing water it tries to press the wing backwards. The copper-thread *k*, fastened to the tube *d*, is pressed against one of the silver contacts *l*, whereby an electric current is closed and a small galvanometer gives deflexion. The contacts are enclosed within an air chamber *m* in order to protect the contacts from salty water etc. By means of a twisting of the handle the tension of the spring is increased and the vane *v* is brought back to its original position. If the handle is turned too far the thread *k* strikes against another contact 1, and another small galvanometer gives deflexion. (The conduits from the contacts are not drawn in the figure, nor are the galvanometers). By making the distance between the contacts small, the position of the thread *k* and of the vane can be quite exactly fixed. The instrument is calibrated in a channel in the usual manner. By making the vane *b* large and the thread *a* fine, the sensitiveness of the instrument may be carried to almost any degree. Dr FALK has (according to oral information) measured currents in lakes with a velocity of 0.1 cm. per sec.

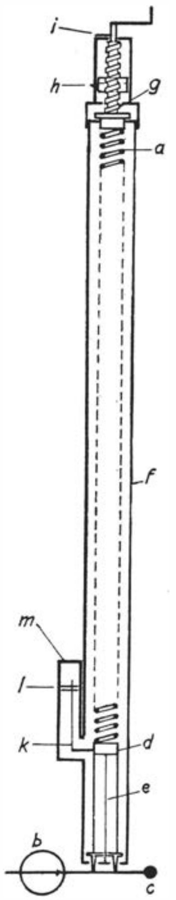


Fig 2. Sketch of the FALK meter.

However, for determining the frequency of the pulsations it was not necessary to calibrate the apparatus. By reducing the space for swinging between the contacts it was found that quite a clear picture of the pulsations was obtained when the apparatus was immersed in the water. If it was adjusted to the average of the velocity, the galvanometers gave a deflection for every deviation from the average.

In Dec. 1934 a measurement was made from the ice of the frequency of the pulsations in the Fyris a short distance north of Uppsala. The depth was 3.1 m.; the thickness of the ice 35 cm.; the measurements were made 15 cm. below the under surface of the ice. The average velocity was there 0.22 m. per sec. (measured with an OTT-meter). — The galvanometers now made deflexions with rather regular intervals of about 0.7 sec., that is to say, three contacts in two sec. (30 contacts in 19.6 sec.). However, the deflexions took place with a slightly irregular variation on the two galvanometers. The following is a series of observations comprising 1.5 min. The letter *h* indicates deflexion of the galvanometer, which indicates high velocity and *l* a low velocity:

h h l h l h h h — h l h l h l — l h l l l h l h h l l l l l h l h l h h h l h l h — l h l l h l l h h l h l h l l l l h l h l l h h h l l h l h l h l h h h h l l h l h l h l h l l l l l h l h l h l h l h l h h l l h h l h l l l l l h l h h l l h l h l.

With some hesitation one might here be able to discover one variation in addition with a longer period than the other. It should in this case have a period of about 14 sec., a value which corresponds quite well to RÜMELIN's formula. It should be pointed out that no deflections caused by the apparatus itself are included here. The deflecting system had in stationary water a $\frac{1}{2}$ period of 1.2 sec.; even these were so moderated by the vane that they could scarcely be determined.

Measurements other than from the ice could not be made due to the lack of a solid pier or the like for the mounting of the apparatus. It is much too sensitive to be used in a little boat. The slightest movement of the boat is registered by the apparatus.

However, several measurements were made in the small Libro stream. There was found at a rather high water-stage in Sept., 1934, a period of 0.4 sec. with — possibly — a higher order of 1.3 sec.

The writer has not been able to decide if these rhythmic pulsations had any connection with the »elongated waves — following each other down the river» as GRUNSKY (1930) has observed in the lower Colorado River. E. S. LINDLEY (in a discussion of GRUNSKY's paper, p. 1141) gives similar observations from the Lower Jhelum Canal in the Panjab and HOFMANN (1917) from the Rhine at Mehlen. In the Fyris such waves cannot with certainty be observed. They must indeed be most strongly marked in large rivers.

Streaming and shooting movement.

As has been mentioned before there are two distinct subdivisions of turbulent movement — streaming and shooting. A clear distinction between these two states of movement is, as REHBOCK (1917 and 1930) especially has pointed out, of fundamental importance for an understanding of the movement of water in a water-course, since in both cases the water has, in many respects, different and at times opposite characteristics. This applies above all to technical science as for instance to the dimensions of canals, but it is important to draw this distinction even when considering the morphological influence of water.

The streaming state of movement prevails at lower velocities up to a marginal velocity, v_{lim}. This is of the same degree as the wave-velocity at a given depth, t, that is to say the same as an average velocity of

$$v_{\text{lim}} = \sqrt{g \, . \, t}$$

where g = acceleration of gravity, 9.81 m. per sec.[2]

If, on the other hand, the prevailing velocity rises above this marginal value the movement becomes »shooting». The transition can only occur at a point on the river where the slope, the cross-section or the unevenness of the bed-surface changes. It is always characterized by a lowering of the water-surface. When shooting water changes to streaming the conditions are more complicated. The surface of the water rises; there is a marked antigradient and stationary waves and even perhaps covering eddies occur.

(»hydraulic jump»). For a given discharge in a river there are two possible water-levels, the one lower for shooting, the other higher for streaming movement. These two only coincide in one case, namely when the two velocities happen to coincide with the wave-velocity, (see for instance BÖSS, 1927).

The surface is smoother in shooting water than in streaming; it is in fact similar to gliding water. When disturbances occur in a canal stationary oblique waves appear if the water is shooting, whereas stationary cross-waves are formed in streaming water (see REHBOCK 1917). A diminution of the area of the cross-section causes, in the case of streaming water, a lowering of the water-surface, a decrease in depth, and an increase in velocity, whereas in the case of shooting water the surface rises, the depth increases and the velocity diminishes. A similar phenomenen occurs when a boat comes on to shallow water with a velocity higher than that of the waves it encounters; it meets with a much lower resistance since it no longer sets in motion an extensive wave-formation.

Shooting water movement may be expected to occur most often in streams and mountain torrents, but it hardly ever occurs in rivers with a slight gradient on lowlands or plains. It requires in fact a relatively high gradient

$$i > \frac{\lambda}{2}$$

where $\lambda =$ the coefficient of friction (see for instance *Handbuch der Experimentalphysik* IV: 4, p. 235). This naturally varies according to the composition of the matter which constitutes the bed and the sides of the river; it also depends on R.

BOUSSINESQ (1877) calculated that movement was »streaming» when the gradient was < 0.0033 and »shooting» when the gradient was > 0.0039. Between these two values these was a period of transition with »torrents de pente modérée», or what FORCHHEIMER calls »Achen». BOUSSINESQ has, however, as FORCHHEIMER (1930 p. 237) points out, obtained too low values. According to the hydraulic formulae of, for instance, BAZIN's (1897) and HOPF-FROMM's λ should be fixed at 0.007—0.010 for a natural river, variations occurring according to the difference in size. The marginal gradient which divides »streaming» and »shooting» rivers should, therefore, be fixed roughly at about 4 to 5 ‰, according to the size of the river. Such gradients hardly ever occur except in mountain rivers; the gradient in rivers on the plains is usually 0.05—0.2 ‰ (PARDÉ 1933).

The differences in the states of movements are due to the fact that the influence of, for instance, unevenness on the bottom may, in the case of streaming water, extend upwards. This can easily occur when the velocity of the waves is greater than that of the water. In the case of shooting water on the other hand this kind of action against the stream is impossible because the velocity of the water is greater than that of the waves. An impulse of one kind or another in the water is thus carried away in the same way as a swimmer trying to go against the stream is carried downstream if his velocity is lower than that of the water.

JOUKOWSKY and TSCHENTZOFF (1925) have offered a physical explanation of these strange phenomena occurring at the transition from one to the other of these states of movement. These authors showed that if the velocity alters from a value which may lie above or below the marginal velocity in question, then a stationary movement is not possible when passing this velocity. There is, in fact, at that point a minimum of energy in the flow, and to pass this marginal velocity would mean an increase in the energy of the streaming water.

The other features of shooting movement are not known as yet. It is turbulent as seen by the vehement »Austausch» (exchange-process). It is, however, impossible to state whether the process is slightly different in detail in the case of »streaming». NEMÉNYI (1933, p. 18) has suggested that the longitudinal pulsations may be much more frequent than cross-pulsations, but no investigations at all have been made.

Cavitation. (Cf. Chapter III).

When the velocity increases in the shooting state of motion the pressure diminishes at certain points in the water. The gasses, therefore, that are dissolved in the water are liberated and take the form of gas-bubbles. The stream, therefore, no longer forms a uniform system but is composed of a gas- and a water-phase. As the velocity increases further the pressure also diminishes and beyond a certain marginal velocity the pressure sinks below the vapour tension of the water at the prevailing temperature. Unless negative pressure should supervene in the fluid then hollows and cavities filled with water-vapour must occur. At an increased velocity these cavities compose no small part of the volume of the fluid.

The maximum velocity of water.

At very high velocities, therefore, the water will change into a mixture of water, air and water-vapour in which the water sometimes composes the smaller part of the total volume. But these cavities represent a high degree of energy. RIABOUSCHINSKY (1931, p. 156) mentions one case, where the potential energy of the cavity is approximately the same as the kinetic energy of the fluid. The high consumption of energy due to cavitation must, therefore, increase the resistance to the movement and tend to lower the velocity.

In modern hydro-engineering the important fact has been proved that there is an upper limit to velocity. According to SCHOKLITSCH (1930, p. 920, 1935, p. 162) this maximum velocity reaches 22 met. per sec. This naturally applies when there is atmospheric pressure and when the water touches on a solid bed; it does not, on the other hand, apply when there is no contact and when the water-mass passes into the free jet of a water-fall; neither is it valid for water under hydrostatic pressure as for instance under a glacier. In these cases the velocity may be higher.

SCHOKLITSCH writes: An der Leerschussrinne des Ruetzwerkes hatte man Gelegenheit einige Beobachtungen über die Bewegeungsweise des Wassers anzustellen, die überraschende Ergebnisse brachten: es fiel dort nähmlich besonders auf, dass bei Steigerung des Durchflusses die Geschwindigkeit sich nach ganz anderen Gesetzen als in flach geneigten Rinnen ändert und sich einer etwa ebenfalls bei 22 met. per Sek. liegenden Grenze nähert.» See also RÜMELIN 1913, p. 86—89.

EHRENBERGER (1926) and SCHOKLITSCH (1926) have studied the phenomenon further by means of experiments and the former has deduced formulae for calculating the water-mass.

Vortices, eddies, rollers and transverse circulations.

In the previous sections a distinction has been made between the various states of movement through which a stream may pass at various velocities. The general character of the movement has thereby been stated.

But in the case of turbulent movement certain other characteristic forms of movement are found in all natural water-courses. Sometimes these further forms of movement include only small parts of the water-mass, as is the case with eddies and rollers, sometimes, however, the whole or nearly the whole of the stream is involved as in the case of transverse circulation.

It is, however, impossible to make a sharp distinction between these secondary movements and the general flow; this is especially true of eddies. It is almost impossible to estimate the part played by eddies in the general state of movement in, for instance, the case af turbulently streaming water. It is, therefore, merely a matter of form that these more or less secundary water-movements have been mentioned separately. But only those phenomena will be treated here which have some direct or indirect morphological importance because of their influence on the processes of erosion, transportation and accumulation, and even these phenomena will be delt with all possible brevity.

J. LUGEON has given a detailed account of water-movements in irregular canyon-like stretches of river (1920).

The most important of these secundary movements from a morphological point of view are undoubtedly the various kinds of eddy-movements, although their influence may perhaps be regarded as indirect. The word »eddy» is used here in the ordinary colloquial sense; the writer therefore rejects the more mathematically exact term that is used in hydrodynamics and includes all circular movement in a part of a watermass, that is to say, he even includes rotation. REHBOCK has given eddies with a fixed axis the name of »Wasser-Walzen». According to FREEMAN 1929, this term is here translated rollers.

Water-rollers. If there are abrupt changes in breadth or depth at isolated points on a river-bed, deadwater may occur between the current and the bed. But this water is not motionless; the current sets it in eddy-movement. REHBOCK (1917) has made a distinction between various kinds of rollers. As regards their morphological action the most important of these are shore-rollers (Uferwalzen) with vertical or oblique axes and ground-rollers (Grundwalzen) with horizontal axes. The shore-rollers may be caused by some projection on the shore and move either up- or downstream from it. It was, however, always found that the rollers beyond the hindrance were more marked and might have a diameter of several hundred meters and, in the case of large streams, a diameter of several hundred meters. Shore-rollers may also occur when the river gradually widens without there being any abrupt projections. At a period of high-water (3. Nov. 1934) the writer observed a case of roller-formation which might be regarded as quite common. The small Libro-stream which runs into the Fyris immediately north of Uppsala has a valley 5—6 met. deep and a flood-plain 30—40 met. wide in which the stream cuts a passage 1—1.5 met. deep. The valley and the stream follow a rather irregular and winding course. At the high-water in question the whole flood-plain was covered with water to a depth of 0.3—0.4 met. but the stream itself followed its usual course. Wherever the stream left the side of the valley a shore-roller occurred. Such swells, therefore, occur at fairly regular distance along the valley as far as the flood-plain reached. But in this case the velocity of the water in the roller was rather small on account of the shallowness of the water.

Towards the right bank of a river the roller moves clock-wise, and anti-clock-wise towards the left bank. The water will, therefore, move in the opposite direction to the current close to the banks. These primary rollers may in their turn cause rotation-movement in adjoining water-masses whereby secundary swells appear. The latter move in an opposite direction to the primary swells. The kinetic energy of these primary swells is, however, smaller and so is their morphological action. It is probably by taking these secundary rollers into account that B. and J. BRUNHES (1904,

p. 12) thought they had noticed after »statistical observations» the startling fact that the water-courses in western and central Europe had far more left-rollers than right-rollers, this observation has not been corroborated by later research. In the course of his observations the writer has found on the contrary that right-rollers near right banks and left-zwells near left banks occur with almost the same frequency.

Water-rollers in a river are of definite importance because of the energy they consume and because they limit the effective breadth of a river. Their importance in regard to erosion and accumulation is harder to estimate but it may possibly be very great in certain cases, as has been pointed out by SALAMON (1926). It may be supposed that shore-rollers can cause erosion sidewards and downwards.

Erosion sideways depends entirely on the rotating velocity of the roller. In a case like that of the above-mentioned Libro-stream the velocity is small and no erosion sideways, due to these large shore-rollers, takes place. In such a case erosion is only possible when a strong current runs along a solid wall having large or small projections. In their proximity, stationary shore-rollers are formed which may even attack solid rock with the transported matter and rougher stones, which they carry with them. This kind of erosion works perhaps mainly in a downward direction by scooping out pot-holes, but during this process the above-mentioned projections are worn away at the same time as the shore is attacked. In this way an important sort of erosion takes place sideways. This is the important type of erosion, called »evorsion», »érosion tourbillonaire» (BRUNHES). This depends entirely on water-rollers.

Erosion in a downward direction by shore-rollers depends largely on the vertical movement of the water in the rollers. As REHBOCK (1929, p. 527) points out accumulation takes place if the water has an upward movement. The conditions here are somewhat reminiscent of cyclonic movement in the air. The bed-matter carried by the water may move in towards the centre, but not away from it.

If, on the other hand, the water tends to move downvards and the movement is similar to that in an anti-cyclone, then the water on the bed must run out from the centre in all directions; in this way the transported or eroded matter is removed. Erosion may become marked and an excavation may occur. The erosion caused in this way is often extraordinarily extensive. In the Säfja which runs into the Fyris south of Uppsala and has a water-mass of 25 m^3 per sec. at high water an excavation approximately 12 met. deep has been formed close to the bridge at Kuggebro. The average depth of the river is about 2 met. at that point. It is certainly possible to find still more striking examples of the power of shore-rollers to effect erosion in a downward direction.

From the morphological point of view the most important question here is whether the water in the rollers has an upward or downward movement. If this is absent the matter present will rotate, be ground to pieces and will be carried away from the vortex in suspended form. It is through this grinding process that erosion takes place. If the river-bed consists of solid rock, then erosion may perhaps in this case be stronger than if the matter transported by the river is carried away by a current that has a downward direction and is centrifugal at the bottom. In the case of such a current, however, erosion will be considerably accelerated if the river-bed consists of loose matter. If an upward current is present, accumulation always takes place even if this current is very weak.

The vertical currents, therefore, do not need to be especially marked or distinct in order to have an important morphological influence; it is sufficient if the *tendency* is there.

It is to be expected that purely local influences should have a pronounced influence on the direction of possible vertical currents. The main current which drives the rollers may, in the points of contact, have a vertical component, that works in an upward or a downward direction. According to REHBOCK (1929, p. 527) rollers with an upward current and accumulation have been observed frequently. This is the usual case, and the ground for the upward motion lies in the friction of the water against bed and sides. FRITZ ROHR (1934, p. 14) observed upward water-movement, when he carried out experimental tests on water rollers with models of harbour-sites (on the right bank of a river) at the Flussbaulaboratorium der Technischen Hochschule zu Karlsruhe. ROHR seems to regard this as a characteristic quality of rollers with a perpendicular axis and suggests, as a physical explanation of this, the friction against the bottom »Hierdurch wird die Geschwindigkeit der Wasserteilchen in unmittelbarer Nähe der Sohle verlangsamt. Da die Wasserteilchen an der Sohle gegenüber der Oberfläche zurückbleiben müssen, entsteht vom Umfang der Wasserwalze her ein Überdruck vertikal zur Drehrichtung der Wasserwalze nach deren Mitte zu gerichtet». But no further calculation of these forces is made.

But the motion of the water in the rollers must also be subject to the the deflective force due to the earth's rotation. This force causes some tendency for a downward current to occur in left-rollers, and an upward vertical current in the right-rollers, even if this tendency is faint and is then combined with the influence of friction. As has been pointed out previously the power of the vertical current is not very important in regard to this process because it only serves to give the rotation a certain direction. The mechanical work required for erosion and transportation is done purely by the roller-motion. See BRUNHES 1904.

If account is taken both of these remarks concerning vertical currents and of the fact that right-rollers occur near the right bank of a river, left-rollers near the left bank, then it will be seen that there should be a *tendency* *towards erosion at right banks and towards sedimentation at left banks due to the influence of the rollers.*

This statement forms a corollary to v. BAER's law. This law expresses the observation that, in the Northern Hemisphere, the water in a river erodes the right bank more than the left bank because of the influence of the deflective force due to the earth's rotation; in this way the right bank will be steeper than the left bank. This fact has been observed in a great number of rivers, for instance in Russian and Siberian rivers, in the Nile and the Danube (see FINGER, 1878). But an influence of this kind has not been able to be found in several large rivers. In the case of the Mississippi for example the differences between the banks may well be ascribed to the influence of winds. On the whole v. BAER's law has been the object of rather much discussion during the last few years. (see for instance W. SCHMIDT, HENKEL, SCHMIDT, W. WERENSKIÖLD and R. WEGENER, in PETERMANN's Mitteilungen 1921, 1922 and 1925, FAIRCHIELD and JONES in Science 1932 and F. EXNER in the Geografiska Annaler 1928). It seems, however, as if the evidence is so strong that it cannot be doubted that considerable erosion takes place on the right banks of large rivers. This erosion occurs, however, largely because the most powerful current is driven towards the right bank where, moreover, the water-level is slightly higher than at the left bank; this is also due to the influence of the earth's rotation.

The previously mentioned influence of water-rollers which has the same effect will probably be of secondary influence compared with the direct influence; this is generally the case with erosion due to rollers compared with direct erosion due to water flowing in the main direction of the river. The above-mentioned vertical movements within rollers depend very largely on purely local conditions; only when the average taken for the whole length of a river is considered and when geological periods are used as time-units can such a law be of any value. And in such a case the influence of the rollers at the various points of erosion on both banks of a river is naturally an important factor.

Eddies. Apart from those water-rollers which are kept in a fixed course by solid limiting surfaces or the like, there also are, as has been stated, moving eddies. These may be of a completely different character, of different size and may have a different origin. They may move in an upward or downward direction; they may be of different sizes, from the small funnel-eddies with a diameter of some centimeters up to those with a diameter of 1—2 meters, the latter being the largest observed by the writer in the Fyris. They may arise as friction-eddies on the surface between water-particles of different velocities. They may be disengaged from an obstacle and move with the current. To this category belongs, among others, BÉNARD-V. KÁRMÁN's »vortex street» in which vortices rotating in various directions, are disengaged in a regular manner from both sides of an obstacle, for instance, of a pillar of a bridge or of some object on the river-bed, a block, a stone, etc.

There are probably also eddies which are caused in several other ways. No attempt will be made to systematize here; only a few indications concerning their importance from a morphological point of view will be given.

In the first place their importance in the question of transportation of suspended material will be pointed out. STEN DE GEER (1911, pp. 141—145) gives a résumé of previous research on this subject.

Eddies have furthermore a very marked influence on the general character of the current. The word »eddying» is almost synonymous with turbulent» when it is used to indicate the state of movement in a liquid. NIKURADSE's photographs (1926) support the idea that eddies may be considered as characteristic of a certain state of water-movement. A very irregular movement certainly occurs in a river when all these different kinds of eddies are present simultaneously. These various eddies may operate in the same or different directions; they gradually diminish in intensity as new ones are formed and so on. Perhaps the best known of these eddies are BÉNARD-KÁRMÁN's vortex-streets which have been subject to thorough experimental and theoretical investigation (see chapters in AUERBACH-HORT: Handbuch der physichen und technichen Mechanik, Band V).

These eddies occur alternately and their frequency and intensity depend on the dimensions and the form of the obstacle and on the nature and velocity of the liquid. These kinds of eddies are worth a certain amount of attention because they contribute towards the formation of pulsations. They may moreover help to set up an oscillation in the water-mass, at right angles to the main direction of the river; this oscillation is reminiscent of those stationary oscillations »seiches», which are found in limited water-masses like lakes and bays. There is, therefore, in a river a tendency for several such oscillations of various frequency to occur; only one of these, however, can be of importance, namely the one which corresponds to the frequency of the oscillations in the water-mass itself, as determined by the seich-formula. This vibration will be made more pronounced because the water-mass is in resonance with it.

These kinds of cross-oscillations are certainly very important factors in the formation of meanders as EXNER (1919) pointed out.

It is possible that the presence of these cross-oscillations may be due to the influence of pulsations.

The transverse circulation. It is well established by observations that at constant or sinking waterstage there is an inward surface drift of water to the middle of a stream. Here the water has a tendency of sinking and at bottom there is a movement from the middle. Therefore, in the stream two spirals of circulation exist.

This slow circulation has the opposite direction when the water-level rises.

The former circulation which is more usual has been pointed out by GIBSON (1909) as being the explanation of the fact that the filament of maximum onward velocity is not situated in the surface but at some distance below. The usual explanation of the phenomenon as caused by the friction near the sides, is, according to JEFFRYS (1929) not comprehensive; »the true explanation must depend on something more fundamental».

These transverse-circulations must naturally have some influence upon the transportation of the solid material. At a falling or constant water-level the bed load must have a tendency to be spread out from the middle; at rising water-level to be concentrated to the middle. The influence on the material in suspension must be rather great. The distribution of the silt at different heights above the bottom is altered. When the water-stage is constant or falling, the silt must be more concentrated at the bottom than normally and the transportation of suspended material on the whole reduced. At rising water-level, on the contrary, the transportation of silt in suspension is facilitated and the concentration at small and great heights above the bed more equalized.

CHAPTER II.

Solid matter in bed-load and suspension.

In the previous chapter, dealing with the movement of water, references have been made to the importance, which the different phenomena encountered there, have for the morphological work of water in erosion, transportation, and deposition. It has thereby been shown how the water's flowing-condition is of deciding importance. Before dealing with the above-mentioned important processes, it is, however, suitable, to first examine somewhat more closely, partly from the mechanical view-point, the influence of water on a particle in it. From the question of the movement of water we now pass over to the problem of the movement of a solid body in water. First we must take into consideration the forces at work.

Falling movement.

In the first place we may consider a particle in a liquid, surrounded on all sides by the same. The particle is to be considered as situated at such a distance from the boundary surfaces that no influence from these can be noticeable. Its density is considered greater than that of the water, and gravity imparts to the particle a downward movement relative to the water. At first it is accelerated but becomes uniform as soon as the resistance assumes the same value as the force at work. This uniform velocity is fixed as to its value by STOKES' law:

$$v = \frac{2}{9} r^2 \frac{\varrho_P - \varrho_F}{\eta} \cdot g$$

In this formula

v = settling velocity of particle
r = radius of particle
ϱ_P = density of particle
ϱ_F = density of fluid
η = coefficient of viscosity of fluid (g cm.$^{-1}$ sec.$^{-1}$)
g = acceleration due to gravity.

STOKES' law is, however, applicable only to small particles; according to GESSNER (1931, p. 21) it is, for instance, within the field of silt-analysis, no longer of practical use above a particle radius of 0.005 cm.

A universal formula, which, when applied to small particles, becomes the same as STOKES' formula, has been worked out by OSEEN:

$$v = \frac{-\frac{3\eta}{r} \pm \sqrt{\frac{9\eta^2}{r^2} + 3\varrho_F(\varrho_P - \varrho_F) \cdot g \cdot r}}{\frac{9}{4}\varrho_F}.$$

Moreover, a whole series of sedimentation-formulae have been prepared and the literature on this subject is abundant; among the contributions presented during the last few years, BENNDORF's (1930) and RUBEY's (1933) papers should be mentioned separately as being especially noteworthy. When in the following, »falling velocity» is mentioned it will always be calculated from OSEEN's formula if nothing else is indicated.

The term r, radius of particle, which occurs in this formula, can be defined in several different manners as can be seen from WADELL's thorough treatment of this subject (1934, a and b). If a particle is not spherical one may hesitate as to which dimension of the particle shall be taken for the dimension given in the formula. In the following »r» is always considered to indicate the radius of a sphere of the same specific gravity and of the same terminal uniform settling velocity as a given particle in the same sedimentation fluid. In this case the calculations are to be carried out according to OSEEN's formula. In analogy with WADELL's terminology the radius ought to be called »OSEEN sedimentation radius».

Through these formulae the falling movement of a body is fixed in relation to the water. In the case of sedimentation-analysis they are applied to the fall of solid particles in a stationary liquid. They are, of course, applicable also when the water and the particle move horizontally. If, on the other hand, the liquid has vertical movements, corrections must be made for them. In the case of vertical components pointing upwards the falling movement of course diminishes in a corresponding degree. When the vertical movement has the same velocity as the falling velocity of the particle in stationary water, the particle remains at rest. If the vertical movement is increased the particle is forced upwards.

This applies without exception to completely regular movement. If, on the other hand, the liquid when moving has a turbulent motion, there is, according to PRANDTL (1931, pp. 129—130), a certain difference between the resistance of a movable body in a stationary liquid and the force which a flowing liquid exerts on a stationary body. In the latter case the resistance is often greater.

Hydrodynamical upthrust.

If the solid particle is not symmetrical compared with its own direction of movement — or that of the liquid, if it is the liquid which is in motion — another force appears. This is pointed at right angles to the direction of the movement and is called »upthrust» (»hydrodynamischer Auftrieb»). Only in the case of symmetry does the force of resistance coincide with the direction of the movement; in the general case the force may have a direction deviating from the direction of the movement, and this can then be divided into two components of which one coincides with the direction of the movement, »the drag», and the other at right angles to it, called »the lift» if it is pointed vertically upwards. Examples of the technical use of the latter power-component are airplane wings and windmill arms. With symmetrical bodies such a component of the latter type may only occur if the body rotates. This is then called the »MAGNUS effect».

The power-component at right angles to the movement now causes the body to assume an oblique movement when falling. If the solid body is at rest in a running liquid it is worked upon by a force upwards or downwards. This can, of course, be thought of as important for the understanding of movements in the bottom-matter.

The conditions close to a solid limiting surface are quantitatively, as well as in several other respects qualitatively, different from those which prevail at a large distance from such a surface. It is found, for example, that a sphere which moves in a parallel course to an even wall is pushed away from it. The same force, tending from the wall, influences, of course, also a sphere when it is at rest close to a wall in a flowing liquid. The latter problem is analogous. The sphere in question not only causes a disturbance in the water close to the sphere, but it also causes small changes in the liquid's state of movement at a distance. Close to the wall the velocity must, however, be nil since gliding movement is out of question. Here, therefore, a change takes place in the regular complex of small disturbances which the sphere should have caused in the case of an unrestricted water-mass. Through this change in the regular conditions a kind of reverted flow appears which acts upon the sphere with a force directed from the wall.

Because of the important influence which this system of forces must exert in the case of erosion and transportation, a short account of the results obtained within hydrodynamics should be given here. This, so much the more, as this power-influence does not seem to have been taken into account nor observed within physico-geography or geology. One has there taken exclusively into account the power working in the direction of the flow. It is, however, evident that by considering the power-influence in question, the explanation of the erosion- and transportation processes is appreciably facilitated.

The especially complicated problem has, from the hydrodynamic viewpoint, been treated in detail by FAXÉN (1921) according to OSEEN's method. His calculations are applicable only to low values for REYNOLDS' number and they give rather complicated formulae: the expression

$$\left(\frac{\varrho_F \cdot v \cdot a}{2\eta}\right)^2$$

where a = radius and v the velocity, must be small compared with l.

H. JEFFREYS (1929) has from the classical hydrodynamic standpoint treated the upthrust in the case of a long circular cylinder resting on a flat bed of a deep stream, with its axis perpendicular to the flow. JEFFREYS says (p. 272): »If a solid rests on the bottom of a stream, the points of contact are points of zero velocity; and the velocity just above the solid, by the equation of continuity, must be greater than the general velocity. Hence the velocities produce high pressures under the solid and low ones above it, and the difference tends to lift the solid up. If the resulting thrust exceeds the weight of the solid in the liquid, the solid will be raised, and will be unable to rest in equilibrium on the floor of the stream». If the density of the solid is ϱ_P, the density of the fluid is ϱ_F, the radius of the cylinder a, and the general velocity of the liquid U, JEFFREYS finds that the solid will be lifted when

$$1.43\, U^2 > \frac{\varrho_P - \varrho_F}{\varrho_F} \cdot g \cdot a\,.$$

The formula, however, refers to two-dimensional flow past a cylinder. JEFFREYS says (p. 274): »In three-dimensional flow past a grain with comparable transverse and longitudinal dimensions the solid will be in contact with the bottom at only a finite number of points instead of all along a line. Some fluid will therefore be able to pass under the solid, less will pass over it, and the lifting force produced by a current of given velocity will be reduced».

In spite of this, the values for the critical velocity calculated according to the formula are correct; in the question of erosion of matter lying on a smooth bottom the formula coincides almost exactly with the empiric formula drawn up by OWENS (see Ch. III).

When the cylinder has left the river-bed the force working vertically changes; it decreases and can also work in the opposite direction. DEMT-

CHENKO (1927) has in accession to RIABONCHINSKI's treatise (1922) given a concentrated description of the occurring powers. He separated, in an unlimited liquid, two forces, to which, in the presence of a solid wall, two more forces could be added.

E. G. RICHARDSON (1934) in a newly published treatise starts from a formula by OSEEN (1912). This formula gives a more exact solution of the problem which has been worked upon by SMOLUCHOWSKI and determines the repulsion between two spheres, of which one is »the image in the wall» of the other.

RICHARDSON has given the following form to OSEEN's formula from the repulsion, the lift, L:

$$L = \frac{9}{4} \pi \eta^2 U \frac{a^2}{d} \left\{ \frac{1 - (1 + 2xd) e^{-2xd}}{2xd} \right\}$$

where $U =$ velocity
$a =$ radius of the sphere
$d =$ distance of its centre from the plane wall
$\eta =$ the viscosity
$x = \frac{\varrho_F \cdot U \cdot d}{2\eta}$
$\varrho_F =$ density of the fluid.

RICHARDSON gives the relative values for variations in L, with the distance from the bottom for different relations between U and d. If U^n is put proportional to d and n is small, as for streamline motion, RICHARDSON finds that the function has a maximum, which when $n = 1$ gives a maximum lift at $d = 1.41$. When $n = 2$ this speak is smoothed out and when n is large — general turbulence — the maximum has disappeared, the lift falling continuously with d, in nearly exponential fashion.

It must, however, be noted that the formula has a very small range of validity. It is applicable only to very small spheres and in the case of laminar movement and loses its validity close to the river-bed itself — the ratio $\frac{a}{2d}$ must be small — as at the transition to turbulent movement. A calculation of the figures which L reaches also show that only very small and light particles can be held suspended by this power.

It may finally be noted that in the case of shallow water an influence from the surface is noticeable and works upon L. HAVELOCK has investigated and determined the resultant vertical force on a cylinder, submerged in a uniform stream (1929). It is found that L is relatively large at lower velocities, larger than the wave-resistance, that L reaches a maximum of about $\frac{U}{\sqrt{g \cdot f}} = 0.65$, where $f =$ the depth of the cylinder below the surface, and that L then decreases in value and changes its symbol at $\frac{c}{\sqrt{g \cdot f}} = 0.84$.

The horizontal force has also been determined by HAVELOCK. In the case of a cylinder it is very small at low velocities but then increases rapidly to its maximum at $\frac{c}{\sqrt{g \cdot f}} = 1$. The same holds true for a sphere (HAVELOCK 1931). Spheroids of various forms show deviating conditions depending on whether they are moving end-on or broadside-on.

The before-mentioned investigations, carried out mainly on a purely theoretical and formal basis, can be applied, with the exception of JEFFREYS' theories, only to laminar movement. The forces mentioned in these works, naturally, do not cease to work when the movement changes into the turbulent state; then they are also active but it is difficult to make any calculations as to their size or effectiveness.

From RICHARDSON's afore-mentioned investigation it is, however, evident how a completely different distribution of the transported material occurs in the case of turbulent movement. The transportation of silt is mainly dependant on turbulence.

The exchange. (Austausch).

The movements close to the bottom itself are decisive for the erosion, the movements higher up in the liquid determine the transportation of the suspended matter. FAGE'S and TOWNEND's (1932) results, as well as those of TOWNEND (1934) show, as has already been stated, that at the centre of a square pipe the turbulence has the same value in all directions. For the transportation the vertical movements caused by turbulence are the most important — that is to say the velocity-components which are lacking at the bottom.

Because of these vertical movements water-masses pass up and down without interruption through an imagined horizontal small surface in the water. On an average these movements nullify each other; when it is a question of a longer length of time the vertical average movement must, of course, in a horizontally flowing river become zero.

Now, however, it must be noted that the water coming from below can contain a larger percentage of, for instance, solid particles in suspension than that which comes from above. The result of this is that the mass-exchange caused by turbulence results in a transportation of solid particles. This transportation is determined as to its size by the difference per second between the upward- and downward-moving mass of particles through the imagined surface.

This reasoning may also, of course, be applied to other contents in the water than the suspended solid particles; also heat, dissolved salts and gases, plankton, momentum etc. are transported. It has, however, been greatly discussed whether or not the transportation of momentum follows exactly the same laws as the transportation of other qualities of the water, but experimental investigations have shown that the difference is not, at any rate, very large. Furthermore, a similar mass-exchange with transportation of different types of qualities also takes place in air. Here also occurs a transportation of water-vapour, ions, pollen, etc. Because of the enormous influence which turbulence and the exchange-process effects within meteorology, it is mainly within this branch of science that this study has been carried out. The importance of this phenomenon in meteorology was first evident in a quantitative investigation by ÅKERBLOM (1908). The theories of the exchange-process have later been developed by WILHELM SCHMIDT, G. I. TAYLOR, L. F. RICHARDSON, HILDING KÖHLER and others. After G. I. TAYLOR's and WILHELM SCHMIDT's works (1915 and 1917) abundant literature on this subject has been published.

From these investigations it has become evident that the Austausch-process is similar in many respects to the conduction of heat. The transport by a liquid of different properties and contents resembles of the conduction of heat in a body. It is also similar to the diffusion-process; instead of moving molecules it is in this case, however, a question of either larger or smaller individual mass-units which cause the phenomenon.

In the case of a constant, that is to say a temporarily unchangeable state the transportation through »Massenaustausch» can be expressed by the following formula, analogous to the fundamental equations for heat-conduction, diffusion and viscosity:

$$S = -A \frac{ds}{dz}$$

where z = the heigth

s = the property or content in the fluid which is transported, expressed in percentage per mass-unit.

S = measure for the transportation of s per time- or surface-unit.

A = eddy viscosity, mechanical viscosity, the Austausch-coefficient, the exchange-coefficient, eddy conductibity.

This coefficient A, for which the name »Austausch-coefficient» will be used in the following, characterizes the intensity of the exchange-process itself but not s. All the changes caused by exchange are thus closely associated with each other, as WILHELM SCHMIDT strongly emphasized (1917 and 1925).

The coefficient was often, especially formerly, regarded as constant with regard not only to time but also to height. Generally this is not always correct and requires in every case special proof. WILHELM SCHMIDT deemed it probable that if the so called law of potency for the velocity distribution is applicable, that is to say, if — on the average —

$$U = U_1 z^{\frac{1}{p}}$$

where U = the velocity for the height of z
U_1 = the velocity for the height 1
then the following formula is applicable for the »Austausch-coefficient».

$$A = A_1 \cdot z^{\frac{p-1}{p}}$$

where A_1 = the Austausch-coefficient for the height 1 above the bottom. If this is introduced into the fundamental formula the following result is obtained

$$S = A_1 \cdot z^{\frac{p-1}{p}} \cdot \frac{ds}{dz}.$$

By this formula it is therefore possible to estimate the average transportation from the bottom of a river upwards which is caused by the exchange-process, and thus resulting in the matter transportation not being wholly confined to the immediate vicinity of the bottom.

Every particle which is forced upwards by the water-mass in which it is floating at the moment, has, however, its own falling velocity, c, in comparison to this water-mass. Here are found therefore, two different tendencies working against each other; one is the Austausch-process because of which in the present case a transportation *upwards* through an imagined horizontal surface takes place; the other is the gravity which causes the particles to sink *downwards*. It depends upon the relation between these two processes whether the result will be a transportation upwards or a fall downwards through the imagined surface. If, on the average, the same quantity is transported upwards as well as downwards a constant state of equilibrium prevails. This can be expressed mathematically (cf. W. SCHMIDT, 1925, p. 64) by the equilibrium-equation:

$$-c \cdot s - A_1 \cdot z^{\frac{p-1}{p}} \cdot \frac{ds}{dz} = 0.$$

The solution can be expressed in the following form

$$s = s_m \cdot e^{-p \cdot \frac{c}{A_1} \left(z^{\frac{1}{p}} - z_m^{\frac{1}{p}} \right)}$$

or after the introduction of the logarithmical decrement

$$s = s_m \cdot 10^{-0.43429 \cdot p \cdot \frac{c}{A_1}\left(z^{\frac{1}{p}} - z_m^{\frac{1}{p}}\right)}$$

where s_m = the percentage of suspended matter for the height z_m above the bottom.

Discussion of the formula.

This formula gives the distribution of the silt at different heights above the bottom along a vertical line which prevails at the state of equilibrium. If the percentage of silt is determined at a certain point and if the terms p and $\frac{c}{A_1}$ are known, it is possible to estimate the percentage of silt at every other point along the vertical line. If, on the other hand, the percentage of silt has been determined at two different points and, furthermore, the velocity-distribution, it will be easy to determine $\frac{c}{A_1}$ and, when the grain-dimension is known, also A_1 which can be said to be a measure of the turbulence.

These results are of theoretical interest by themselves. They are also of value for the selection of methods for determining the transportation-work of a river. As the equation can give certain information concerning the morphological influence of a river in the case of erosion and sedimentation — as will be shown in the following chapter — the formula will be discussed very briefly here.

It should then, in the first place, be pointed out that the formula presents *statistical averages*. It is only applicable to average values and must not be applied to the state at a given instant which should be quite clear from the preceding. Pulsations and various other disturbances cause the momentary values to deviate to a rather considerable amount from the average.

The influence of the falling velocity. The term c in the formula which represents the falling velocity characterizes only a single particle-dimension of a certain density. For another grain-dimension a different distribution is obtained. A larger grain-dimension is thereby concentrated farther down as is apparent from the formula. For further enlightenments of the above-mentioned, the distribution of four different grain-dimensions up to 5 meter's height over the bottom has been graphically explained in Fig. 3. For the calculation the following values have been used: $p = 8$ and $A_1 = 10$. The concentration at 2 cm.'s height over the bottom has been assumed to be equally large for all three grain-dimensions and has been set at 1. The specific weight of the particles has been set at 2.65. Of the four values for c the smallest ($c = 0.0000892$ cm. per sec. = 1.98 cm. per every 24 hours) has been chosen to correspond to clay; according to GESSNER (1931, table 16, p. 186) the radius should be 1 μ (0.001 mm.) if at the given value of c the temperature is 20° Celsius. The falling velocity 0.0357 at 20° Celsius corresponds to a grain-dimension of 0.020 mm. (20 μ) characteristic of silty loam; $c = 0.778$ corresponds to a grain-dimension of 0.10 mm., that is to say very fine sand and $c = 6.662$ cm. per sec. corresponds to a grain-dimension of 1 mm., that is to say coarse sand. The graph shows how the coarse sand is concentrated in the immediate proximity of the bottom. In the example chosen the concentration at 30 cm.'s height is already less than 10 % of the value at 2 cm.'s height, and at 5 meter's height only 0.3 % of the same value. A material which may be characterized as very fine sand is still found in a concentration which is about half of that prevailing at the height of 2 cm. Of the silty loam 97 % still remains and in the concentration of the clay no noticeable change has taken place. The small particles are therefore very uniformly distributed over the whole surface, while the large particles are highly concentrated in the vicinity of the bottom. They cannot be transported with the same ease in a suspended state.

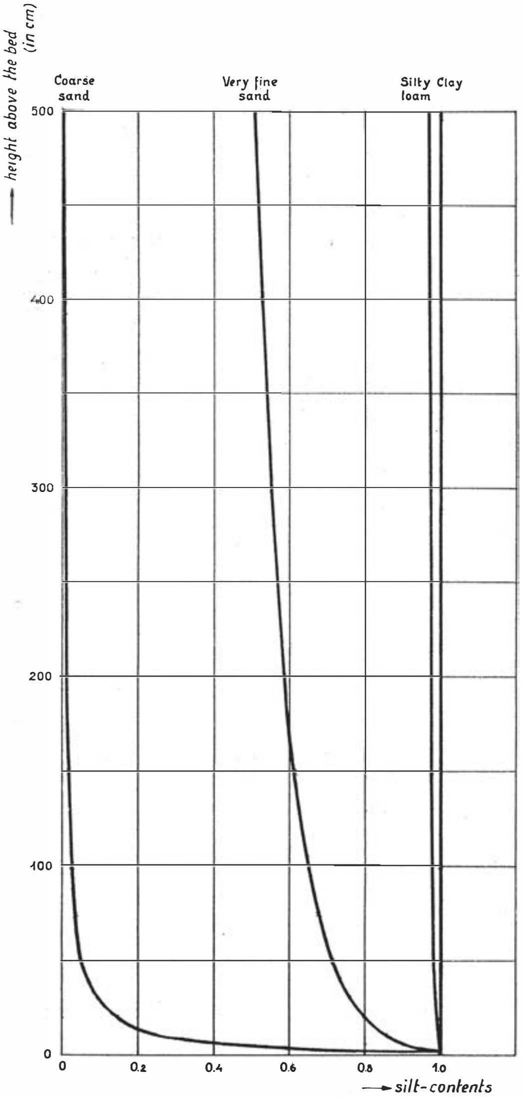


Fig. 3. The distribution of suspended material at different heights above the bed according to the formula on p. 273 for $p=8$ and $A_1=10$.

An analysis of the transported matter at different depths gives, therefore, different distribution curves for the grain-dimension. The exchange-gravity-equilibrium is different at different depths. If one wishes to fix the distribution-curve for the total amount of transported matter in a river this would be possible through calculations by means of the given equation.

For the sake of simplicity the falling velocity has previously been regarded as the characteristic of the particles. It must, however, not be overlooked that the falling velocity, apart from the particle-dimension depends upon the water, which, among other things, varies with different *temperature*; it also depends on the *specific weight* of the particles and the water. The influence of these can be briefly stated in the following manner.

At low temperature the falling velocity decreases; the sedimentation takes place at a slower rate through the cooperation of changes in viscosity and density. The difference of density between the water and the particles decreases; thus the latter appear to be lighter. *Sediment-transportation takes place more easily during the winter than during the summer.* In the distribution of silt at different depths an equalisation enters at lower temperatures and the curves in Fig. 3 are straightened and are displaced somewhat to the right. Suspended matter also effects the density of water. OWENS (1911) has by experiments shown that the effect of suspended whiting on the specific gravity of the water was the same as if it had been dissolved. Fine suspended matter will retard the fall of larger particles to a great degree.

Influence of velocity-distribution. This factor does not play an important part in the ability of a river to transport a matter in suspension, above all, not at higher values for p. A change in the value of p from a relatively high value to a still higher value is almost always without effect upon the transportation of silt. At low values, however, a change can be of importance. The influence of the velocity-distribution is illustrated in Fig. 4, applicable for very fine sand ($c = 0.778$ cm. per sec.) assuming that $A_1 = 10$. The distribution of silt has been calculated when $p = 4$, 8, 12 and 20. It is easy to see that the last three curves lie close together, while the curve for $p = 4$ lies more at the side.

The influence of turbulence is, on the other hand, especially great. This is also to be expected since the mass-exchange is the most important condition for the maintainance of the particles in suspension above the immediate proximity of the bottom.

The mass-exchange caused by turbulence is characterized by the Austausch-coefficient, A_1, found in the formula. For the decision of the value of this coefficient very few fixed points are found, since the number of determinations of it for a river are still few. It is known, however, that it increases quite rapidly with velocity. KÖHLER (1933, p. 35) presumes that A increases somewhat more rapidly than the square of the velocity.

In the lowest layers of a flowing liquid A is almost proportional to the square of the velocity, and KÖHLER (1929) has deduced the formula

$$A_1 = a + b \cdot v^2.$$

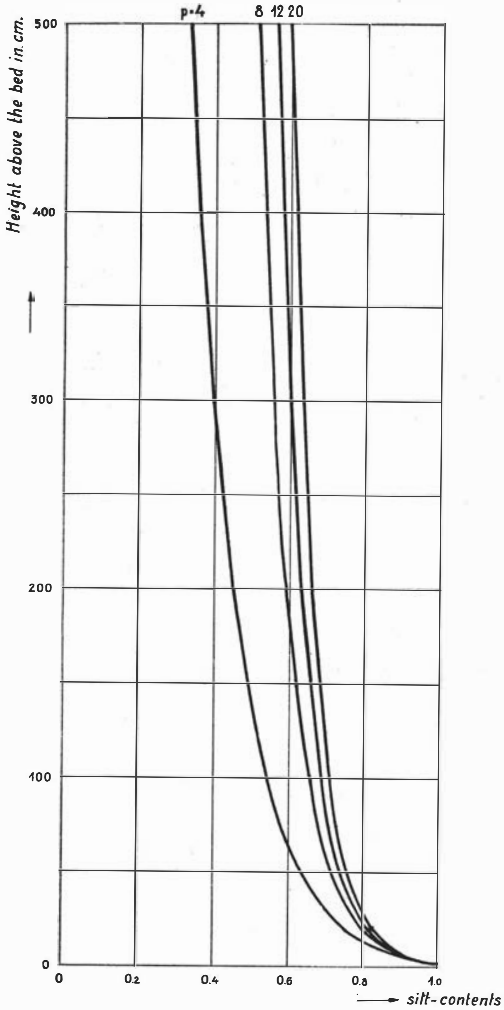


Fig. 4. The distribution of very fine sand in suspension at different heights above the bed for $A_1 = 10$ and different values of p, according to the formula on p. 273.

In this formula the constant a generally has a low value. It should be negative in order to indicate the laminar velocity-range below the critical velocity. The value of a should generally be difficult to fix directly, since at lower velocities other processes than the exchange-process are of influence — in the sediment-transportation for instance, the hydrodynamic upthrust.

Another factor which influences A is the roughness of the river bed. In KÖHLER's formula this is expressed by the constant b. A_1 naturally increases with incresed roughness as NIKURADSE's measurements show so well (1931, p. 245).

The turbulence also varies because of other factors, for example with the temperature — it decreases as the temperature decreases. Viscosity has no specially important influence. Certain influences, not well known, of the form of the river-bed are considered to be of more importance. According to PRANDTL (1933) and others the turbulence-conditions, for example, are quite different in sharp bends than in straight courses. These changes in turbulence which are produced by different causes have, as has been mentioned before, a very great influence on sediment-transportation. This influence is evident from the fact that when turbulence is increased the distribution of silt is more uniform; it is more easily transported. In the case of low values of A, however, transportation in suspension takes place only with difficulty — with the exception of clay — and is concentrated at the proximity of the bottom. Fig. 5 shows this fact in a very clear manner. The distribution of very fine sand ($c = 0.778$) has there (for $p = 8$) been shown in diagram form for 3 different values of A_1, namely, 1, 10 and 50. The first value may be considered to correspond to a slowly flowing level river, while $A_1 = 50$ represents the conditions in a more rapidly flowing river with greater »roughness». It is found that very fine sand at a height of 5 m. above the bottom still has a concentration of 88 % of the value at 2 cm. A level river transports, however, this very fine sand in suspension only with difficulty. Already at a height of 20 cm. the concentration has decreased to 10 % of the value at 2 cm.'s height. This fact will be further discussed later on. A dispute has arisen between hydro-technicists concerning the question, if one — for the obtaining of representative water samples — is entitled to assume that the distribution of silt is constant from the bottom to the surface. The present example, Fig. 5, shows that one, for the estimation of these conditions, must proceed with great carefulness. In the case of mountain rivers the change in the concentration of fine sand is quite negligible but for rougher matter the distribution becomes less regular. To judge from a surface sample from a level river there should be no transportation of very fine sand in suspension.

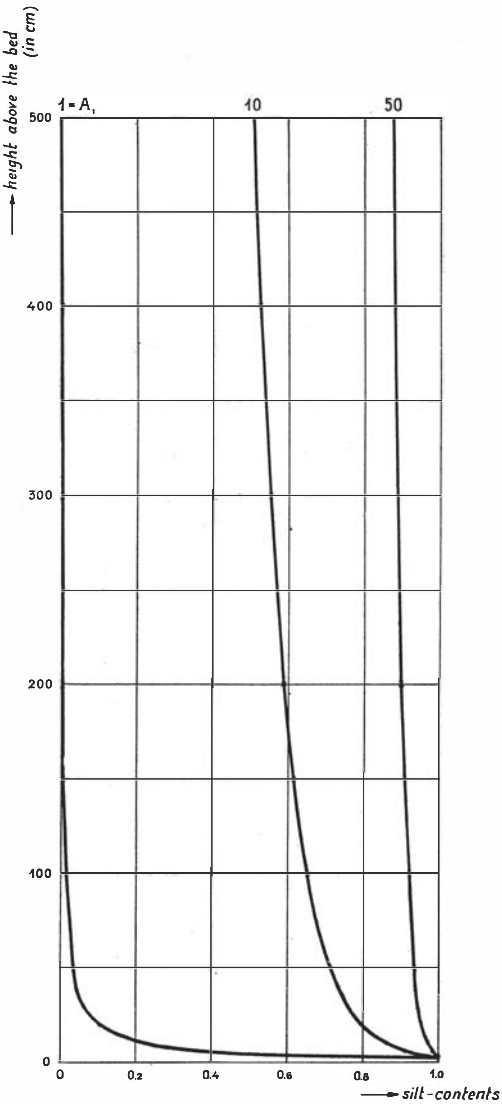


Fig. 5. The distribution of very fine sand in suspension at different heights above the bed for $p = 8$ and different degrees of turbulence.

Distribution of silt in the case of erosion and sedimentation. This discussed equation represents a state of equilibrium, the exchange-gravity-equilibrium. The river does not perform any other work than transportation; a state of equilibrium prevails with neither erosion nor sedimentation. In the sediment-management of the river neither increase nor decrease takes place.

If such is the case the distribution becomes irregular at least during the time which is required for the exchange process and gravity to establish the new state of equilibrium. For this transition the previously stated simple formula can no longer be applied; instead the following equation must be used because now the time-factor must also be taken into consideration:

$$\frac{\partial s}{\partial t} = \frac{\partial}{\partial z}\left(\frac{A}{\varrho} \cdot \frac{\partial s}{\partial z}\right)$$

where ϱ = density of the fluid.

HILDING KÖHLER (1932 and 1933) has succeeded in solving this equation also for variable A. KÖHLER assumes the validity of the law of potency and introduces as boundary conditions that at the bottom or at the ground s is a function of time only and that, at a certain starting time ($t = 0$) s is a function of height only. KÖHLER's general solution (see H. KÖHLER: Meteorologische Turbulenzuntersuchungen, I, equation 65, p. 45) will not be repeated here. He has, however, applied his result by computing the special cases which are applicable, among other things, to the question of erosion.

We assume that water in a river, disregarding the load of sediment, suddenly flows over the bottom with an easily erodable matter which the river can transport in suspension. The matter which is loosened by erosion is carried upwards by the influence of turbulence at the same time as new matter is being eroded. If the erosion continues so that the concentration remains constant = C at the bottom it will, in the water, according to KÖHLER (1933, p. 49—51) be:

$$s = C\left[1 - \frac{p^{\frac{2}{p+1}} \cdot z^{\frac{1}{p}}}{\Gamma\left(\frac{1}{p+1} + 1\right) \cdot (p+1)^{\frac{2}{p+1}} \cdot \left(\frac{A_1}{\varrho}\right)^{\frac{1}{p+1}} \cdot t^{\frac{1}{p+1}}}\right]$$

where Γ represents the so called gamma-function which is found tabulated for instance by HAYASHI (1926). It is evident that for any height the concentration increases uninterruptedly to a value close to the concentration C, which, however, it does not reach. In KÖHLER's formula presented above no consideration has been taken to the particles falling movement. Through the reduction made for this fact the concentration becomes less than presented here above.

If the water then flows over matter which it cannot erode and if sedimentation does not take place, the state of equilibrium determined by the equation on page 273 appears.

When erosion takes place this is apparent in the distribution of silt through higher concentration downwards than is in correspondance to the state of equilibrium indicated by the equation. The suspended matter no longer has equilibrium-distribution but is now under balance.

The conditions may also change towards the other direction so that a downward movement of the silt appears. This is due to a change of turbulence since a change of the other variable factor, the velocity-distribution, characterized by p, does not have such a large effect. With a decrease of velocity and of the roughness of the bed of the stream, a change appears in the silt-distribution at different heights; it aims at a new equilibrium-distribution. This new distribution matches a lower concentration in the upper layers, in comparison with the bottom layers, than was found before. At the same time there occurs a deposition of the roughest matter, if the river transports all possible grain-dimensions up to largest which it is able to transport along the bottom at the moment. Sedimentation, therefore appears. Before the silt has had time to adapt itself to the new state of equilibrium the water-layers higher up in the water have a higher concentration and the lower layers a lower concentration than is in accordance with the equilibrium-distribution.

Sedimentation appears in silt-distribution through higher concentration in the upper layers of the liquid than is in correspondance with the state equilibrium indicated by the equation on p. 273. The suspended matter has no longer equilibrium-distribution but is over equilibrium.

By confirming these two rules a method should therefore be available to decide directly through measurements if a river at a given moment is eroding, depositing sediment, or merely transporting. It should only be necessary to determine the percentage of silt — for one and the same c-value — at at least two different depths and then compare these values with those which were calculated from the equation. The Austausch-coefficient and its variation should naturally then be determined in another way than out of the silt-distribution.

A method for an immediate determination of the effect of a river on its matter in a cross-profile did not exist earlier. Within hydrotechnic it must be of an especially great practical value. At every river-regulation one must take a position in reference to this difficult question as to whether under the new off-flow conditions a risk is found for increased depth-erosion or possible silting up of the course. Especially large values are very often risked and the possibilities of beforehand-calculations are not great. KENNEDY's formula does not always give accurate results.

By the above outlined method it would be possible to decide, by determining the silt-distribution, A for different heights and p, at different velocities, at which limiting velocities erosion and sedimentation enter. If one wants to avoid the above mentioned processes it is easy by means of these limiting velocities to determine the new succession of water-stages so that these inconveniences are eliminated.

Even from a physiographical point of view it is important to know the morphological influence which different water levels and velocities cause.

The given method must, however, be applied with care and discrimination. First of all, the change in silt-distribution which the transverse circulations etc. cause, must be taken into consideration. Furthermore, the taking of samples must be done carefully as it is of importance to obtain a representative average of the percentage of silt. One supposition is that the ratio $\frac{c}{A_1}$ has such a value that the silt-distribution is really sensitive to a change in turbulence. If the transported matter is clay the distribution is quite independant of velocity and turbulence. In the concrete example which is illustrated by Fig. 3 the very fine sand seems to be an especially sensitive indicator; but in other cases other grain-dimensions might be more suitable.

As the suspended matter in the Fyris is composed of clay, with equal distribution over the profile, an investigation along these lines could not be carried out.

Distribution of silt over a cross-section.

The foregoing discussion applies only to a single perpendicular line in a current. The influence of the sides of the current has not been taken into consideration — as has been pointed out. Here arises, therefore, the difficult problem of the distribution of turbulence over a whole cross-section. From the theoretical viewpoint no solution has been presented — scarcely even a dealing of the problem. As it is three-dimensional it offers great difficulties.

Experiment. In order to obtain at least a general survey over the variations of the Austausch-coefficient along a perpendicular line and over a whole cross-section — and in order to verify the attempt made by WILHELM SCHMIDT — the following experiment was carried out in a canal where the disturbing subordinate circumstances occurring in a natural river were to a certain amount eliminated.[1]

The experiment was carried out in the large experimental channel in the Hydraulic Laboratory at the Royal Technical High School in Stock-

[1] See the preliminary report in HJULSTRÖM: Das Transportvermögen der Flüsse und die Bestimmung des Erosionsbetrages. Geografiska Annaler, 1932, pp. 244—258.

holm during the autumn of 1930 with the kind permission of the prefect of the Hydraulic Institute, Professor HJALMAR O. DAHL. The experimental channel in question was made of cement, was 30 meters long, 1 meter wide and 1.5 meters deep. The pumps were able to pump the water with a maximum velocity of a little over 1 m. per sec. About in the middle of the channel a metal pipe (3/4 of an inch in diameter) was laid across

Fig. 6. An experimental channel at the Hydraulic laboratory of the Royal Technical High School at Stockholm.

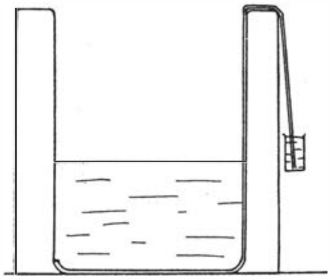


Fig. 7. Arrangement for measurement of the spreading of salt in a stream.

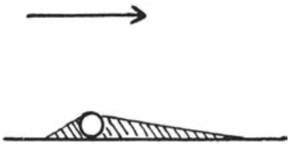


Fig. 8. The metal pipe and its plastercoating.

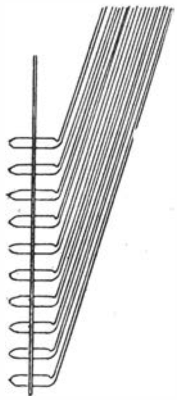


Fig. 9. The pipettes for sampling.

the bottom and from there upwards along one side into a cup with concentrated table salt-solution (Fig. 7).

In the part of the metal pipe which lay across the bottom a large number of small holes had been bored, the total surface of which did not quite amount to the cross-section area of the pipe. In order to avoid the forming of eddies and increased turbulence, the part of the pipe which was below the water surface was covered by a plaster coating (Fig. 8) in order to form a stream-line surface. When the water surface in the cup was slightly raised over the water-surface in the canal the table salt-solution poured out through the holes in the tube and then spread, through the influence of the »Austausch»-process, upwards in the water. In order to determine this spreading water samples were taken to determine the table salt-percentage at given points in the liquid. The sample-taking was carried out with the aid of an apparatus which is described in Fig. 9. Ten glass-pipettes each with a volume of 25—30 ccm. were fastened vertically one above the other, 5 cm. apart, to a perpendicular wooden frame-work. These dimensions were due to the fact that the experiments were carried out in a water-depth which was never more than 0.5 m. The glass tubes which led diagonally upwards were extended by a rubber tube which could be closed air-tight by a clamp. The whole apparatus was immersed in the water and the clamp opened so that some of the air escaped whereby the pipettes were slowly filled with water.

In order to obtain a good average value for the table salt percentage it is important that the water is caused to run slowly into the pipettes. When these have been closed at the top the apparatus can be taken up from the water and emptied into a test-tube. The most suitable way to do this is to place the test-tubes in a rack 5 cm. apart; then the apparatus may be held above and emptied by opening the clamp.

The measuring of the table salt percentage was carried out by measuring the electric conductivity, by means of which great exactitude was obtained. Before the beginning of the tests a sample of the water (tap-water from the water-system) was taken and its conductivity was determined. By the addition of known quantities of salt-solution a rating curve was determined from which the salt percentage of the samples could be read.

In order to determine the salt percentage at different points of a cross-section, 5 such pipette-holders were fastened beside each other in a rack. By this means samples from 50 different points of one half of a cross-section were obtained simultaneously. Fig. 10 shows the position of the sample-points in relation to each other. The samples were taken at four different sections one after the other; the first sample was taken 9 meters from the introduction-point of the table salt solution, and the others at intervals of 4 meters, numerated I—IV.

In connection with the taking of the samples measurements were made of the velocity at different depths with the help of an OTT current meter in order to obtain complete curves for the velocity-distribution. For the sake of control a calculation of the water-mass was made, by conducting, during a certain number of seconds, the water flowing from the canal into a basin with a known cross-section area. By reading the water-height in the basin the water-mass could easily be determined. At the same time the temperature of the water was read.

According to the general rules for experimental investigations of this type[1] such investigations should be carried out only at a distance of 50—100 times the breadth of the channel, from the place where the water is introduced; thus avoiding surging or eddying movements at the upper end of the channel. This rule could not be followed because of the great width of the channel. The distance in question was only about 12 times

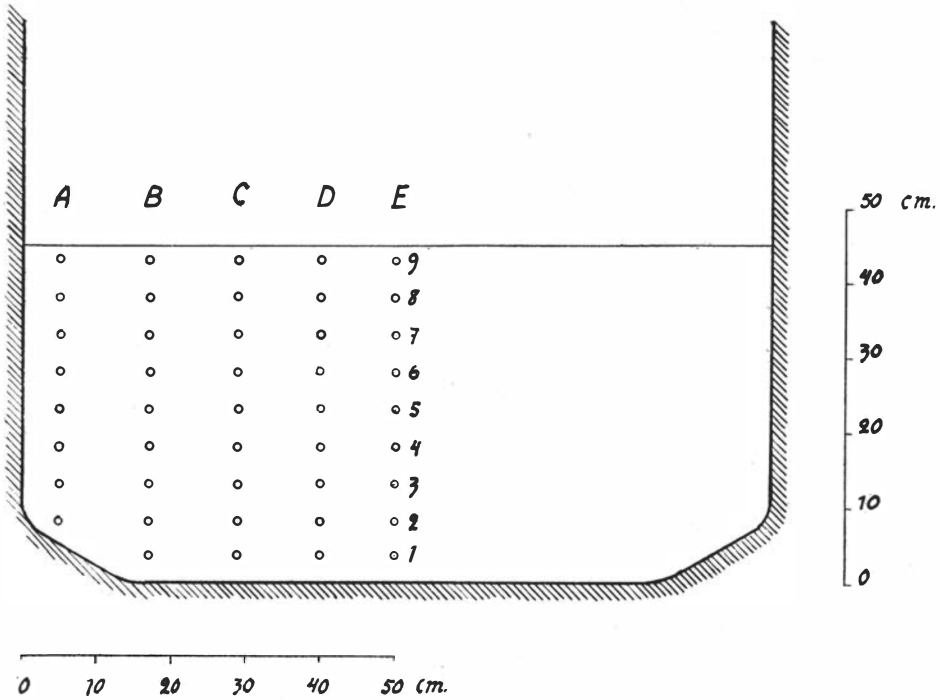


Fig. 10. Diagram of the situation of the sample-points.

the breadth of the channel. In order to obtain a calmer flow of the water, a special grating with parallel wooden bars was arranged at the upper end of the channel. It is possible, however, that in spite of these precautions certain irregularities were present in the current which caused a smaller degree of exactitude in the measurements which, in turn, caused some irregularities in the results.

These irregularities were especially noticeable at high velocities. Here the fact appears that the plaster-coating of the pipe for the supply of the salt-solution was sometimes removed by the water. Thereby the turbulence increased, a ground roller appeared at the tube, and the salt-solution was

[1] See for instance EISNER: Offene Gerinne, in Handbuch der Experimentalphysik, Band 4: 4, Leipzig, 1932.

immediately forced high up in the current in an abnormal manner. The ground roller could be easily observed because of the movements of solid particles and impurities in the water. It was also shown by the distribution of the contents of salt in the water. In such a case this was abnormally high at a height of about 20—30 cm from the bottom. — On the other hand, pulsations have an impeding influence at low velocities. It is difficult to obtain average values which are required by the theory without taking especially large volumes as samples — considerably larger than the pipettes which were used.

Only by building the pipe, which introduces the salt-solution, in the bottom itself so that an even surface is obtained — preferably in a long or narrow canal with calmly flowing water — and by procuring samples of greater volume would it be possible to make measurements of the intensity of the turbulence over a large range of velocities.

In the following a measurement (Nov. 12, 1930), with a water-mass of 0.43 m.[3] per sec., a waterdepth of about 45 cm. and the distribution of velocities which is given in Table 4 will be more fully described.

Table 4.

Velocity of the water in the sample points, cm./sec.

	A	B	C	D	E
Surface	68	76	82	84	85
9	71	79	84	87	88
8	72	80	86	88	89
7	72	80	86	88	89
6	71	79	85	87	88
5	70	78	84	86	87
4	68	76	82	84	85
3	66	74	80	82	82
2	60	68	75	77	77
1	(54)	62	68	70	71

In this table are shown the velocities for the sample points. They consist partly of direct measurements (15) and partly of interpolated values.

The measured values for the salt percentage are shown in Table 5.

As is seen, several irregularities appear in the profiles further away which made their use difficult for calculations. Only the following series have been used: I A, B, C, D, E, II A, B, C, D, III C, E, and IV E. Profile I is therefore complete, and the salt percentage in it is given in Figure 11.

Table 5.

The concentration of salt in the sample points. (Exp. Nov. 12, 1930).

	Section I					Section II				
	A	B	C	D	E	A	B	C	D	E
9	0.0	0.0	0.6	0.0	0.0	0.0	0.0	3.1	0.0	0.0
8	0.0	0.0	0.9	0.0	1.2	0.0	3.2	5.5	0.0	0.6
7	3.8	0.4	1.8	0.2	3.0	7.0	6.2	6.9	2.4	2.1
6	9.7	3.9	7.5	0.9	5.0	16.3	13.4	13.3	4.7	5.9
5	26.4	16.9	19.2	5.5	9.1	34.2	22.1	22.2	12.8	6.8
4	48.0	24.6	36.3	19.0	21.9	53.6	34.4	35.1	24.9	22.5
3	89.0	41.6	50.0	34.4	48.1	82.3	46.5	45.3	39.1	54.0
2	144.2	72.0	62.1	63.0	75.5	124.8	62.4	54.5	60.3	76.9
1		115.0	89.9	130.2	124.8		88.8	74.4	110.7	119.7
	Section III					Section IV				
	A	B	C	D	E	A	B	C	D	E
9	0.0	0.0	8.6	1.1	0.0	0.0	3.9	15.3	8.9	7.2
8	4.3	1.0	9.9	3.1	1.5	3.4	19.7	18.4	11.0	7.7
7	10.2	5.4	11.8	4.0	3.9	20.1	21.3	18.6	21.7	8.9
6	23.6	8.1	16.8	8.8	6.0	36.9	27.2	20.1	23.3	13.7
5	54.1	9.4	22.6	19.5	17.5	49.1	28.5	23.5	27.6	20.9
4	56.7	30.6	32.9	30.7	28.9	63.7	65.4	28.3	29.4	29.1
3	61.6	33.3	38.8	51.4	41.2	53.7	65.1	34.6	32.2	38.3
2	123.1	49.7	46.9	56.9	57.7	31.4	31.2	38.7	37.5	48.9
1		52.4	60.0	65.7	98.9		57.2	41.3	41.9	67.6

In this figure the salt percentage has been illustrated by lines which connect points with the same salt percentage. As is seen, these lines do not run parallel to the bottom but show very strange deviations. At half the depth the deviation is thus greatest about half-way between the side and the middle of the current. Higher up the deviations become even greater, and the curve for a salt percentage of 1 mg. per lit. has an especially curving form. These facts indicate an irregular distribution of the intensity of the turbulence.

The Austausch-coefficient has been computed in a graphical way direct from the formula:

$$\frac{\partial s}{\partial t} = A \cdot \frac{\partial^2 s}{\partial z^2}$$

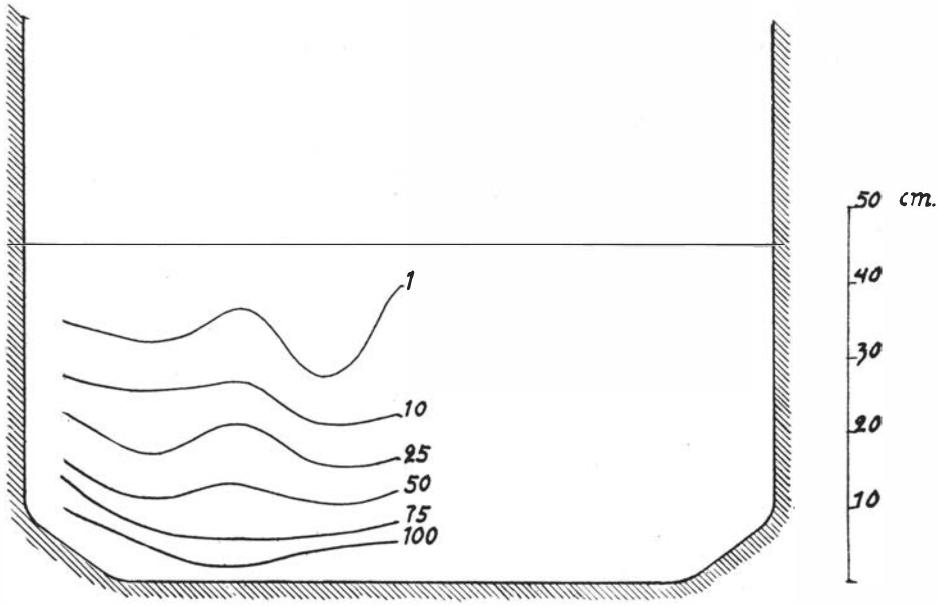


Fig. 11. 5 meters downstream a place, where a salt solution has been uniformly supplied from the bottom, the salt has a distribution as indicated by the isarithms for a salt content of 100, 75, 50, 25, 10 and 1 mg./liter.

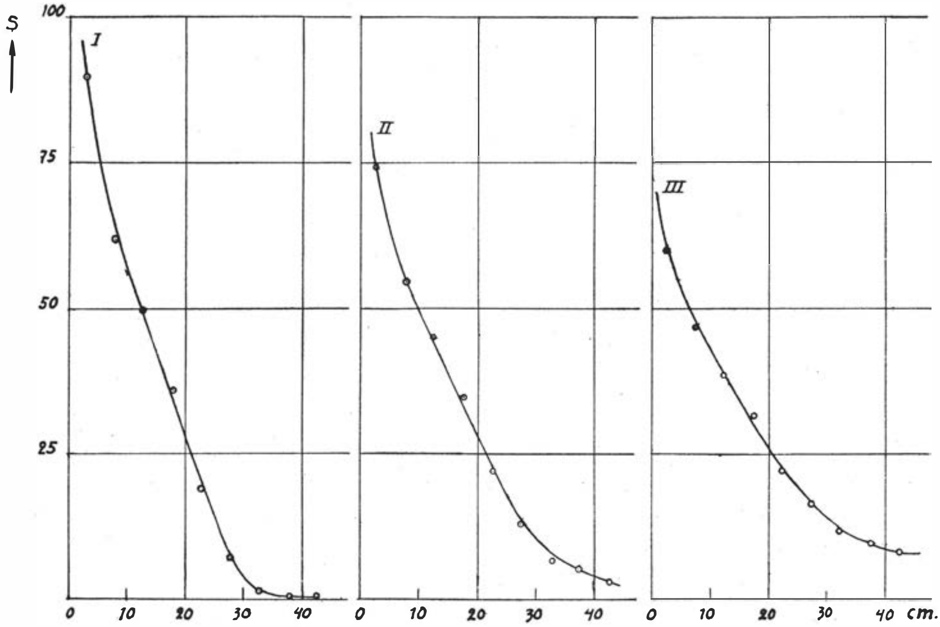


Fig. 12. The distribution of salt at different heigths, 5, 9 and 13 meters downstream the pipe supplying the salt solution. The curves for I C, II C and III C.

so as to avoid every kind of assumption. Curves were drawn for the salt percentage as a function of time and of the height above the bottom; the derivatives were obtained by drawing the tangents. As an example, the appearance of the curves for the distribution of the salt solution at different heights at a distance of 27.5 cm. from the wall of the canal (Series C) is given in Figure 12.

As is seen, the salt percentage decreases upwards in a rather uniform manner. At a greater distance from the pipe which introduces the salt, its distribution, however, becomes less accentuated; the salt becomes more uniformly distributed. At a great distance all differences are evened out, and the whole water-mass has assumed the same salt percentage. This levelling process is shown more clearly in Fig. 13.

The isarithms for the same salt percentage are spread out more and more as the distance from the profile where the salt-supply takes place increases. The velocity at different heights along the considered perpendicular is shown in Fig. 14.

When the salt-supply begins and a stationary state has not yet appeared the distribution is therefore quite different. Salt which is forced up to a higher layer is carried downstream by this layer. Higher layers can therefore in this case have a greater salt percentage than lower layers — this, however, only for a short time before the lower water layers have had time to increase their contents of salt. An example of this is shown by section 4 in Table 5. It was important not to let out too much salt into the water with respect to the increased corrosion of the pumps, and this sample has possibly been taken too early, before equilibrium has had time to appear. — Similar conditions appear of course with the transportation of suspended matter in natural rivers. If solid matter is suddenly eroded and carried in suspension, the water layers which lie a bit higher up than the

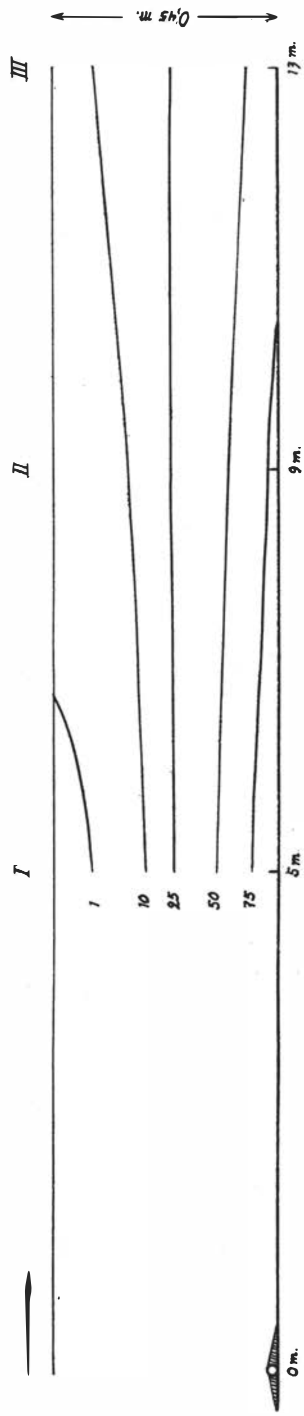


Fig. 13. Longitudinal profile through the perpendiculars C showing the distribution of salt above the bed.

Table 6.

The values of the Austausch-coefficient in the sample points.

	A		B		C		D		E	
		Average		Average		Average		Average		Average
9					I: 2.34 II: 2.57 III: 2.30	2.40				
8					I: 1.68 II: 1.77 III: 1.76	1.74			I: 0.98 II: 1.45 IV: 1.79	1.41
7	I: 0.33 II: 0.35	0.34	I: 0.52 II: 0.83	0.68	I: 0.62 II: 0.80 III: 1.23	0.88	I: 1.16 II: 0.20	0.68	I: 0.53 II: 0.88 IV: 0.80	0.74
6	I: 0.32 II: 0.38	0.35	I: 1.04 II: 1.20	1.12	I: 0.80 II: 0.94 III: 1.01	0.92	I: 0.43 II: 0.49	0.46	I: 0.52 II: 0.66 IV: 1.02	0.73
5	I: 0.38 II: 0.32	0.35	I: 1.24 II: 1.40	1.32	I: 0.52 II: 0.44 III: 0.48	0.48	I: 0.50 II: 0.94	0.72	I: 1.17 II: 1.26 IV: 1.29	1.24
4	I: 0.28 II: 0.32	0.30	I: 0.91 II: 1.47	1.19	I: 4.55 II: 2.86 III: 3.67	3.70	I: 0.93 II: 1.26	1.10	I: 0.94 II: 0.81 IV: 1.30	1.02
3	I: 0.18 II: 0.23	0.21	I: 0.31 II: 0.45	0.38	I: 2.96 II: 2.62 III: 2.84	2.81	I: 0.35 II: 0.48	0.41	I: 0.72 II: 0.26 IV: 0.68	0.55
2	I: 0.25 II: 0.17	0.21	I: 0.30 II: 0.46	0.38	I: 0.63 II: 0.56 III: 0.63	0.61	I: 0.05 II: 0.14	0.10	I: 0.45 II: 0.30 IV: 0.42	0.39
1			I: 0.29 II: 0.29	0.29	I: 0.38 II: 0.40 III: 0.37	0.38	I: 0.19 II: 0.25	0.22	I: 0.19 II: 0.21 IV: 0.31	0.24

bottom-layer suddenly become enriched, and below the place of erosion the top-layers may have a larger silt-content than the underlying layers. This condition reminds one of temperature-inversion in the atmosphere and causes naturally an increase in turbulence.

From the values of the derivate $\frac{\partial s}{\partial z}$, computed from regular curves such as those in Fig. 12, new curves, showing this derivative as a function of the height, z, have been drawn and from these the second derivative has been calculated. No regard has, therefore, been taken for any horizontal diffusion, caused by turbulence. Since the change in the salt percentage here is small, an error can not have been caused by this. — The values of the Austausch-coefficient, obtained in this way, are given in Table 6, and their average value in Fig. 15.

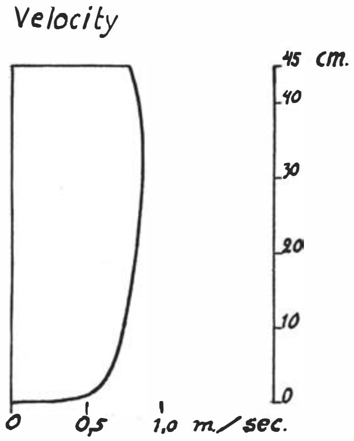


Fig. 14. The velocity in the sample points C 1—C 9.

The isarithms show a very complicated course. The exchange-process has its greatest intensity not in the middle but in two centres (the picture is assumed to be symmetrical), one on each side of the middle line and somewhat below half the depth. These are connected with a zone of rather high turbulence which then extends obliquely upwards towards the sides of the canal. Upwards from this centre with high turbulence the cofficient A decreases, but then again obtains a higher value near the surface. Within this upper zone with intensive turbulence the state of turbulence seems to be especially unstable judging from the rather varying values which are obtained (Table 6) for the points concerned.

The complicated states of turbulence, given in Fig. 15, deviate considerably from the more simple regularity which has been taken for granted at the deduction of the formulae on p. 273, and which should be used, until a more general law for the variations in A can be established.

The obtained distribution of the turbulence seems to agree with PRANDTL's formula:

$$A = \varrho \cdot l^2 \cdot \frac{dv}{\partial z}$$

where v=the velocity and l=the mixing path. A has its highest values where the change in velocity is greatest, with the exception of the bottom itself, where the mixing path is small. The two centres of turbulence are separated because in the middle of a channel the change in velocity along the vertical does not reach such high values, usually, as nearer the sides. —

By measurements in pipes and closed channels NIKURADSE (1929, 1931) has found, that A has its maximum value halfway between the wall and the central line. Because of the symmetry, however, no separated maxima of turbulence exist here.

For open channels and rivers JOHN B. LEIGHLY (1932) has published the only hitherto present calculations of the intensity of turbulence as ex-

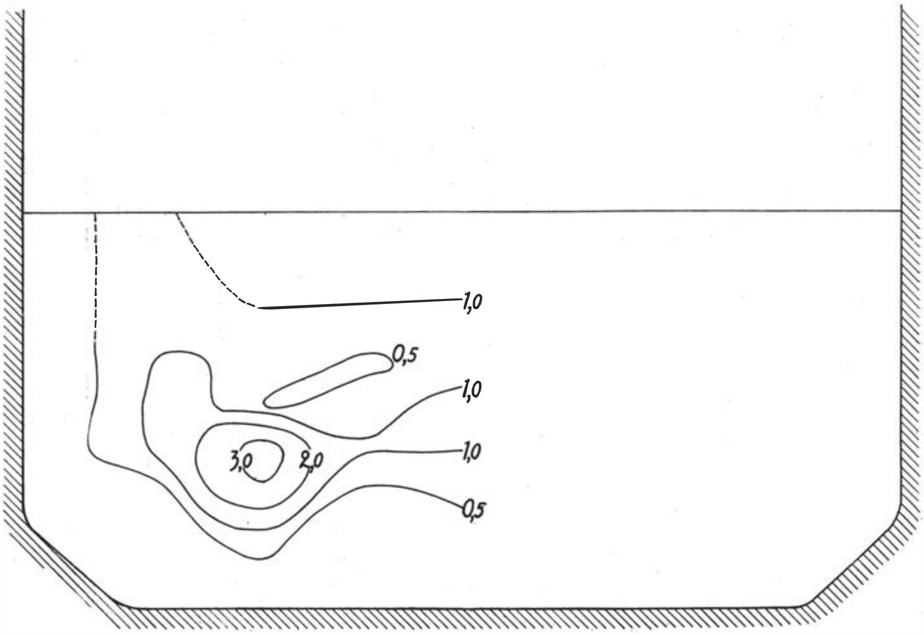


Fig. 15. The distribution of the Austausch coefficient in a cross section.

pressed by the Austausch-coefficient. Starting from a formula expressing the shear stress on the bed, often used in hydraulics, he deduces the expression

$$A_z = -\frac{m_z \cdot g \cdot \mathcal{J}}{\left|\frac{du}{dz}\right|_z}$$

where $\mathcal{J}$ is the slope and m_z the mass of water in the proximal part of a prism of water from the line of maximum velocity and limited by lines normal to the surfaces of equal velocity. In a later paper (1934) LEIGHLY has also used SCHMIDT's equation for the distribution of suspended matter for determining the average of A.

LEIGHLY's pictures show a striking conformity with the result of the investigation described here. He has also the characteristic presence of two maxima, one on each side of the central vertical.

LEIGHLY's conclusion that the contents of silt must be great in these flanking threads of turbulence is strengthened by Fig. 11.

The morphological significance of this distribution of the intensity of turbulence has been formulated by LEIGHLY (1934, p. 463): »All stream deposits are formed in areas that are lateral to some thread of maximum velocity and its flanking threads of maximum turbulence.» Perhaps this law may be explained in the following way. The velocity at the bottom is largest below the thread of maximum velocity; the scouring power is great here. At some distance from this line, for example below the threads of maximum turbulence, the erosion is probably still great on account of the turbulence, in spite of the somewhat lesser velocity. At any rate there is, however, no deposition here as the matter transported is especially easy carried away.

As to the values of A these are much higher in natural streams than those found in the flume. According to LEIGHLY's interesting papers they reach values of several thousands in large rivers; in the Fyris the writer has obtained values up to 75 from measurements of the silt content. Naturally the velocity has an influence in this case as well as the roughness of the bed, but perhaps the dimensions of the rivers are of importance as well. The mixing path may in large rivers attain great values.

CHAPTER III.

Erosion, transportation and deposition.

Erosion.

The force with which a running fluid influences its bedding, causing erosion and transport of any material there, depends upon the qualities and velocity of the fluid. For any certain specified fluid the *velocity* decides the erosion and transportation, other conditions being similar in the various instances. A great number of investigations have also been made in order to fix quantitative laws for the influence of the velocity. However, the results arrived at generally do not agree with each other very well. According to the various writers the same material is eroded at differing velocities. It is thus not surprising that, within the technic for solving practical hydraulic construction problems, the principle of using the velocity as an independent variable is being relinquished. An additional reason for doing this is that the conception velocity is somewhat indefinite, as surface-, bottom-, or average velocity may be referred to but not specifically mentioned. In the technic, one has instead endeavoured to make a change to more easily definable factors, such as slope, depth or hydraulic radius. French and German hydraulic construction technicists have introduced the conception »force d'entrainement», »Schleppkraft» or »Stosskraft», tractive force, in which these units are included, a conception which has been used with success in many cases. — But, not even by using that conception has it been possible to make any considerable approach to solving the problem of the bed-load movement. From a survey of most of the published data on bed-movement O'BRIEN and RINDLAUB (1934) have concluded that none of the equations for critical tractive force or rate of bed-movement is, however, sufficiently reliable to be used for design.

From a geological point of view the introduction of the conception tractive force means no advantage, rather the contrary. The problem of explaining a certain series of layers or stratification would certainly be desirably facilitated by a knowledge of the depth, and such information may sometimes be obtained by the aid of geological methods. But the slope and the hydraulic radius of the stream that has transported the material concerned are generally of no great interest, and can but seldom be determined. From a geological and geographical point of view it would appear more advantageous to relate the qualities of the sediments to velocity rather than to a product of other factors; this also from a mechanical point of view.

Relationship between erosion velocity and grain size.

Even though the principle of expressing the force of erosion and traction as a function of the velocity has, to a certain degree, been considered antiquated and out-of-date, investigations have been made during the last few years to make clear this relationship. In the following there are mentioned some points of view on the erosion, transportation and deposition of bedload based on old and new investigations. They are mainly caused by an endeavour to give a graphical picture of the relationship between the kind of material and the minimum erosion velocity, and would appear to be confirmed by the writer's observations in the field and in laboratory.

In order to express the relationship mentioned it is necessary first to more clearly define the variables, the velocity and kind of material. As far as the speed is concerned it would certainly, to obtain an exact result, be necessary to have a whole curve or formula stating the variation of the velocity according to the height above the bottom. As such a diagram is never obtainable it would certainly be preferable to use the bottom-velocity. But this is only stated in a limited number of cases, and is more difficult to decide than the surface- and average velocity. For these reasons the *average velocity* has been made use of, it being presumed that this is 40 % greater than the bottom velocity. This percentage depends inter alia upon the depth, but it has been presumed that this exceeds one meter. In shallower water the velocities stated here will be somewhat less, roughly about 10—20 cm./sec. less. — Greater demands as to exactitude cannot be satisfied at present.

The kind of material is, of course, characterized by the specific gravity, the shape and grain size of the particles. The last mentioned quality is undoubtedly of paramount importance, seeing that the shape has no very great effect, which is shown by experience, and the specific gravity is subject to but slight variations, 2.6—2.7. As indicated by modern investigations, for inst. GILBERT's in 1914, SCHAFFERNAK's in 1922 and KRAMER's in 1932, the composition of the material as to grain size is of very great importance. For different relative relations of quantity between the grain sizes in various materials the corresponding erosion velocities will vary, also in cases when these sizes are the same. It may be this complicated influence of the composition of the material that causes the results of all investigations of the relation between the velocity of erosion, transport and the grain size to become so inconsistent, as mentioned above. For a graphical picture the least complex case has been selected, i. e. when the material is uniform, monodispersed. But also in such cases varying results were obtained. A body is put in motion at varying velocities, dependent upon whether it is on a rough or a smooth bedding. A severely defined and practical starting point is obtained by presuming that *a uniform material moves over a bedding of loose material of the same grain size*. Table 7 gives the values stated in the literature to correspond to erosion, i. e. a spontaneous starting of quiescent material under these conditions. This velocity will in the following be called *erosion velocity*.

The difficulties encountered when making such a comparison are firstly that it is not always possible definitely to decide whether the erosion velocity in question under the conditions stated really is that concerned, and secondly that the statements of velocity, depth and grain size occasion certain questions. The information selected and contained in the table is not all equally reliable, LAPPARENT's might be questioned seeing that in his observations the eroded material was not always moved over a bedding consisting of the same material. The same lack is the most common cause for other observations having to be excluded, and it mostly occurs when studies of natural rivers have been made. On the other hand laboratory tests must also be excluded for highly dispersed systems such as clays, as the stratification may have been changed due to silting. In cases where the surface-velocity has been stated, it has been reduced 20 % to obtain the average velocity, and — as already mentioned — the bottom-velocity has been increased by 40 %.

The question of varying velocities is connected with that of varying depths. The difference between the bottom-velocity, important with regard to erosion, and the average velocity used in practice, is increased with the depth. THRUPP (1908) has made a graph of the scouring power in relation to velocity and depth, Fig. 16 being an extract showing the course of a curve. It is, however, reproduced very reluctantly as it appears to be founded upon a rather limited amount of observation material, and as it is not for uniform material. Generally speaking, it might, however, be said to give a correct idea of the conditions, at least for limited depths when the material for observation is more comprehensive. The curve in the figure states the velocity for which coarse sand is moved. — The velocities given in Table 7 and in Figures 17 and 18 are for slightly varying depths, but in most cases a correction has been inserted when the figures stated have been for such limited depths as 1 foot by adding 0.2 m./sec. The

Table 7.

Erosion velocities for a monodisperse material on a bed of loose material of the same size of particles.

Author:	Characteristics of the material (by the resp. author)	Size of particles	Erosion velocity
		mm	cm/sec.
Etcheverry (Fortier and Scobey p. 951)	Stiff clay soil	(0.0015)	137
Fortier and Scobey	Stiff clay (very colloidal)	(0.0015)	130
» » »	Alluvial silts, when colloidal	(0.005)	130
» » »	» » » non-colloidal	(0.005)	76
Umpfenbach (Penck, 1894, p. 283)	Feiner Lehm und Schlamm	(0.05—0.1)	26
Etcheverry (Fortier and Scobey)	Very light pure sand of quick-sand character	(0.13)	27
Gilbert, 1914, p. 69	Grade B	0.38	24
Lapparent (Schoklitsch, 1914, p. 25)	Schlamm, grob	0.40	15.0
Telford (» , » , » »)	Feiner sand	(0.45)	15.2
Gilbert, 1914, p. 69	Grade C	0.51	28
Lapparent (Schoklitsch, 1914, p. 25)	Sand, fein	0.70	20
Gilbert, 1914, p. 69	Grade D	0.79	34.1
» , » , » 70	Grade E	1.71	34.4
Etcheverry (Fortier and Scobey, p. 951)	Coarse sand	(2)	45 à 60
Schaffernak, 1922, p. 14		2	25
Sainjon (Schoklitsch, 1914, p. 24)	Kiesel	2.50	50
Gilbert, 1914, p. 70	Grade F	3.17	54
Schaffernak, 1922, p. 14		4	49
Gilbert, 1914,	Grade G	4.94	64
Schaffernak, 1922, p. 14		6	61
Gilbert, 1914, p. 70	Grade H	7.01	85
Schaffernak, 1922, p. 14		8	81
» ,		10	104
» ,		12	120—125
» ,		14	125—150
» ,		16	130—180
» ,		20	189—197
» ,		25	203—210
» ,		30	218—221
» ,		50	238
» ,		70	266—280

velocity statements may thus be said to cover depths of at least one meter. FORTIER and SCOBEY (1926) state this correction to be suitable. But the greatest difficulties have been encountered when the size of particle should be defined. The literature often contains such very indefinite statements as for inst. »large stones». The Table has therefore been made to include both the information supplied by the writer in question and the numerical value of the size of particle stated in the Diagram. This has been put in brackets in Column 4 in case it was not given in the original. The valuation then made has, of course, occasioned a certain subjectivity due to the existing confusion in the terminology in this sphere.

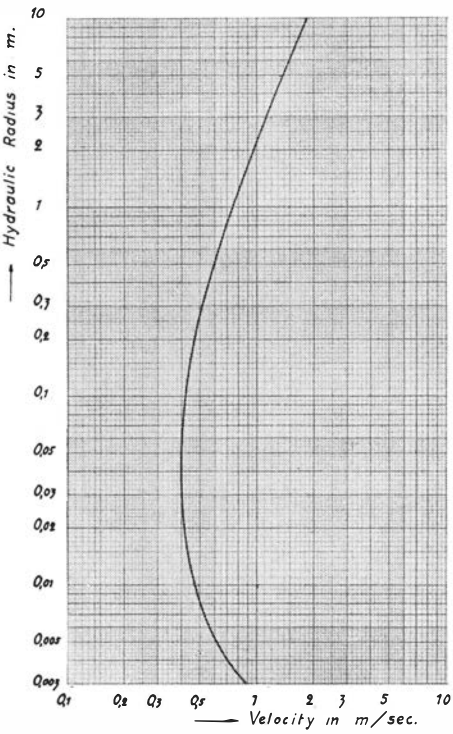


Fig. 16. The scouring power for coarse sand in relation to velocity and depth, according to THRUPP (1908).

These are the reasons why the curve in Figures 17 and 18 has not been shaped as a simple curve but as a zone. It must of course only be considered as an endeavour to make a preliminary comparison of the results obtained up to date, and may later be replaced by a more exact relation. But this will require much additional work.

In Figures 17 and 18 the values of the Table have been made the basis of a graph. (Note the upper curve.) The Figures show the same thing, but in Figure 18 the values have been dotted in a logarithmic scale in order to more clearly illustrate the interesting conditions connected with a small size of particle in a better manner than is possible in an ordinary scale.

The most noticeable deviations of the erosion curve in these illustrations from older accounts, for inst. SCHAFFERNAK'S (1922, p. 14) and S. A. ANDERSEN'S (1931, p. 33), is that it has a minimum and does not go down to the origin of the coordinate system. The minimum is not at the size of particle 0 but within the range 0.1—0.5 mm. This thus indicates that loose, fine sand, for inst. of quicksand character is the easiest to erode, whereas silty loam and clay as well as coarser sand and gravel, etc. demand greater velocities.

The great resistance of the clay to erosion was first strongly empha-

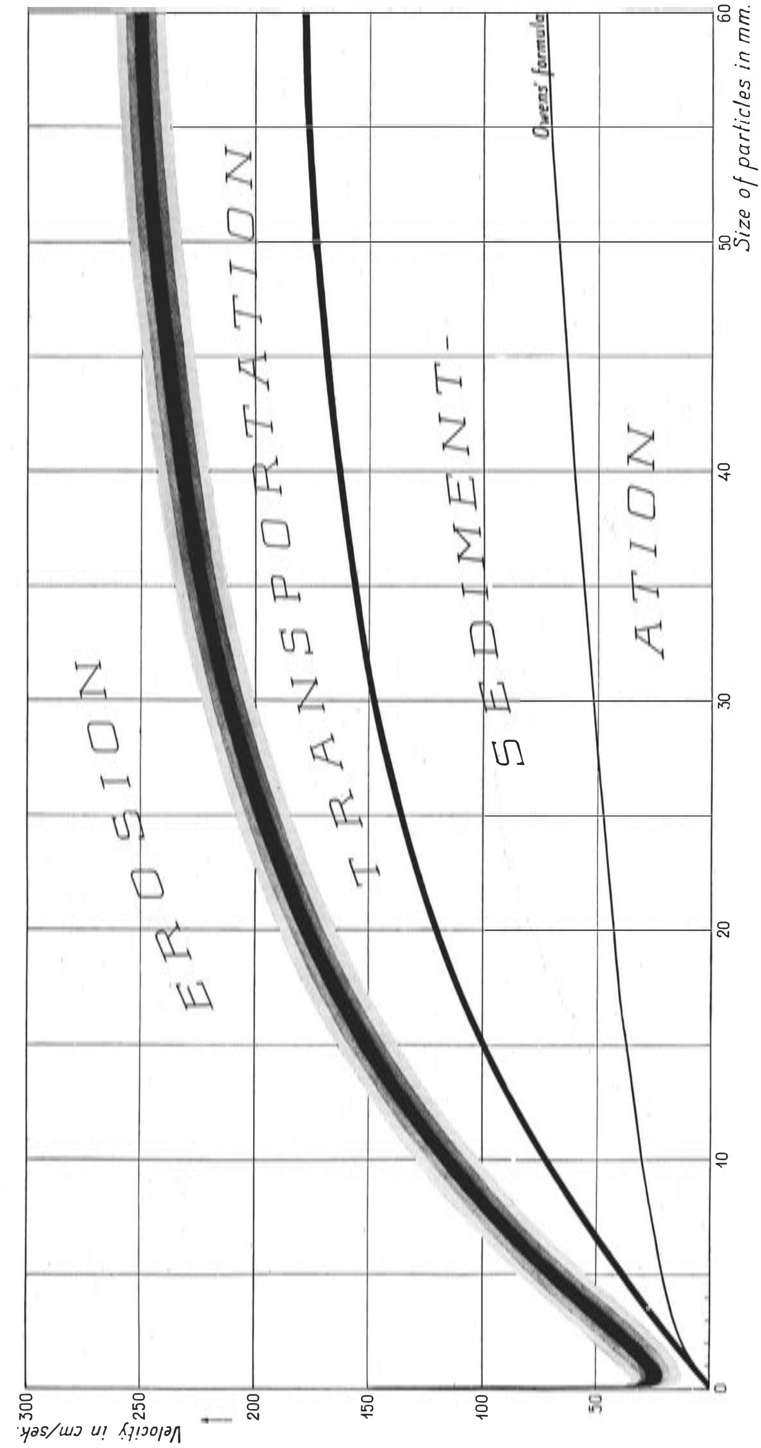


Fig. 17. The curves for erosion and deposition of a uniform material.

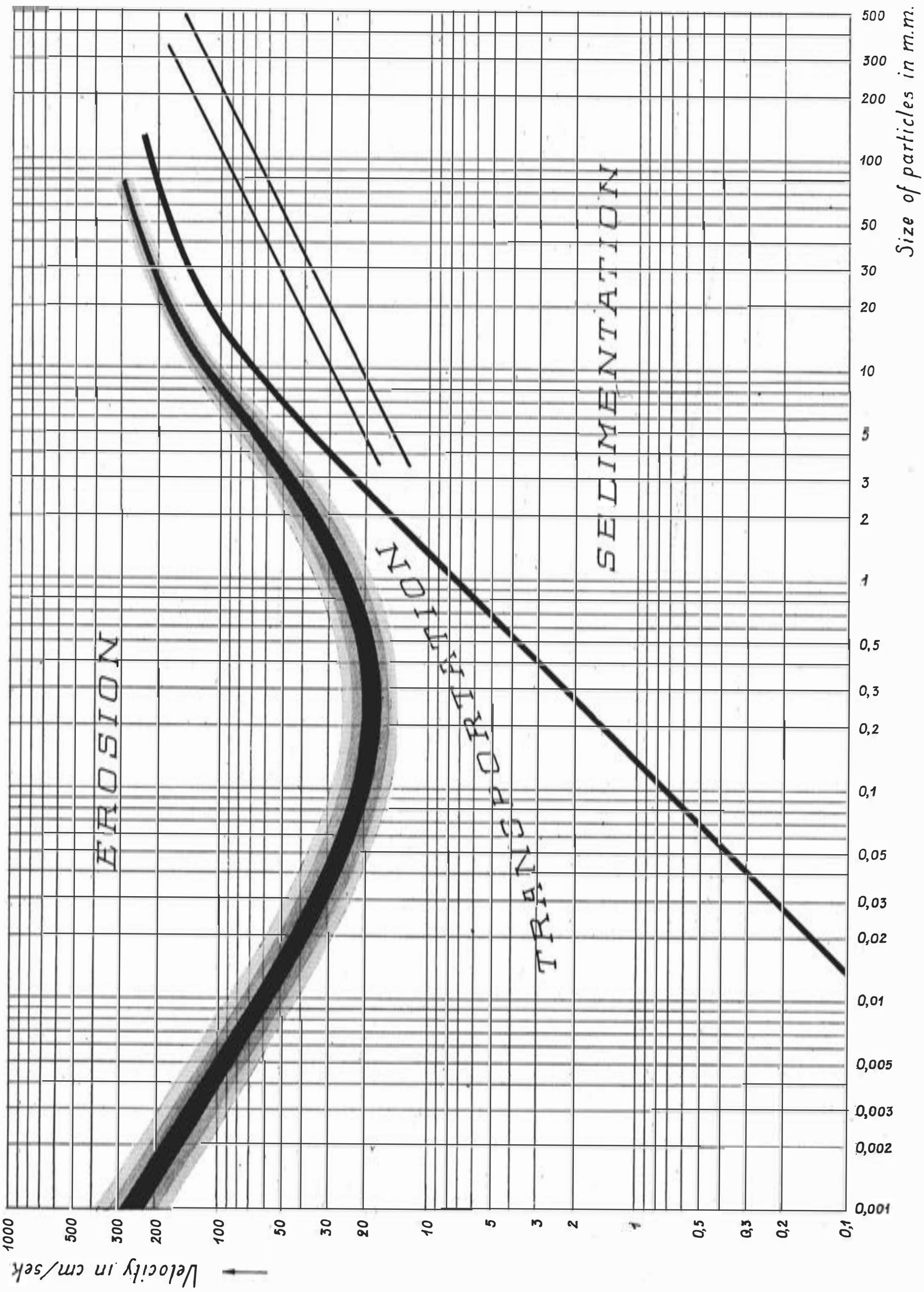


Fig. 18. The curves for erosion and deposition of a uniform material. (Logaritmic scale).

sized by the American hydraulic engineers FORTIER and SCOBEY in a paper on permissible canal velocities 1926.

This quality in clay of course depends upon the influence of cohesion and adhesion, which powers tend to unite the particles. The effect increases in line with an increased degree of dispersion, inter alia due to the number of contact points between the particles of a certain weight quantity thus being increased. It is therefore only when the size of particle is small that they become noticeable in the erosion. See for inst. DENSCH in Handbuch d. Bodenlehre, Vol. VI and BRENNER 1931.

In hydraulics it must certainly be considered of great importance to be able to calculate with these great erosion velocities for clay, for consequently the cross-section of for inst. a projected irrigation canal may of course be made correspondingly smaller and the cost of construction be reduced. Even though this condition was but recently pointed out, it is an old observation. FORBES (1857, p. 475) gives the following result of experiments tried inter alia on brick-clay from Portobello: »The brick clay in its natural moist state, had a specific gravity of 2.05; and water passing over it for half an hour at a rate of 128 feet in the minute, which was the greatest velocity I could conveniently obtain, made no visible impression on the clay. When this clay was mixed with water, and allowed to settle for half an hour, it required a velocity of fifteen feet in the minute to disturb it. This mud sank in water at a rate of 0.566 feet in one minute, but the very fine particles were very much longer in subsiding.» In a work by ETCHEVERRY[1], not obtainable in Sweden, quoted by FORTIER and SCOBEY, it is also mentioned that stiff clay soil and ordinary gravel soil have the same maximum mean velocity safe against erosion, namely 4.00—5.00 feet per second (121.9—152.4 cm/sec.). When engaged on engineering work for irrigation in India already in 1874—75, also KENNEDY (quoted from GIBSON 1919, p. 345), when publishing his oft-used formula for the critical velocity at which a long canal will maintain its channel in silty equilibrium, stated that this velocity is greater for loam and silt than for light or coarse sandy soil.

Finally, also CHATLEY (1921) in his silt-studies in China arrived at the conclusion that silty and clay beds will bear very much higher velocity than sandy beds. He has made the formula

$$v = \frac{0.02}{d} \text{ centimetres per second,}$$

v being = the erosion velocity and d = the size of particle. It is valid for grains held in place only by mutual cohesion, thus for the ascending branch in Figures 17 and 18, and agrees very well with these. CHATLEY

[1] ETCHEVERRY: Irrigation Practice and Engineering. Vol. II: The Conveyance of Water. New York 1916.

states that the actual limits of velocity (200 cm/sec.) and grain-size (0.0001 cm.) in the Huangpu and Yangtze also agree with the formula. A qualitative graph of the variation of eroding velocity with size of particles also exists, in the main corresponding with the curves made by the writer.

Mixed materials.

As already mentioned these reflections are valid for uniform material. Certainly such material is not unusual, but generally, the tractional load of a natural stream includes particles with great range in size. Erosion velocity in this case means the velocity for which also the greatest size, that a *great* number of particles attain (i. e. *normal maximum* acc. to NELSON 1910, p. 21), is loosened from the bedding and removed. In his monumental work on the transportation of débris by running water (1914) GILBERT has shown how the erosion velocity[1] varies with mixed grades of the particles. He composed inter alia mixtures of two different grain-sizes with differing mutual relations of the weight quantities. The results of his experiments show that the mixture is easier eroded when an addition of fine material is made to coarser, and most easy when the mixture contains an average of 75 % of the finer sand. The tractability of the mixture then decreases to the value valid for the finer sort.

GILBERT (1914, p. 178) points out that when a finer grade of débris is added to a coarser the finer grains occupy interspaces between the coarser and thereby make the surface of the stream bed smoother. One of the coarser grains resting on a surface composed of its fellows, may sink so far into a hollow as not to be easily dislodged by the current, but when such hollows are partly filled by the smaller grains its position is higher and it can withstand less force of current. The larger particles are moved more rapidly than the smaller, a condition which the writer has always found correct when the velocity is not too violent and the particles roll or slide over the bottom. The traction then usually occurs in the shape of small stream ripples or dunes (»Transportkörper» acc. to AHLMANN, 1914 a). When the velocity is increased saltation and suspension are added. In these kinds of transportation the velocity of the coarser particles is less than that of the finer ones — a condition which may thus occur occasionally but not generally as RUBEY (1933 b, p. 498) appears to have interpreted DAUBREE's and GILBERT's statements. In the Karlsruhe laboratory the writer observed in 1931 in a testing channel, whose bottom consisted of natural sand from the Rhine transported in the shape of stream ripples, the following approximate velocities for the movement of the sand particles when the velocity of the water was about 50 cm/sec.:

[1] Certainly, GILBERTS investigations concern the lowest transportation velocity, but the accordance with the results of other writers shows that they are valid also for the erosion velocity.

5	mm.'s	grain	size	30 cm/sec.
2	»	»	»	25 »
1	»	»	»	15 »

When the velocity is increased so that the water can transport also larger particles these will roll faster than the others, if once started. Nor do the larger particles stop now and then but roll incessantly. The small particles have a comparatively greater friction to surmount in the crowd of particles of the same size and will have a short moment of rest now and then, calculated in the velocity figures above.

According to GILBERT (1914, p. 173) the amount of increase in the transportation of the coarser débris appears to be greater as the contrast in fineness of components is greater, and in the extreme case the transportation of the coarser is multiplied by 3.5.

KRAMER's investigation (1932) of erosion and traction of three different kinds of sand completely confirm these observations. Sand composed of grain sizes 0.385 to 5.0 mm. is eroded at a lower velocity than sand of 0 to 5.0 mm.'s grain size. An addition of fine-grained material to a certain mixture increases the coarser material's tractability in the beginning, but at last a condition is arrived at when the added material cements the mixture and prevents the transport of the originally loose but now cemented grains. The reduction of the pore volume decreases the tractability of the material.

SCHAFFERNAK's curves (1922) also show the same thing. They clearly indicate the increased transportation due to a limited addition of fine matarial (Mischungstype II) compared with the reduction when an ample quantity of the fine material is added (Mischungstype IV) (see his Figs 10 and 12).

According to the works of various writers quoted above there is thus a tendency to decrease the tractability if a mixture of a sufficient quantity of the finer material is added, and this even if it is not so fine that cohesion and adhesion may be considered of great importance. The particles being very fine, their influence will of course be great also with a fairly limited concentration. As stated by FORTIER and SCOBEY the greatest effect is exercised by the finest particles, the colloids.

To this must be added that also the nature of the water affects the erosion velocity. Material carried along with the water has a purely mechanical effect, which may cause the bed-load to be stirred and thus make it an easy prey to erosion. FORTIER and SCOBEY report interesting experiences also in this respect. With the aid of all sources at their disposal, inter alia an inquiry to all hydraulic technicists, they have made a comparison of the maximum permissible mean canal velocities for varying nature of water, which Table is reproduced below (Table 8). The

Table 8.

Maximum permissible mean canal velocities. (From FORTIER and SCOBEY 1926).

Original material excavated for canal	Velocity in feet per second after aging of canals carrying:		
	Clear water, no detritus	Water transporting colloidal silts	Water transporting non colloidal silts, sand, gravel or rock fragments
Fine loam (non-colloidal)	1.50	2.50	1.50
Sandy » (» - »)	1.75	2.50	2.00
Silt » (» - »)	2.00	3.00	2.00
Alluvial silts when non-coll.	2.00	3.50	2.00
Ordinary firm loam	2.50	3.50	2.25
Volcanic ash	2.50	3.50	2.00
Fine gravel	2.50	5.00	3.75
Stiff clay (very colloidal)	3.75	5.00	3.00
Graded, loam to cobbles, when non-colloidal	3.75	5.00	5.00
Alluvial silts, when colloidal	3.75	5.00	3.00
Graded, silt to cobbles, coll.	4.00	5.50	5.00
Coarse gravel (non-colloidal)	4.00	6.00	6.50
Cobbles and shingles	5.00	5.50	6.50
Shales and hard-pans	6.00	6.00	5.00

velocities are valid for straight courses. »At sinous alignement a reduction of about 25 % is recommended. Likewise the figures are for depths of 3 feet or less. For greater depths a mean velocity greater by 0.5 feet per sec. may be allowed.» It is seen from the table that water transporting colloidal silts may generally be allowed to have a much greater velocity than clear water and water transporting non-colloidal silts, sand, gravel or rock fragments. The colloids »will make the bed all the more tough and tenacious, increasing its resistance to erosion.» FORTIER and SCOBEY also point out that »all experienced canal operators know the trick of holding muddy water above one chick structure after another until the mud has painted over the sides and bottom of a new canal, reducing seepage losses and making the bed of the canal less susceptible to scour.» In the discussion in the paper quoted, R. H. HART states (p. 961) that an important consideration is the position of the ground-water table with respect to the water surface of the canal. As long as the latter is higher, seepage is out of the canal, and there is a tendency for the finer materials to be carried into the interstices between coarser particles, thereby permitting a silting-up process. On the other hand, if the ground-water table is higher, as frequently happens, seepage into the canal takes place and the whole process is reversed.

It is also evident from the Table that the difference between erosion velocity for water transporting non colloidal silts, sand, gravel or rock fragments and clear water with no detritus is not so great except for coarse gravel, cobbles and shingles. The first-mentioned water in this case fills the interstices and the erosion velocity is increased. As regards finer material it has been observed that in the case that it is colloidal, it is less able to resist water with detritus than clear water. Conditions will be reversed for non-colloidal material.

These accounts show how complex natural erosion really is. It is not to be wondered at that the determinations of the erosion velocity have given such varying results. The deviations from the erosion curve in Figures 17 and 18 for non-monodispersed material may, however, be expressed in such a manner that values lying above the curve depend upon cementation with fine material, whereas values below the curve denote a less comprehensive mixture of finer components which smooth the surface.

Of the formulas that have been made and which do not agree very well, there is one by OWEN (1908, p. 418), which when re-expressed to be valid for a specific gravity of 2.7 and for cm. as a unit of length, reads

$$d = 0.0011\, v^2,$$

d being = the diameter of the particle in cm., and
v » = the erosion velocity in a special case, for the transport of coarser material over fine sand or clay.

This formula agrees remarkably well with the one obtained by JEFFREYS (1929) in a theoretical manner, see p. 268, which with the same designations as above reads

$$d = 0.0010\, v^2.$$

In the curves, Figs 17 and 18, OWEN's formula is graphically expressed as a fine line. The velocity in the formula in question is for the surface-velocity of a stream with a depth of water of 2.5 to 152 cm. It may be presumed to be approximately equal to the average velocity of a greater depth.

In this connection an interesting observation by W. W. RUBEY (1933 a) is worth mentioning, namely, that the current required to move a particle along the bottom of a stream (after OWEN's formula) is approximately the same as the settling velocity of the same particle in still water.

The description of the velocity as given here is certainly very approximate. It is not the average velocity that is decisive for the erosion but the velocity in the bottom-layer, where the increase in velocity in proportion to the height over the bottom is great, and where particles of different sizes are thus affected by different velocities. In a laboratory investigation M. WELIKANOFF (1932) aimed at a physical expansion of the erosion theory. He investigated the connection between velocity and grain size, AIRY's law, and found that the said law is not fully correct. The grain size must not be put proportional to the square of the velocity. The formula should read

$$\frac{v^2}{g} = \alpha \cdot d + \beta$$

where g = the acceleration due to gravity and α and β are constants, β being dependent upon the depth. WELIKANOFF also found that for a small grain size other conditions occur, so that from a grain size of from 0.4 or 0.5 mm. the constants α and β have other values. According to WELIKANOFF the »$\frac{1}{n}$ potential function» cannot be made the basis of a more exact theory.

Though it is thus impossible to mathematically formulate a theory explaining the particulars of erosion the process would, however, appear to be fairly well explained in its main features. The active powers are the pressure of the water in the direction of movement and further the hydrodynamic upthrust and the effect of turbulence. The latter affects the water's direction of movement which becomes greatly variable. The vertical velocities of the turbulence become also of importance. When observing the movements of the individual particles the question soon arises as to what degree of effect may be attributed to the turbulence in this respect. The grains of sand appear to be lifted; this is also seen from the film made at the Karlsruhe River Hydraulics Laboratory. See also SCHAFFERNAK's (1922, p. 12—13) expressive description.

The pulsations of the water will be of very great importance for the erosion. When the velocity fluctuates the erosion will be by fits and starts. In addition to the value for the average velocity the force and frequency of the fluctuations are also of very great importance (see page 252).

The material loosened by the erosion is easily transported when once in motion. The coarsest material which the stream can transport is tracted as bed-load and the finer particles are carried in suspension. Saltation is a transition state between these two modes of transportation.

Erosion may occur when the water with constant velocity comes across material that the stream is capable of eroding. It may also occur due to increased velocity. If the eroded material cannot be transported in suspension it will in the former case only result in an increase of the bed-load.

In the latter case, it may, on the other hand happen that part of the bed-load is put into suspension. The process of this change of new-eroded material or of bed-load to suspension has been treated above.

Erosion by running water in solid rocks.

The mechanical erosion by running water in solid rocks is generally assumed to take place

1) by »evorsion», that is to say by the wearing of excavations by eddying water with or without the help of stones, and

2) by the direct wearing of the solid rocks by silt-laden water.

The forms caused by the first-mentioned erosion process are especially characteristic pot holes, while, of course, the direct wearing process through its own nature becomes less noticeable from a morphological point of view. MAURICE LUGEON (1914—1915) has shown that under certain circumstances, a marked »striage» is called forth in those parts of the bottom and the shores which are especially exposed to the current. They obtain an appearance which makes them deceptively similar to those wind polished rock-formations which are found in deserts.

The relative importance of the two types of mechanical erosion is difficult to estimate and certainly varies to a high degree with the consistency of the solid rock, with the velocity of the flowing water, with the mass of transported silt, etc. CHAMBERLAIN and SALISBURY (1906, p. 140) describe pot holes as »a peculiar rather than important erosion feature», which certainly implies an underestimation. The importance of this type of erosion has especially been emphasized by J. BRUNHES, who used the name »érosion tourbillonnière», also by AHLMANN (1914) and LJUNGNER (1930). There can be no doubt as to the great importance of the mechanical erosion caused by transported solid particles in eddying or directly flowing water. K. G. GILBERT (1875, p. 73) even goes so far as to say: »It is to be doubted whether pure water, or water with no mineral matter in mechanical suspension, has any appreciable erosive power. In the beds of streams of clear water, disintegration, if not due entirely to solution, at least depends so largely upon it, that the surfaces of calcareous pebbles are covered by spony films marking the depth to which the removal of the most soluble matter has extended».

In the following, the writer will point out or attempt to show that another, hitherto unobserved, mode of mechanical erosion by means of running water also exists. In the case of this type of erosion the presence of suspended matter is not necessary; it can only appear, however, with very high velocities, and occurs by means of corrosion and corrasion in connection with cavitation.

Briefly, cavitation implies that, with high velocities, hollows are formed in the water which are able to collapse with great violence, as a »implosion», while developing a very high pressure. Marked erosion of solid matter close to the place of »implosion» is thereby caused.

Cavitation or the formation of hollows is a phenomenon based on simple physical laws and has been known for a long time. It has been treated only very slightly in the field of physics, but it has been highly observed within the field of technics after its destructive influence on metal surfaces which are exposed to rapidly flowing water, as, for example, ship's propellors and turbines, and its lowering of the efficiency in hydraulic machinery was discovered in England in 1894. During the last 20 years

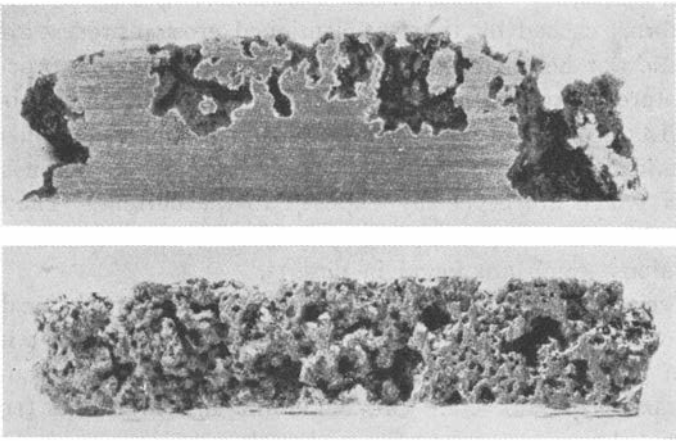


Fig. 19. Cast iron destroyed by cavitation-erosion.

cavitation has been the object of intense study in the field of engineering. Many important points have not as yet been made clear as is found from the following account of the most important papers about cavitation research, mainly ACHERET (1930, 1931 and 1932), WEINIG (1931), FÖTTIGER (1926 and 1932) and COOK (1928).

Origin of cavitation.

Cavitation — the formation of hollows — presupposes low pressures within the liquid. Now the question arises as to how such pressure-reductions can be brought about in a flowing liquid.

BERNOULLI's equation for stationary potential flowing without friction or eddy-formations which, for further discussion, may be considered as approximately valid in this case. According to this formula the energy of the liquid is constant, that is to say, the sum of the kinetic, potential, and pressure energy does not change with time and has the same value at all points along the flowing-line (see for instance W. KAUFMANN, I, 1931, p. 48 or LAMB, p. 19):

$$p = \text{constant} - \varrho \cdot g \cdot z - \frac{\varrho}{2} c^2$$

where p = the pressure
ϱ = the density
c = the velocity
z = the geometric height over a certain zero-plane.
g = the acceleration of gravity.

As is seen the pressure becomes low if the sum of the potential and kinetic energy is large. Thus when the velocity is increased the pressure is decreased.

In natural water courses are always found gases, dissolved in larger or smaller quantities, above all gases of the air, especially oxygen, nitrogen, argon and carbonic acid. Their volume relation in solution is not the same as in atmospheric air. It should be especially observed that the volume relation between oxygen and nitrogen in water-absorbed air is 1 : 2, while in atmospheric air it is about 1 : 4. (KRÜMMEL, I, p. 293). Oxygen's absorption-coefficient is, namely, twice as large as nitrogen's. Thus air dissolved in water contains twice as much oxygen as atmospheric air. According to HENRY's law the amount of gas absorbed by the water is proportional to the pressure of the gas. If the pressure in the liquid is below the pressure which corresponds to the saturation at the temperature and the gas-content in question, the gas surplus is liberated in the form of bubbles. In water which at 760 mm's atmospheric pressure contains a volume percent of a gas, $\frac{p - p_d}{760}$ of the previous absorbed air volume will remain at the absolute pressure of p mm. Hg. Every volume of water has therefore delivered the gas volume

$$\frac{a}{100} \cdot \left(1 - \frac{p - p_d}{760}\right) \cdot \frac{760}{p - p_d}$$

measured at the existing pressure. This gas volume is indeed rather small; — water contains about 3 volume-percent of the air's gases — but can be imagined as playing quite an important role. — It ought at the same time to be pointed out that the conditions are somewhat complicated by the evaporation from the liquid by these gas bubbles.

This separation of gases which can often be observed in swift streams (air bubbles behind stones) causes no erosion. The actual cavitation appears only when the absolute pressure p on a water particle sinks nearly to or below the waters vapour tension p_d, at the temperature present, that is to say:

$$p \leq p_d.$$

The vapour tension p_d depends on the composition of the liquid and on the temperature, t. For water p_d is:

$t°$	0°	5°	10°	15°	20°	25°	30°
p_d	0.0063	0.0089	0.0125	0.0173	0.0236	0.0320	0.0429 kg. per cm^2.

As soon as the pressure sinks below these values hollows and cavities are formed in the water.

Cavitation always appears at those points in the liquid which have the lowest pressure, that is to say, close to the restricting walls, above all at cross-section reductions, where the velocity is great. When eddies are formed the lowest pressure prevails at the centre of the eddy, and their cavitation appears often in connection with the forming of whirl-pools.

The water is no longer a continuous medium — possibly with solitary air bubbles — but is composed of a gas- and a waterface. It appears as if the water is boiling in an open vessel at a medium temperature (OSBORNE REYNOLDS, 1894).

It is easy to calculate at which velocity this state appears by means of BERNOULLI's formula.

If one disregards the effect of gravity and assumes that the working pressure powers are formed only by the air pressure B, one will find that cavitation in a gas-free liquid appears, when the velocity reaches the value of

$$c = \sqrt{\frac{2(B - p_d)}{\varrho}}.$$

From this it can be calculated that for a pressure of 760 mm. and a temperature of 0 the *velocity* becomes *14.3 m. per sec.* — that is to say, a very high value.

However, this velocity decreases with the air pressure, that is to say, with the height over the sea. The following Table 9 and the Fig. 20 founded on it may give an idea of the velocities in question.

In column 2 the height above sea-level has been given which the selected barometer-pressures correspond to fairly well (according to HANN—KNOCH). It is found that the decrease of the boundary velocity with height is at first almost constant, 0.8 m. per 1000 m., but that it afterwards diminishes. Even at the height of 6000 m. the boundary velocity's 9.8 m. per sec., that is to say, $^2/_3$ of its amount at sea-level. The temperature's influence by the changing of the water's vapour tension and density is noticeable only at high atmospheric pressure; however, this factor vanishes completely when compared with the atmospheric pressure.

Table 9.

Limiting velocity for beginning of cavitation at different temperature and pressure.

B mm.	Height above sea-level	Velocity for beginning of cavitation			
		0°	10°	20°	30°
760	0 m.	14.3	14.3	14.2	14.1
714	500	13.9	13.9	13.9	13.9
673	1.000	13.5	13.5	13.5	13.5
632	1.500	13.1	13.1	13.1	13.1
594	2.000	12.7	12.7	12.7	12.7
557	2.500	12.3	12.3	12.3	12.3
523	3.000	11.9	11.9	11.9	11.9
459	4.000	11.1	11.1	11.1	11.1
402	5.000	10.4	10.4	10.4	10.4
351	6.000	9.8	9.8	9.8	9.8

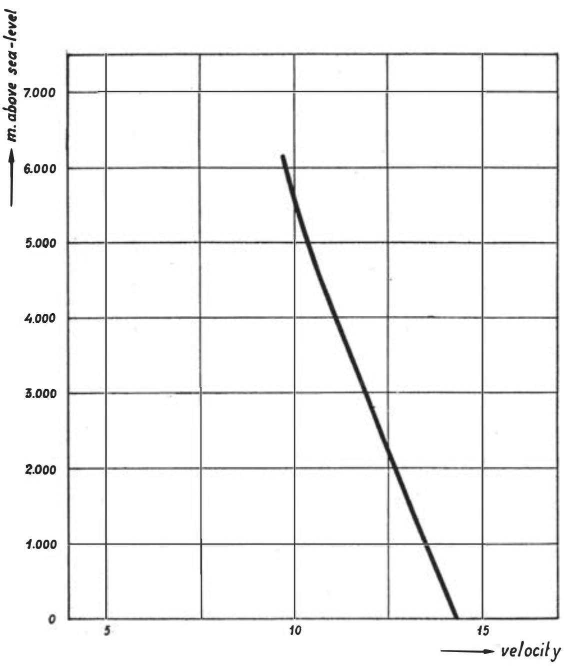


Fig. 20. Velocity for beginning of cavitation.

These values for the velocity are valid only if a liquid is eddy-free and gas-free. However, for turbulent streams with which we are here concerned, the pressure is changed very rapidly in an irregular matter. Therefore, if one calculates with the average for these pressures which characterize the flowing, one does not obtain the absolutely lowest pressures which are deciding for cavitation, but *higher,* as ACKERET (1930) has pointed out. The values given above for the velocity are therefore too high. It may, however, be assumed that the error is probably lower than 10 %. The previously mentioned gas percentage in the water also contributes to the lowering of the boundary velocity. This may therefore be set at about *12 m. per sec.*

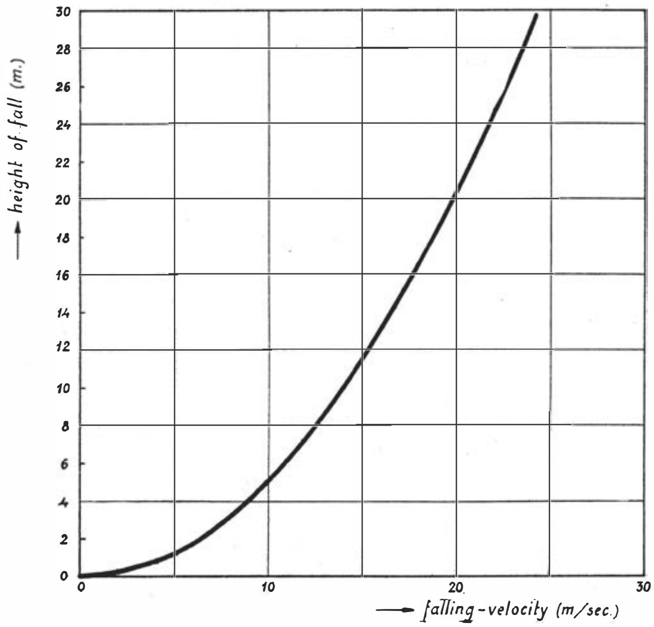


Fig. 21. The falling velocity.

It may be objected to that even after these reductions the velocity remains so high that it is encountered only very seldom in nature. Velocities of 12 m. per sec. are probably not very common. The average velocity in currents remains within rather narrow limits and attains in large rivers seldom more than 3 m. per sec., while in the wild mountain streams it rises to 5 or 6 m. per sec. (PENCK, 1894, Band I, p. 269). JOSEF FISCHER (1913) has given this matter a special investigation in which it is pointed out that the mountain rivers in Southern Bavaria *as a rule* attain velocities of 3—5 m. per sec. at high water (»hohen und höchsten Wasserständen»). It is therefore by no means unjustifiable to assume velocities above the cavitation boundary within these parts of a river course — at a not too low water depth — where the gradient is the greatest. In rapids and water-falls the velocities in question should appear rather frequently. However, any direct measurements of the velocity have not been published. In a water-fall with a freely falling water-jet a fallingheight, h meters, is, however, required according to the elementary laws for uniformly accelerated motion without air-resistance (TORRICELLI's theorem)

$$h = \frac{v^2}{2g}$$

in order to obtain the falling-velocity, v m. per sec. ($g = 9.81$). Fig. 21 shows graphically the relation between falling-height and falling-velocity. It is then found that at a falling-height of 11.5 m. the falling-velocity is 15 m. per sec., at 20. 4 m. the falling-velocity is 20 m. per sec., at 100 m., 44.3 m. per sec. etc. These falling-velocities are transformed, in the case of a horizontal surface, into horizontal velocities, and according to the results obtained within technics this transformation takes place without great loss of energy.

From this analysis it is found, without further explanation, that the velocities required for cavitation appear in water-falls quite often. Even in rapids they may occur when the water-mass is pressed together between obstacles on the river bed. But in rapids may also occur the previously mentioned (p. 257) maximum velocity which the water cannot surpass.

Disappearing of cavitation.

It is, however, the collapse of the formed holes, which in this connection is of the greatest interest.

If now no increase in pressure occurs, the hollows and bubbles continue their course until they vanish at the surface. But when the velocity decreases, the pressure is increased and the hollows collapse. Fig. 22. This collapse takes place with the production of very sharp noises and violent impacts because of the almost complete absence of elastic buffer influence. The increase in pressure always takes place very rapidly, (»Verdichtungsstoss», FÖTTIGER 1926 p. 20 and following, ACKERET 1932, p. 234 and following, 1931, p. 468 and following). The pressure-conditions which arise by contraction in a tube are shown by Fig. 23 (according to ACKERET, 1931). Cavitation at the narrowest portion of the tube where the velocity is the greatest is apparent by the formation of a white non-transparent foam. The pressure has there decreased to the vapour-tension of the water at the prevailing temperature. When then, due to an increase of the cross section (or some sort of daming-up) the velocity is decreased, the pressure increases and cavitation ceases at a sharply marked line. Fig. 23 shows this sudden pressure-increase in the liquid.

This sudden pressure-increase in a liquid at the increase of the area of the cross-section corresponds, in a natural stream, to the earlier mentioned (pp. 255—256) hydraulic jump (Wassersprung) which often appears at the transition from streaming to shooting state of motion.

The absolute amount of the increase in pressure is not great — according to ACKERET (1930, 1931) at its highest:

$$\frac{1}{4} \cdot \varrho_0 \cdot v_0$$

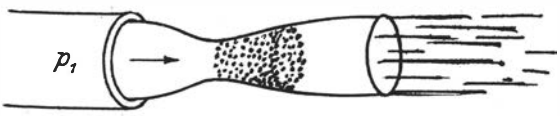


Fig. 22. Cavitation at a contraction of a tube.

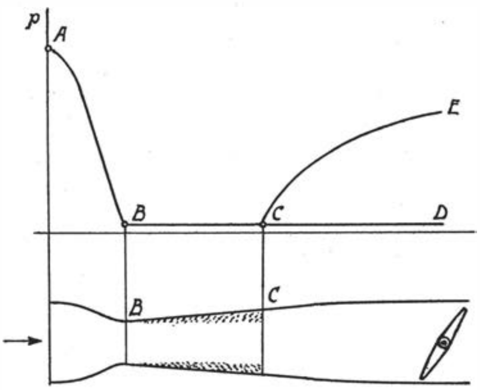


Fig. 23. The variations of pressure at a contraction of a tube.

where ϱ_0 = the density of the water
v_0 = the velocity of the water at the smallest cross-section of the tube.

A bubble, containing water-vapour and possibly even some of the water's dissolved gases, which passes, with great velocity, the place at which the pressure suddenly increases, is compressed very rapidly. Rapid instantaneous photographs show that the bubbles are thereby pressed together along the longitudinal line so that the back wall bounces against the front wall. It is at this blow that the above-mentioned high pressures arise. A calculation of their size is very difficult to make without a closer knowledge of the physical process. PARSON and COOK (COOK, 1928) calculate the pressure to 10,000 atmospheres while assuming a vacuum in the hollows. FÖTTIGER (1926), assuming isothermal compression, also attains high values, about 1,400 atmospheres. However, it is necessary to take into consideration the gas contained in the bubbles and also the increase in temperature. The hollows contain water-vapour and — to a smaller extent — other gases. Water may, at 0° contain 30 ccm. air per liter. At the sudden compression of the bubbles, an increase in temperature takes place which may be quite important. The increase in temperature causes, in its turn, the water to evaporate and the steam percentage in the bubbles to increase.

ACKERET (1930) has made a thorough calculation of the appearing pressure while giving special regard to the gas content and the increase in temperature, and has obtained values from several hundreds to thousands of atmospheres. But he points out that there is little probability that by means of theoretical procedure one could proceed further without experiments.

Direct measurements have not as yet been successfully carried out. However, also water-drops which move in the air with great velocity, for example, 40 m. per sec., have an influence similar to that of these bubbles in the water. The pressure, which is produced when a drop bounces against a solid surface and attacks it (see p. 229 above), has been successfully measured. P. DE HALLER (1933) has, by means of a pietzo-quartz-cell, shown that the arising pressures have a size of some hundred atmospheres. Because of the absolutely similar influence of corrasion it may be assumed that, at the ceasing of cavitation, pressures of the same size appear.

For the arising temperatures no measurements have been obtained. But H. SCHRÖTER's (1934) observation seems to be of importance in this regard, namely that rubber, which was exposed to cavitation, already after 3 min. was so heated that it partially melted away and was deformed. Since this is the fact with flowing water at room-temperature (or below room-temperature), the temperature must, of course, be very considerable at those points where, for very short moments, it is increased with lightning-speed. The heat conduction power is also small.

Finally, it should be pointed out that other than the above-mentioned pressure forces are at work, namely the capillary and electric forces. The bubbles become electrically charged by the presence of an electric dubble-layer. These capillary- and electric forces, which are also highly dependant upon each other, disappear at the collapse of a bubble, and contribute to the increase in temperature. The ozone odour which can be noticed near water-falls, indicates the presence of strong electric fields.

The destructing influence of cavitation.

These pressure-blows similar to hammer strokes cause a corrosive influence which is extremely feared within technics. Metal surfaces are eaten away with unparallelled speed. Above all, propellors, turbines and pumps are exposed to this type of corrosion. The time in which these attacked parts are practically unfit varies in certain cases between 1—2 hours' and a month's activity. (FÖTTIGER, 1926, p. 27.)

Parts of a metal surface corroded by cavitation show a rather typical appearance (see Fig. 19). Thus is formed a highly gorged, porous surface which has the appearance of having been fretted; it is in rather sharp contrast to the polished appearance which is caused by the wearing away by sand. If the water contains sand, the surface may, of course, thereby be polished and evened.

Now it must be noticed that these corrosions are formed only at those places where the hollows collapse but not where they are formed or on the surface which they pass before collapsing. This has been interpreted as an evidence of the correctness of the conception that a purely mechanical phenomenon causes corrasion. The strong and continuous hammering of the surface must naturally have a destructive influence even if the force of these pressure blows lies below the hardness of the matter, »Ermüdungsfestigkeit». This may moreover be completely different in river water as compared to air. The corrasion of glass, the dependance of high velocities in the water etc. — all these experiences indicate, according to the general conception, that the mechanical influence has a deciding importance. (WEINIG, 1931, p. 928.) But the physical-chemical influence should not be overlooked and merely regarded as secondary. In the hollows gases are also present. At high pressures and high temperature a strong active chemical influence must be considered, especially that of oxygen. Furthermore, a disintegration of carbonic acid gas into carbonid oxíde and oxygen may be assumed; oxygen may combine with nitrogen and form oxygen-forming oxides etc. The mixture of these chemically active gases now reachs a higher pressure and a higher temperature in the same degree as the compression becomes more violent, which usually depends on the velocity of the flowing water. At high velocities the chemical activity is highly increased — the reaction velocity is increased rapidly with temperature. Therefore, the influence of the increase in velocity can hardly be interpreted as evidence of the correctness of a purely mechanical explanation of the phenomenon. The weakening of the matter caused by the pressure blows becomes apparent by, among other things, the formation of microscopically small cracks in which the gases, of course, find an extended action-field.

An estimation of the relative relation between the mechanical and the chemical influence cannot be made, but the facts which have hitherto been published do not seem to justify a simply mechanical interpretation of the destructing influence of cavitation.

If the flowing liquid contains solid particles in suspension their corrasive influence will be increased enormously. The collapse of the hollows takes place at high velocity. A particle which is close to the collapsing liquid-wall receives an acceleration which is of very short duration, it is true, but which is, on the other hand, very strong, against the solid surface which it hits with great velocity. In accordance to an above quoted calculation of the pressure, according to PARSON and COOK (COOK, 1928), a wall of a collapsing hollow should, in their example, have at a certain moment a velocity of 730 m. per sec., that is to say, double the velocity of a rifle bullet. It is certainly too high a value, but some ten m. per sec. may be considered to correspond to the force of the measured pressure blows. It is, therefore, evident that the particles in suspension are accelerated up to very considerable velocities just at the moment of their being thrown against the solid surface and must contribute to the hammering of the solid surface in an effective manner.

The importance of the material. What power of resistance do the different types of matter have against the influence of cavitation?

This question has been the object of an especially intensive study within industry and technics of what concerns the permanence of different types of metal. According to SPRINGORUM (Hydraulische Probleme, Seite 231) it has been shown that the structure is of deciding importance. A rough cristalline alloy, for example, is attacked violently in a short time even if it is extremely hard, while a structure, as far as possible fine-grained, with a velvety appearance resists all attacks incomparably better.

No investigation of the resistance-power of different types of rock against erosion in connection with cavitation has been made either directly or relatively in relation to metals. There is no doubt that solid rocks are corroded as an example exists of the corrosion of quartz. According to FÖTTIGER (1932) quartz used in a membrane for under-water signalling was rapidly destroyed. This has in this case, of course, taken place under very special conditions, but the phenomenon is quite the same.

The above mentioned example is the only one the writer has been able to find mentioned in connection with cavitation-erosion of a mineral, and as this is applicable just to hard quartz one is justified in assuming that erosion can take place much more markedly in the case of other minerals and even hard rocks.

What forms may now be expected to appear through the above described corrosion-influence? The literature on cavitation offers no information on this question which is important from the geographic and geologic point of view. The conditions for its appearance indicate that a great many varying forms are to be expected.

The collapse of the bubbles at the sudden increase in pressure can, naturally, occur directly in the liquid without any influence on the solid surfaces which confine the current — this may be expected to be the most frequently occuring case. In order that any corrosion and corrasion may occur, the local flowing conditions must be such as to force the bubbles very close to a solid surface at the instant of the collapse. The occuring erosion form, therefore, depends on the appearance of the section between the limiting solid surface and the surface — or rather the disk — at which the collapse takes place. But the section between two surfaces is, of course, a line and one might therefore expect a groove, straight or curved. If the limiting surface has the form of a rotation-surface, the surface of contact may assume the shape of all kinds of conic sections, as, for instance, ellipses, hyperbolas, parabolas, or straight lines. In the experimental in-

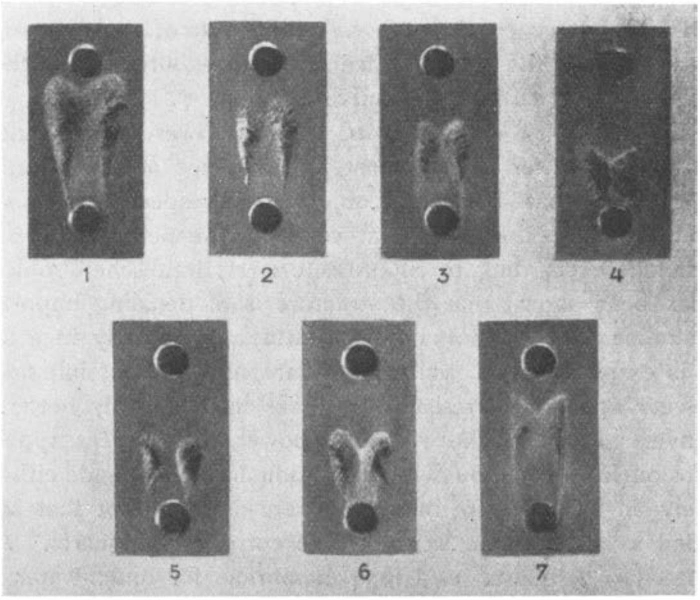


Fig. 24. Forms caused by cavitation-erosion. The direction of the water is upward. According to P. DE HALLER.

vestigations it has been shown that the limit at which the gas bubbles disappear does not have an altogether constant position but oscillates about an average position. In laboratory tests with small water-masses the oscillating remains within 1 cm. In natural water courses it may be expected to be larger. Moreover, the limiting surface may change its position and be displaced forwards or backwards and change its gradient with variations in the velocity of the water. The corrosion therefore takes place along a zone, the breadth of which varies with the angle between the back limiting surface of the cavitation field and the solid limiting surface. The breadth of the zone also increases with the length of the time of the cavitation as SCHRÖTER (1933) has convincingly shown. Experiments by SCHRÖTER show that erosion by cavitation may also work along a surface (op. cit. Fig. 22).

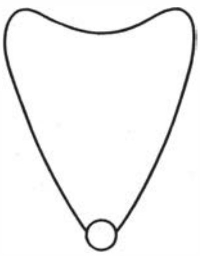


Fig. 25. A usual form caused by cavitation-erosion.

A very common form of cavitation-erosion influence is shown in Fig. 24 (P. DE HALLER, 1933, Abb. II, p. 260). It shows the appearance of a metal plate which has been exposed to cavitation in a special test arrangement, consisting of a rectangular tube with rapidly flowing water. Cavitation is produced by a bolt fastened in the lower hole, and the water flows, in the picture, from below upwards. The bolt mentioned, which thus rises above the plate, probably causes cross movements in the water which influence the appearing forms. These are therefore shallow hollows in the metal surface and have forms which in their appearance vary greatly. But they may all be imagined as included in the heart-shaped figure which is shown in Fig. 25. It is drawn after the pictures given by ACKERET, SCHRÖTER and DE HALLER.

SCHRÖTER also shows how a hole in a metal surface (1933, Fig. 19) causes cavitation-erosion in the shape of a ribbon in the direction of the stream.

Erosion of solid rocks by cavitation.

In a natural current, cavitation may be thought of as occuring at some obstacle. There the currents are forced together, the velocity increased, and the pressure decreased so that cavities in the water appear. The bubbles continue with the current, and when the velocity decreases, they collapse.

Glacio-fluvial erosion by cavitation.

The most favourable conditions for the occurance of cavitation are found where the greatest velocities are found. These, in their turn, appear, as has been mentioned, in water-falls and in water under hydrostatic pressure, for instance under a glacier. When the great ice-caps during the quaternary glaciation reached the period in their recessive state when their temperature was no longer too low for the existence of running water in their interior, a very high hydrostatic pressure must have been prevalent there. Water was then flowing along the bottom, at a very high velocity, more or less concentrated to tunnels. That the hydrographic pressure must have been very important is apparent from the fact that the flowing direction of the water is independant of topographical irregularities (LJUNGNER, 1930, p. 399). The velocity of the water has certainly at many points been above the cavitation-velocity.

Do then forms of erosion within the ice-capped areas appear which may be taken as having been caused by *cavitation-erosion?*

In the most detailed description which exists of glacial and fluvio-glacial forms of erosion in solid rock, namely LJUNGNER's (1930), is found a thorough description of several such forms. The most important of these is the peculiar formation which LJUNGNER describes under the name »Sichelwanne» (the sickle-trough). As Fig. 26 shows[1] it consists of a hollow in the solid rock of a groove- or bow-shaped appearance.[2] As is seen it is

[1] The photograph has been kindly put at my disposal by Dr LJUNGNER.

[2] The writer has observed them in the fjord of Oslo and in Bohuslän.

highly similar to those forms obtained through erosion by cavitation, and it is easy to assume that it has been formed in the manner mentioned. The similarity is quite striking in spite of the somewhat different conditions during its formation. The erosion marks, shown in Fig. 24 and Fig. 25 have, as has been mentioned before, been formed by cavitation behind an obstacle rising somewhat from the corroded surface which was not the case with the sickle-trough (»Sichelwanne»). This may, on the other hand, be thought of as having been formed, for example, behind a morain-block

Foto *Erik Ljungner.*

Fig. 26. The »Sichelwanne», according to LJUNGNER.

fastened to the under surface of the ice, which is in contact with the solid rock surface. LJUNGNER mentions the presence of »Sichelwannnen», drawn out in the longitudinal direction. The obstacle which caused the cavitation can here be thought of as having been removed, following the movement of the ice. The formations mentioned often appear in groups; LJUNGNER's example of their spreading in the flowing direction of the water is especially interesting. Several blocks, one after the other, may be thought of as having caused cavitation — or the obstacle may have been transported. Here may perhaps lie a possibility of determining the movement of a block in the lowest layer of the ice. A closer knowledge of the influence of cavitation here may perhaps lead to important results.

Erosion by cavitation in natural streams.

The writer has not been able to make investigations into the appearance of the erosion forms in question. In the Fyris the conditions for their appearance are not present, and consequently the forms do not exist there.

However, in the foregoing it has been pointed out that the necessary and sufficient conditions are present in many water courses. The knowledge of the nature of the thus formed erosion forms is, however, as yet so negligible that a pointing out of the influence of cavitation-erosion at the formation of present forms may cause difficulties. Furthermore, the following condition should be taken into consideration. The forms caused by the type of erosion in question have little resistance against the attack of other kinds of erosion. If, therefore, an erosion form is caused mostly by cavitation-erosion, a further small erosion, for example, wearing away by transported mineral matter, may alter its appearance so that the impression is obtained of the latter erosion type being the only type prevailing.

If a river passes through a large lake in which all its matter is deposited and thereafter flows over a water-fall or a rapid, no erosion should take place there other than that by direct solution of the rooks, according to the current theory as it has been formulated, for example, by GILBERT (see p. 305 above).

The complicated appearance of the erosion forms in a natural stream running through solid rock indicates a rather varied influence on the solid rock. JEAN BRUNHES (1902) has in his treatise: Le travail des eaux courantes: La tactique des tourbillons, taken his examples partly from granite islands in the Nile at the first cataract, and partly from the north slope of the Swiss Alps. He presents interesting pictures from both territories. In these pictures phenomena are found which might easily be interpreted as marks from cavitation-erosion.

An erosion form at which cavitation-erosion may have been at work is shown in the facetted surfaces which GILBERT (1875) pictures in WHEELER's Report. No acceptable explanation of these phenomena has been presented. However, in order to be able to present complete evidence it would be necessary to make an experimental investigation.

From the geographic and geologic view-point it is to be regretted that in earlier laboratory investigations attention has not been directed to these appearing forms. However, from what has been done in this field, for example by SCHRÖTER, DE HALLER and ACKERET, it has been found that the erosion forms have a rather varied appearance. But they all consist of hollows and cavities.

These may possibly serve as the first beginning of pot-holes. In natural streams a cooperation always exists between the three types of erosion; erosion by cavitation, evorsion and wearing by transported mineral matter. — However, the large principal difference which exists between the first mentioned type of erosion and the other two should be observed: the former does not require the presence of mineral matter in the water and works very effectively without it. On the other hand, the last two types can hardly come into action if such is the case.

The relative effectivity of the three processes certainly varies greatly with different types of rock. But it must be regarded as being probable that erosion by cavitation plays a rather important part in the forming of canyons.

Deposition.

It has long been known that the velocity for which a certain transported material is deposited is another — and lower — one than the erosion velocity. This is evident from SUCHIER's surveys as early as 1883. PENCK (1894, p. 284) has on that basis arrived at the approximate value 1.4 for the relation between the erosion velocity and the lowest velocity for transport only, which latter velocity coincides with the velocity when deposition begins. This border velocity will in the following be called the *lowest transportation velocity* to avoid the expression sedimentation velocity which is used to denote the velocity with which a body falls in water.

In the literature there is considerably less information to assist in determining the lowest transportation velocity than for the erosion velocity. The very severe condition that the deposition is to be on a material of the same kind as the deposit itself can scarcely be fulfilled by any other than SCHAFFERNAK's investigation. In that investigation the relation between the two velocities was found to be rather near 1.50. The lower transportation velocity is thus 2/3 of the erosion velocity. In Figures 17 and 18 this velocity curve has been inserted after SCHAFFERNAK's Figure p. 14.

This curve differs from the erosion curve in the manner that it makes no bend upwards for the smallest grain sizes but falls to very low velocity values for the grain size 0, (WELIKANOFF 1932), indicating that fine material is deposited at these low velocities. But here the curve is extrapolated; SCHAFFERNAK's smallest particles had a diameter of 5 mm. One is inclined to presume that the curve in this instance approaches OWEN's curve. That is nearly identical to JEFFREY's formula for the upthrust. It is that power that is decisive for the deposition of these fine particles. The turbulence has generally discontinued at these low velocities; the particles have sedimented to the bottom layer and it is the value of the upthrust that decides whether they are to remain inert on the bottom or not.

The lowest transportation velocities for mixed materials are difficult to define, as there are very few direct measurements to decide the matter.

Table 10.

Difference between erosion velocity and lowest transportation velocity in percent of the erosion velocity. (After KRAMER.)

Material	Slope	Depth (cm.)	Velocity-difference in %
Sand I.	1: 800	3.57—4.12	14
0—5 mm.	1: 1.000	4.73—5.30	30
Sand II.	1: 400	1.60—1.64	26
0—1.77 mm.	1: 600	2.94—2.50	28
	1: 800	5.53—2.86	30
Sand III.	1: 600	2.88—2.93	9
0.385—5 mm.	1: 800	4.22—3.75	5
	1: 1.000	5.20—4.83	1

KRAMER has made observations »bei fallenden Wasserständen — um das Aufhören der Geschiebebewegung festzulegen». Unfortunately it is not quite clear whether his lower limit for the starting of the transportation due to increased water velocity corresponds to the conception of erosion velocity used here, which is also necessary if comparisons are to be made. But presumably that is the case. From KRAMER's tables has been calculated the proportional amount of the necessary decrease from erosion velocity to the lower transportation velocity, for which deposition is commenced. The decrease varies for varying slope or depth, as will be seen from Table 10 below. Sand I there denotes a mixture of well-polished quartz-particles of the sizes 0—5 mm. Similar to the following, however, it contained no colloids; according to the curve no grains of less than 0.1 mm. In sand II the coarser components were removed (grain sizes 0—1.77 mm.), and in sand III the finer ones (grain sizes 0.385—5 mm.).

As will be seen from the table the difference in velocity is the least for sand III, from which the finer grains were removed, and the greatest for sand II, consisting of fine particles. This probably depends upon the great increase of the erosion velocity required for the finer material due to cohesion. Sand III covers a more comprehensive range of sizes of the sand particles; the result may be that a limited decrease of the velocity may cause the largest particles to stop. Sand I, containing all the grain sizes, has a value for the difference in velocity which is between these two values but nearer that for the finer sand.

According to other investigators (KRAPF and KREUTER) the tractive force causing the bed-load to move is 30 % greater than that for which deposition occurs (KRAMER 1932). This would correspond to an approximate difference in velocity of about 12 % in the case as above. This is, however, disputed by SCHOKLITSCH's (1914, p. 34) unauthenticated statement: »Eigene Messungen im Versuchsgerinne zeigten dass dieser Unterschied vom Gehalt der Sohle an feinem Zwischenmaterial abhängt, und dass er für feines gleichmässiges, rein gewaschenes Geschiebe ohne Zwischenmaterial nahezu gleich Null ist.»

Keeping to published measurements it would, however, appear that for a uniform material af the same composition as that of the bottom the velocity may be reduced to the curve in Figures 17 and 18, as per SCHAFFERNAK, without deposition occurring. For a mixed material the deposition begins for greatly varying velocity-decreases, dependent upon the quantity of fine material and upon the size of the largest particles in the mixture. In this case there is probably a very complicated co-activity between several factors. Consequently, the results differ so greatly that according to different investigators the velocity may be reduced from the figure for erosion by 54.5 % (acc. to DUBUAT) or only 1 % (acc. to SCHOKLITSCH and KRAMER), before deposition commences. Another cause that contributes to the varying statements is that the erosion velocity may have been calculated in different manners, i. e. either as the velocity causing the finest material to start moving or, as the velocity when not only the finest material is transported but for which all grain sizes up to the normal-maximum are put in motion. However, it is generally the latter conception that has been intended.

OWEN's fixation of the erosion velocity for comparatively large particles on a smooth surface lacks parallels for the lower transportation velocities, excepting SUCHIER's results above mentioned. According to them the relation between the two velocities was 1.4. But SUCHIER's erosion velocity is rather much above OWEN's; it agrees very well with the erosion-curve for a uniform material as shown in Figures 17 and 18. In this case the difference undoubtedly depends upon a whole layer of loose material moving over a smooth surface, whereas in OWEN's experiment single stones were placed on the bottom. In the former case, there was a friction against the neighbouring particles too, the friction thus possibly attaining almost five times the value as compared with the latter case. A spherical particle may have seven contact-points in the former case and but one in the latter.

Better values not being available, we shall use SUCHIER's 1.4 for the velocity-quotient, corresponding to a proportional decrease of the velocity from erosion to deposition of 29 %, which is also a good average value. This value being introduced into OWEN's formula, it is found, seing that $(1.4)^2$ approximately equals 2, that *in the velocity for which a certain grain size is eroded deposition occurs of grains of twice that grain size.* This thus holds good, approximately, for the transportation of coarse particles (> 7 mm.)

over a smooth sandy bedding, but according to Figures 17 and 18 also approximately for a uniform material moving over a bottom of the same material on condition that the grain size of the material is between 8 and 30 mm. It would thus appear to be a fairly common condition. The above term is independent of the validity of OWEN's formula, and only provides for the grain size being in proportion to the square of the velocity (acc. to NEWTON, AIRY, and others; see SCHOKLITSCH 1914, p. 200, 40—45), and that the relation between erosion velocity and lower transportation velocity is 1.4.

Problems concerning the stratigraphy of the deposit.

The viewpoints that have been expressed here concerning erosion and deposition may assist to explain some of the peculiar stratification conditions and irregularities often found in for inst. glacifluvial strata. One remarkable observation is that coarse glacio-fluvial material and whole eskers, rest on clay. See for inst. NELSON, 1910, p. 145 and 146, HÖRNER, 1927, and SANDEGREN, 1929, with a discussion by ASKLUND, CLAESSON and RUDEBERG. Considering the old conception that the erosion velocity depended upon the size of the particles it appears peculiar that the clay was not eroded away by the considerable velocity that must have occurred when the superposed coarser material was transported.

A look at Figures 17 and 18, however, will show that such a transportation and super-deposition is rather easy to explain from a dynamic point of view. The question as to how the increase in velocity, noticeable from the character of the sediments, can have occurred involves a special series of problems, which must be solved separately.

The transportation of a certain kind of material over a bedding of loose material of another mechanical composition is of rather great interest.

The deposition pre-supposes transportation of the material concerned. And this transportation in turn must be the work of a certain water-velocity. In the event of the material not being too small-grained, this velocity may be so great that there is a risk of the bedding being eroded. In other cases this will not be the case.

Let us first examine the case of erosion. The loosening of the material as expressed by *erosion* causes a mixture of the coarser transported material with the finer, eroded material. This mixed material now acquires another — and usually greater — mobility than the material originally transported. GILBERT's experiments, mentioned on page 300—301 above, show that the mobility of a mixture increases up to the point where the finer material (i. e. what has been eroded, in this case) amounts to approx. 75 %. The material is thus rapidly removed and the bedding is quickly eroded — as long as the composition remains the same. Unless the layer affected by the erosion is very considerable it will thus be removed rather quickly. We can, therefore, not expect very often to strike deposits of the coarser material on a finer bedding of such a kind as may easily be eroded. When this occurs, there will be a transition zone, containing a mixture of the two kinds of material and no clearly defined contact-surface. The thickness of the transition zone may be expected to increase somewhat downstream.

In the cases when *no* erosion occurs a closer study reveals that there are two differing series of combination possibilities. A given material, with a grain size of for inst. 1 cm., may first of all be transported and deposited over a bottom consisting of loose material from blocks down to a certain smaller grain than the material itself. On the other hand a bottom consisting of smaller grain would be eroded. Not until the grains are considerably smaller than 0.1 to 0.5 mm., for inst. clay, may transportation without erosion again be possible, this material not being so easily eroded.

Fig. 27 illustrates and defines these conditions. The Figure is a schedule on the basis of Fig. 18, *a* denotes the erosion curve, *b* the curve for the lowest transportation velocity, both for a uniform material, *c* is the curve for the lowest transportation velocities of coarser grains on a smooth bedding. We examine which material a grain size characterized by the abscissa 1 can be transported without erosion. The ordinate 1—2 is drawn till it reaches the curve *b* at 2. The lowest velocity has then been determined for which transportation may still occur and deposition just begins on a bottom consisting of loose material of the same grain size. Transportation and deposition of the given material may of course take place on a coarser bedding but also on the same material, seeing that this is not eroded until the velocity is greater, as denoted by point 3, and even on finer material. For the velocity for which deposition commences, erosion of a considerably finer grained material takes place; the size of the particles for this material is obtained by drawing the line 2—4 parallel to the axis of the abscissa. It is thus denoted by grain size 5. According to what has previously (p. 322) been explicated this is approximately half of grain size 1. Here it may, however, be pointed out that in this case it will undoubtedly be somewhat smaller, the transportation being easier on the slightly finer material. Curve *b* should be a little lower. In the lower part of the figure a coarse striation denotes the range within which transportation and deposition of material 1 may occur without eroding the bedding.

Another similar range is also shown by the figure in the smallest grain size groups. Transportation and deposition of fairly coarse material perhaps also over silty loam and clay. Here again, as has been mentioned, we find a higher erosion velocity due to cohesion forces. The transportation of coarser material over a bed consisting of clay must however be looked upon as if it were over a smooth surface. To decide the lower transportation velocity we must therefore not start from curve *b* as in the former case but from curve *c*. Point 6 denotes that velocity. This is the erosion velocity for the grain size denoted by abscissa 8. Smaller sizes of

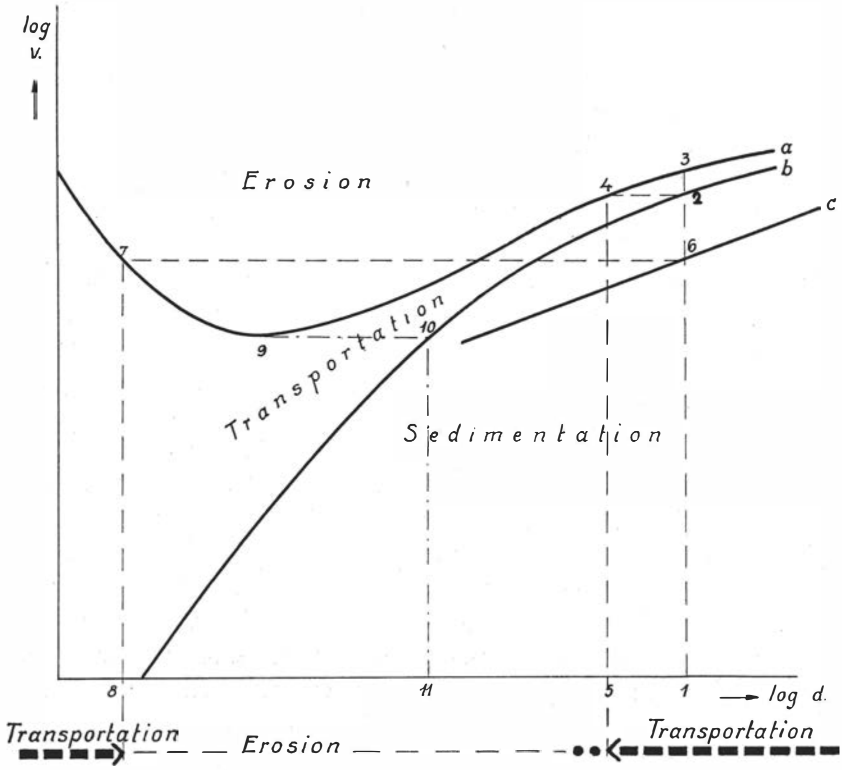


Fig. 27. Figure illustrating the deductions about the transportation and deposition of bed-load.

particles have a greater erosion velocity. The transported material mentioned may thus be transported and deposited on a fine material of a grain size up to the value denoted by abscissa 8.

But this grain size cannot yet be decided with any great degree of exactness, curve *c* being so indefinite as to position. The quantity of material transported is probably of a certain importance. SUCHIER's values even exceed those expressed by curve *b*, whereas in OWEN's tests the lower transportation velocities must be below curve *c*. In the former case a whole stratum was transported, in the latter single particles. Judging from this we might be inclined to believe that the velocity (points 6 and 7) would be higher, and grain size 8 displaced towards lower values. Another factor with the same effect is the material contents of the water. The coarse material transported must, of course, endeavour to erode the clay. This effect is also evident from Table 8. FORTIER and SCOBEY there state that the erosion velocity for water transporting non-colloidal silts, sand, gravel or rock fragments as compared with that of clear water without detritus is subject to a decrease from 114 to 91 cm./sec. The decrease is thus not very considerable but the curve branch to the left of the minimum, point 9, is lowered a little and point 8 is somewhat displaced towards a smaller grain size. We must also presume that the coarser material easily sticks in the clay, which will, so to say, be paved and will thus be protected from erosion.

From point 8 up towards point 5 there is, however, a series of grain sizes over which the material mentioned cannot be transported by running water without erosion occurring. That interval encompasses the most easily eroded material, fine sand and similar material, which is removed at these velocities.

The curves for the lower transportation velocities being examined to find the grain sizes that correspond to the minimum velocity for erosion of a uniform material (draw a line from point 9 parallel to the axis of the abscissa until it intersects curve *b* at 10 and then find the corresponding grain size 11), we obtain the maximum grain size transportable without erosion and depositable over every kind of material. A comparison with Fig. 17 and 18 indicates that this grain size is 2 to 3 mm.

Very coarse sand or fine granule can thus, as all finer material, be transported without erosion over every kind of other material, finer as well as coarser. A fluvially transported sediment of particles coarser than fine gravel can, however, not be transported without erosion over a material of a mechanical composition of grain sizes from clay up to a figure approximately expressed in the following Table, the last column. It is therefore seldom found as a super-stratum on such material.

Table 11.

Composition of deposited material	Composition of bottom material	
	may be	is but seldom
10 cm. particles	silt clay, 3—4 cm. and greater	0.0001—3—4 cm.
5 » »	» » , 2 » » »	0.0001—2 cm.
3 » »	» » , 1.5 » » »	0.0001—1.5 »
2 » »	» » , 1 » » »	0.0001—1 »
1 » »	» » , 0.5 » » »	0.0001—0.5 »
0.5 » »	» » , 0.2 » » »	0.0001—0.2 »
0.2 » and smaller	all kinds of material	

When the grain size of the suspended material is increased there will simultaneously be an increase in the grain size group of the lying material that is eroded when the suspended material is transported.

The values stated in Table 11 have been taken from Fig. 17 and 18. They are not more exact than are those figures, and are likewise valid for material of a uniform composition.

Conclusions.

Finding in a deposit material on top of a finer one it is unusual for their respective grain sizes to appear in the combination shown in columns 1 and 3, Table 11. Should this be the case, 2 alternatives appear.

1. The coarser material was not brought there by running water. In this case there may be a clearly defined contact surface.

2. The coarser material was brought there by a stream which eroded the finer material, but had no time to erode it away entirely before the velocity of the water diminished and deposition occurred. There is a border zone where the two kinds of material are mixed.

It would be of interest to get these conclusions, based on empirical data, verified by direct tests.

Transportation.

The area above the erosion curve in Figures 17 and 18 indicates erosion, and the area below the curve for the lowest transportation velocity deposition. Between these two curves there is evidently a field indicating transportation. For bigger grain sizes this field is of a considerable width as also for the very smallest sizes (see Figures 17 and 18). Thus for a uniform material of these sizes there is rather a wide range of velocities, within which a material in motion is transported further before deposition occurs. Under the supposition mentioned there is then a kind of equilibrium without either erosion or sedimentation. The total quantity of matarial transported neither increases nor decreases. For a mixed material containing all grain sizes up to the largest which the river is able to carry, circumstances are more complicated to the above. The erosion velocity meaning the velocity for which all grain sizes up to the normal maximum are put in motion, and the lowest transportation velocity the velocity at which the material starts to deposit, the transportation interval still becomes shorter than for a uniform material. If the velocity is kept constant to any certain value within the transportation interval mentioned, there exists neither erosion nor sedimentation; we have a kind of equilibrium. If the velocity changes to another lower value within the transportation field, there is no change in the total quantity of material transported, but the relation between the bed-load and the suspended material is displaced. Part of the latter material is deposited in the bed-load. If on the contrary the velocity increases, the quantity of the suspended material increases and at the same time an erosion of finer particles of the bed may take place.

The motion of the bottom-layer.

The current- and other physical conditions prevailing in the lowest zone of a river are extremely complicated, and have defied every effort to make a fairly exact description. They are presumably very variable.

This boundary-layer where the transportation of the bed-load takes place, gets a high specific gravity due to the pressure of solid material, this of course influencing the current. The turbulence is of course strongly affected thereby, and it must be impeded in the same manner as when stable stratification occurs in the atmosphere, for inst. at temperature inversion. Water with a heavy load of sediment, and therefore heavy, should be raised and substituted by lighter water thanks to the exchange-process. If the increase of the silt percentage is sufficient, the turbulence will, therefore, have to cease or become very diminished. At least, in certain cases there is, therefore, along the bottom a *boundary-layer* with a *laminary* or a *slightly turbulent* motion.

This problem is analogous to the problem of the stability of a fluid in which the density and velocity vary with height above the ground, a problem studied in hydrodynamics and meteorology. It has been treated by inter alia: LEWIS F. RICHARDSON (1920) PRANDTL (for inst. 1932), TAYLOR (1931), and GOLDSTEIN (1931). As a criterium for the appearance of turbulence the following expression has been stated:

$$-\frac{\frac{g}{\varrho}\cdot\frac{d\varrho}{dz}}{\left(\frac{du}{dz}\right)^2}$$

where $\varrho =$ the density $\left(=\frac{1}{g}\cdot(1+0.63\ S)\right.$, where $S=$ the sediment contents, if the specific gravity $\left.=2.7\right)$

$u =$ the velocity
$g =$ the acceleration of gravity
$z =$ the height above the bottom.

If this expression is < 1 the motion is turbulent according to RICHARDSON; if it is > 1 the motion is laminary. But »a theory like this one, which supposes the mean velocities to be horizontal straight lines, can only fit in with observations at a height above the ground which is large compared with the irregularities of the surface.» (RICHARDSON op. cit. p. 365).

If the expression $\frac{g}{\varrho} \cdot \frac{d\varrho}{dz}$ is greater than the square of the change of the velocity the motion is laminary. Consequently, the decrease of the silt percentage towards the surface is, as mentioned above, of fundamental importance. The decrease must not be too inconsiderable if a laminary motion is to prevail. The decrease has its greatest value in erosion, when the bottom-layer is enriched and the equilibrium distribution of the silt percentage has not yet occurred.

However, erosion must not necessarily occur exactly at the place intended; the main object is that the lower layers be greatly enriched with silt compared with higher layers. This may also be the case below an erosion place in the river, which, however, must not be so far below that the silt distribution has already been stabilized. It is of decisive importance that an increase in the quantity of material suspended and in the saltation zone takes place. The transportation of material in contact with the bottom has no, or in any case minor importance; a deposition of this material may even occur. Therefore, it is not easy to relate the presence of this laminating bottom-layer to the conditions on the spot. But generally the following rules may be stated. The prospects are *greatest* for the appearance of a bottom-layer with laminary motion when there is a *rising water-level* accompanied by erosion. The water-level *falling*, accompanied by deposition, the decrease upwards of the silt percentage has its lowest value, and the prospects for the appearance of such a bottom-layer are the *smallest*. To obtain a starting point in order to judge the conditions when there is only transportation without erosion or sedimentation, the values previously mentioned for the variations of the velocity and the silt percentage with the height above the bottom have been inserted in the above expression, by way of trial (pp. 272 and 273). After derivation one finally gets the condition for laminary motion:

$$1 < \frac{0.63\, g \,.\, c \,.\, p}{A_1 \,.\, u_1^2} \cdot \frac{S}{1 + 0.63 \,.\, S} \cdot Z^{\frac{p-1}{p}}.$$

A_1 here indicates the Austausch-coefficient at a height of 1 cm. above the bottom, which would cause the silt distribution present if the motion was turbulent.

If $c = 6.6$ — equivalent to a grain size of 1 mm. at $+ 15°$ C, $p = 8$,

$g = 981$, $A_1 = 10$, and $u_1 = 5$, it is found that in order to get a boundary-layer of 10 cm. density, a silt percentage exceeding 109 gr./liter is necessary there.[1] This must be considered an extremely high value which should be rare at the low values indicated for turbulence and velocity. If we instead estimate the density of the boundary-layer this is found to be 7 mm., the silt percentage being put at 10 gr./liter. Consequently, the layer would be extremely thin — so thin that it may be completely disregarded. And then the formula would scarcely be valid.

The example chosen refers to a river running rather slowly with limited turbulence, where the silt percentage strongly decreases upwards, and where there are thus great prospects for the formation of boundary-layers. A boundary-layer nevertheless not appearing here, this indicates that no laminating boundary-layers occur or are at least very rare in a state of stability without erosion or sedimentation.

Thus, laminating boundary-layers along the bottom of the river are principally found in connection with *erosion.*

However, this cannot be anticipated in all rivers. The first condition is, that a solid material really is transported in a greatly enriched layer along the bottom, the bed-load. Such a layer does not appear in all rivers. If the bed consists of fine clay and erosion occurs, the small particles are immediately brought in suspension and spread in the water. This is the case in the Fyris, the writer thus having had no opportunity to study these bottom-layers. — Nor is it probable that they will appear in rapid mountain streams with great turbulence. On the other hand, rivers with a sand bottom and a slow calm course afford great possibilities for the formation of such bottom-layers, especially if the grain size of the bottom material is not too limited.

What may the effect be of such a bottom-layer?

First of all, the erosion must of course decrease, when the water above the bottom has a laminary motion or diminished turbulence. This need not stop the erosion but it is less active, as already explained (Chapter II).

Another important effect is that the velocity changes. For a turbulent current, the increase in the velocity and the velocity itself close to the bottom are greater than were the current laminary, other conditions being similar. See formulae p. 231 and 246 and Figure 28. Higher above the bottom the conditions are reversed; the velocity is greater for a laminary motion than for a turbulent one. The effect of a boundary-layer appears in an increase in the velocity, which is greater the thicker the laminating boundary-layer is. The turbulent velocity-curve now does not start from the bottom but from a velocity-value already existing, namely from the velocity prevailing in the contact surface between the laminary

[1] All the formulae presuppose cm., gr., and sec. as units.

boundary-layer and the turbulent current above it. The laminary boundary-layer serves as a lubricant between the bottom and the water. The friction decreases and the hydraulic formulae for the velocity as a function of hydraulic radius and slope or the like loses its validity. The formulae of KUTTER, BAZIN and MANNING pertain to this.

As mentioned above no observations could be made of this laminary boundary-layer, since transportation of bedload is non-existent in the Fyris. However, there is an interesting investigation from the Nile made by A. B. BUCKLEY (1923, see also the discussion which is not less interesting). It is based on material which is partly incomplete and difficult to interpret; for instance the investigation at Beleida, 1921, shows only a general influence on the velocity by the silt transportation. From the description it is not possible to definitely ascertain when erosion and when sedimentation or transportation prevails. BUCKLEY has also expressed the silt percentage as a factor influencing the velocity and not the criterium mentioned. The examinations at Menufia give a better illustration; the rapid

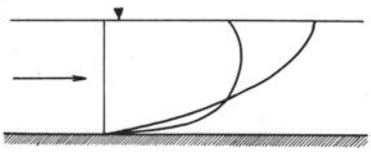


Fig. 28. Distribution of velocity for laminar and turbulent flow. The curve upwards inclined to the left is valid for turbulent, the other, parabolic curve for laminar motion.

decrease in slope, the silt percentage rising, signifies a decrease in the friction against the bottom (10—27 August 1919). However, these measurements are not completely conclusive owing to the lack of observations regarding the changes in the river-bed.

The study of the formation and effect of the laminary boundary-layer would be a profitable task for a laboratory investigation.

Modes of transportation.

A factor that renders it more difficult to understand the conditions in the bottom-layer and also the velocity distribution as well as the whole transportation of solid material, is the imperfect knowledge of transportation mechanics.

The writer has previously made a difference between the transportation of bed-load and suspended material, and in Chapter II transition stage, saltation, has been mentioned. The transportation of the bed-load may, however, be effected in still more ways. GILBERT (1914) has further explained these ways in his admirable book on transportation of débris by running water. He at first makes a difference between movement of individual particles and collective movement. In the movement of individual particles »sliding» is a negligible factor. The roughness of the bed causes particles that retain contact to roll. — Rolling is the mere prelude to saltation». (op. cit. p. 26). Saltation or jumping was caused by the hydrodynamic upthrust, but of course the vertical velocities of the turbulence are also rather important, at least in the toplayer of the saltation zone, where a transition to suspended matter exists.

Individual particles in the bed-load thus move in one of the following ways:

1. sliding;
2. rolling;
3. saltation.

Transportation by rolling may easily be effected without saltation, especially of mixed débris. On the other hand saltation would not appear usual otherwise than in connection with the transition state, rolling.

There is perhaps more of a graduation difference than a species difference between the transportation states mentioned. And also when sliding and rolling the grains are forced to lose contact with the bed for very short distances; these little jumps increasing in length, we get a transition to saltation.

When several individual particles move forwards over a river-bed in one of the above mentioned ways, their movements sometimes are arranged in an extraordinary manner, by which the morphology in miniature gets its structure at the bottom.

GILBERT writes: »In another experiment a bed of sand was first prepared with the surface level and smooth. Over this a deep stream of water was run with a current so gentle that the bed was not disturbed. The strength of current was gradually increased until a few grains of sand began to move and then was kept steady. Soon it was seen that the feeble traction did not effect the whole bed, but only certain tracts, and after a time a regular pattern developed and the bed exhibited a system of waves and hollows. As the waves grew the amount of transportation increased, showing that, under the given conditions, the undulating surface was better adopted to traction than the plane». (op. cit. p. 30). The velocity being increased a state gradually developes, when the dune[1] motion ceases, and the sand surface becomes comparatively even, »although some-

[1] In the following the writer, in agreement with GILBERT, will often use the term dunes for these small submerged ribbons of sand on the bed of streams, arranged transversally to the direction of the stream. CORNISH (1914) employs the term current-marks. They must not be confused with the great continental dunes, which in many respects follow other laws.

what ruffled in the run immediately following the disappearance of dunes». The velocity being further increased there developes another kind of motion, characterized by antidunes which travel against the current instead of with it. »Their downstream slopes are eroded and their upstream slopes receive deposit. They travel much faster than the dunes, and their profiles are more symmetric» (op. cit. p. 31).

Thus GILBERT also distinguishes between three different kinds of collective movement, in which the bed is characterized by different appearances:

1. the dune mode of traction;
2. the traction without waves uniformly over a plane bed;
3. the antidune mode of traction.

The two first of these three ways are most usual while the third one does not appear so often.

Perhaps to these three different kinds of movement there may be added one kind more. This sort of movement resembles the dune mode of traction but the forms of transportation are not exactly the same. Instead of parallel transverse dunes there appear, when the state of movement of the water i *shooting*, a pattern of tongue-like waves of sand, separated by furrows. This kind of movement has been investigated by H. BLASIUS (1910). Any detailed explanation of these forms is, however, not yet set forth.

There is a very extensive literature about these dunes or current-marks. No details as to their appearance or occurrence will be given here, (see AHLMANN (1914), and HENNING KAUFMANN (1929) with valuable bibliography). Only some points of view will be expressed here.

The origin of the dune mode of traction.

To understand the conditions of existence of these current marks the writer would consider it essential to study their first appearance on a smooth surface. This is easily done in a laboratory-channel with a sand bottom. In one case the writer observed in such a channel how the first indication of the dunes on a smooth sand surface *suddenly* occurred. The water poured down on the sand from a model building of a veir-construction with a height of about 30 cm. Due to the erosion below the fall an excavation was formed and the material was transported downstream. The erosion only took place at the excavation and thus the transportation occurred over a material of the same composition. At first the movement was approximately uniform on the smooth surface, but suddenly there were formed, almost momentarily, one or two current marks shortly below the excavation. This sudden forming must give the observer the impression that it has something to do with the pulsations of the water. The motion of the sand grains does not take place with a quite constant velocity but with minor variations around an average value — in the same way as the water. The grains also make short stops owing to the roughness. It seemed as if the formation of the current marks in the smooth surface took place due to an especially strong increase in the momentary velocity value, an extremely strong pulsation. On the occasion in question the sand grains were swept over the bottom with considerably greater velocity than on the average. It is difficult to observe if superficial inequalities play any greater part in the localisation of these first current marks. They may surely form a core for them but they are not necessary. Even if the bottom is quite smooth current marks may anyhow be formed. HENNING KAUFMANN's (1929 p. 9) theory of an accelerating effect of small obstacles on the formation of current marks seem to be plausible.

The observation showed that the appearance of these current marks is connected with the pulsations of the water, an observation which must seem both clear and unavoidable to every examiner. In his observations on transportation of bed-load in the Indalsälven AHLMANN (1914 p. 24) has arrived at the same result. »Das Transportdelta bildet sich auch auf einer ungestörten, ganz ebenen und homogenen Oberfläche durch die Pulsationen des Wassers». AHLMANN seems to be the first to mention this fact. To a certain degree it also agrees with H. JEFFREY's statement[1], that »the beginning of any sand-wave seems to depend on turbulence». The effect of the pulsations may, however, occur in several ways. One might possibly expect, that it simply consists of a direct sand aggregate caused by pulsation following each other. When the first formed dunes have moved on a bit, a new pulsation comes sweeping sand forward to a new dune. In this case, the distance between the crests of the dunes divided by the rate of advance of the dunes should indicate the time-interval between two pulsations of such a force as to form dunes in the sand bottom of the stream. However, this theory is contradicted by the observation that pulsations of equal force appear much more often. They have, however, not the same effect until earlier formed dunes have had time to move on a short distance. Not until then is a new dune formed on the spot where the previous one was formed. Further, it is difficult to understand how several dunes of this type can simultaneously appear when the erosion suddenly begins on a whole surface, as in the above cited experiment by GILBERT. It would appear reasonable to expect the movable sand to be transported in an even layer over the bottom, almost in the same way as a carpet is dragged over a floor.

[1] Additional notes (pp. 121—159) by HAROLD JEFFREY's to *Vaughan Cornish:* Ocean waves and kindred geophysical phenomena. Cambridge 1934.

This not being the case there must be some other factor making the motion rhythmical and creating the extraordinary morphological phenomenon. If there is in the motion itself any tendency towards non-uniformity, this must further be accentuated by the pulsations. For instance, if there is a tendency towards wave formation a powerful pulsation will result in it, so to say, being conserved in a smooth surface consisting of movable material. The current marks then formed move on owing to the general transportation, and new pulsations only influence the transportation but do not change the general appearance of the bottom.

It is evident from the lack of correspondence in dimension as well as sometimes in the moving direction too, that the waves of the surface are of no decisive importance — at least not generally. The waves of the surface generally have a much greater wave-length than the dunes, usually 5 to 20 times greater. However, they are able to influence the pulsations at a low depth of water.

Several scientists V. CORNISH, O. BASCHIN (1899), DE CANDOLLE, SOLGER, MAYER (1928) and others, have expressed the opinion that a wave formation of the kind that appears in the boundary-surface between two mediae of differing densities and moving conditions (HELMHOLTZ-waves) might have a certain influence. F. EXNER (1920) also refers to some kind of fluctuations in the boundary-surface. As the question of the possible occurrence of a wave formation in the boundary-surface, movable sand-flowing water, does not seem to have been the subject of a quantitative investigation but in EXNER's special case, an examination of the applicability of the theory might not be unjustified. In the following, G. I. TAYLOR's investigation of the effect of variation in density on the stability of superposed streams of fluid (1931) as well as a similar investigation by B. HAURWITZ (1931) are used tentatively as a starting point.

Transportation by rolling. TAYLOR points out that the wave system and stability of the surface of separation of two superposed homogeneous fluids which move with relative velocity are well known. Such a system is always unstable, but with a given relative velocity $U_2 - U_1$ and a given ratio of densities $\frac{\varrho_2}{\varrho_1}$ only waves whose wavelength is less than

$$\frac{2\pi \cdot \varrho_1 \cdot \varrho_2 (U_2 - U_1)^2}{g(\varrho_1^2 - \varrho_2^2)}$$

are unstable. Longer waves are propagated at a constant speed and with constant amplitude.

If one tries to apply this on an inhomogeneous liquid such as sand in water the density should apply to the whole mixture. At first let us consider the case of the velocity slowly increasing up to the value when the finer particles are put in motion. There is then a layer of sand rolling over the bottom, and above that pure water. In the boundary-layer between these two layers there is then a tendency towards wave formation which seems to increase due to the influence of the pulsations. If the density of the water is considered = 1, and in the movable sand layer = 1.1, and the difference in speed between the latter and the former (i. e. between the sand and the water above it) equal to 20 cm./sec. we find that waves whose wave-length is less than 13 cm. are unstable, while longer wave-lengths subsist. The stabilising effect of the density distribution is also at very small relative speeds of the two fluids insufficient to stabilise short-length waves which have the greatest effect on the motion. It might be expected that out of the waves for which the motion is stable the shortest ones should be of the greatest importance with regard to the influence on the bottom. A tendency towards wave formation being at hand, the shortest possible waves should in this case first of all be observed, i. e. the limiting wave-length.

Consequently, the decisive factor for this wave-length is the velocity difference in the boundary-layer as well as the density inside the two layers. The limiting wave-length increases with the square of the velocity difference. If in our example $U_2 - U_1 = 25$ cm., the wave-length is = 21 cm. The rules for this velocity difference are not known however. (See p. 301). No systematic study of the motion velocity of the sand grains exists. But PENCK (1894 p. 281) cites an investigation made by T. E. BLACKWELL which gives some illustrations. The velocity of the grains increases rapidly when the speed of the water is increased over the value at which the grains are put in motion. When the velocity has reached a certain value, the increase is less rapid. After that it finally makes a new rapid increase, upon transition to saltation or suspension. However, this is only the case for coarser grains, minimum weight 42 grams. In all these cases, the velocity difference was greater than 40 cm./sec. and often considerably higher (except for light pieces of coal with a specific gravity of 1.26). However, it does not appear under which circumstances BLACKWELL's tests were performed. This is really a pity considering the great importance of the bedding. In a homogeneous material the velocity difference and thus also the wave-length is, of course, greater than after the addition of a fine-grained material. — P. HAHMANN (1912) has, however, by experiment found that the distance between the crests of the dunes is directly proportional to the velocity of the water. This should mean that the velocity of the sand, U_1, is connected with the water's, U_2, by the relation:

$$U_1 = U_2 - \sqrt{U_2 \cdot \frac{k_1}{k_2}}$$

where $k_1 = \frac{2\pi \cdot \varrho_1 \cdot \varrho_2}{9(\varrho_1^2 - \varrho_2^2)}$

$k_2 =$ the proportionality factor in a relation between wave-length λ and velocity of water, U_2,

$$\lambda = k_2 \cdot U_2.$$

k_2 increases with the grain size and decreases with rising viscosity of the water; probably it also depends on other factors. — However, it would be a kind of argument in a circle to use this relation to decide the limiting wave-length. So we return to our example.

Erosion causing more material to be brought to the bottom-layer, the density of same is increased; the stream grows more stable and shorter wave-lengths can now appear. If the density should increase from 1.1 to 1.5, the limiting wave-length is decreased from 21 cm. to about 5 cm. (for $U_2 - U_1 = 25$ cm./sec.).

Since erosion generally occurs more easily in a finer sand than in a coarser one, this agrees with the observation that the distance between the dunes increases with the grain-size. — The suppositions regarding the density are, of course, very hypothetical and not easy to check by observations. However, they seem to be very plausible in consideration of the fact that the specific gravity of the sand generally is about 2.6 to 2.7.

However, it has followed from the example that these estimated values, especially when a minimum density difference between the two layers is assumed, very well agree with the values observed. The theory of a wave-formation according to HELMHOLTZ would, therefore, seem successfully usable, though not strictly valid near a boundary.

Transportation by rolling and saltation.

In this case there are three layers, as a transition layer has been formed, which brings about the transition of the water and the rolling bottom material.

The case of three superposed fluids has also been solved and one special case been worked out by TAYLOR. He says: »There is a difference in regard to the type of condition of stability between fluids in which the velocity and density vary continuously and those in which both of them are discontinuous». If the velocity and density of the layer of rolling material is U_1 and ϱ_1, of the water U_2 and ϱ_2 as before, and of the intermediate transition layer (height h) resp. U_3 and ϱ_3, in TAYLOR's example $\varrho_1 : \varrho_3 : \varrho_2 = 1 : 1.5 : 2$; thus very high concentrations in the lower layers, indicating erosion and small grain sizes. In the transition layer the velocity increases linearly from U_1 to U_2. »It appears that for any given value of $U_2 - U_1$ there is always a range of wave-lengths in which the flow is unstable, but as the wave-length diminishes the effect of the transition layer is to make the flow stable again for very short waves, which in the discontinuous case become more and more unstable the shorter the wave-length». (TAYLOR p. 500). With the prevailing indication system the wave-length is $\frac{2\pi}{\varkappa}$, and $\varkappa$ thus the number of wave-lengths on the distance 2π units of length (cm.). The thickness of the layer of transition has an important effect on the limiting wave-length. If h is low, so that $\varkappa \cdot h$ can be $= 0$, the limiting wave-length is $\frac{4\pi}{g} \cdot \left(\frac{V}{1.75}\right)^2$, for $\varkappa \cdot h = 1$ it will be $\frac{4\pi}{g} \cdot \left(\frac{V}{1.53}\right)^2$, for $\varkappa \cdot h = 1.6$: $\frac{4\pi}{g} \cdot \left(\frac{V}{1.47}\right)^2$, for $\varkappa \cdot h = 3.0$: $\frac{4\pi}{h} \cdot \left(\frac{V}{1.3}\right)^2$, and for very high $\varkappa \cdot h$ $\frac{4\pi}{g} \cdot \left(\frac{V}{1.67}\right)^2$. If the velocity difference $V (= U_2 - U_1)$ is put $= 30$ cm. the limiting wave-lengths will be respectively 3.8, 4.9, 5.3, 6.8, and 8.4 cm. Greater wave-lengths may thus occur, but not shorter ones, without causing the movement to become turbulent. Only if the thickness of the layer exceeds a value corresponding to $\varkappa h$ between 1.0 and 1.6 a further series of wave-lengths is possible, namely, very short waves. (For $U_2 - U_1 = 30$ cm./sec. and $\varkappa \cdot h = 1.6$ the upper limit will be only 1.1 cm., and for $\varkappa h = 3.0$ it will be 3.2 cm.).

Owing to the strong concentration chosen for the example, which concentration will not be so usual in nature, the wave-lengths estimated are shorter than those usually seen. As far as the magnitude is concerned the result is, however, correct, and an estimate of another example with less density downwards, will give the wave-length a higher value, in better agreement with reality. It is thus evident that the theory is applicable also in this case.

The example calculated by TAYLOR shows, amongst other things, the influence of the thickness of the saltation-zone. When this increases the wave-length grows at the same time. The thickness of the saltation-zone in its turn depends upon the velocity of the water; it grows as the velocity increases.

The actual work of a river as shown by the forms.

The special manner of transportation caused by the dune mode of traction is to a very high degree rhythmic. The movement is rhythmic not only in time, in that the particles have a certain changing between rest and movement, but also in space, in that the mass of transported matter changes in a regular manner in the dune.

For a closer analysis[1] of transportation of this type, for example a

[1] The examination was caused by the attempts to find a method for the determination of bed-load.

series of stream ripples, according to Fig. 29, the following simple reasoning which, however, does not seem to have been used earlier, is taken as the starting-point: *If the form of the dunes is to be maintained unchanged the same amount of matter must be carried away per time unit from every surface unit of the windward sides of the dunes.* If this is not the case a change in the form of the dune takes place immediately.

Transportation by rolling. First of all the case will be examined when transportation takes place exclusively through rolling, and saltation and suspension are not present as forms of transportation. In the case as shown by Fig. 29 the mass of rolled matter must increase from 0 at the point *a* up to its maximum value at the point *b.* The longitudinal section, Fig. 29, can therefore at the same time be regarded as a diagram, where the ordinate gives the intensity of the transportation and the abscissa the distance. For the distal declivity this description is highly approximative; here the eddies, described by many authors, are at work to the leeward of the crests of the dunes.

If the dunes maintain their form unchanged, this kind of transportation must imply equilibrium. Neither erosion nor deposition takes place, only

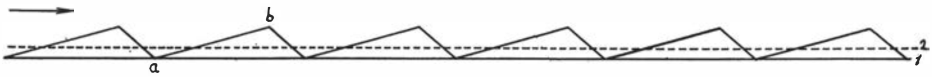


Fig. 29. Current-marks.

transportation. Erosion would imply an increase in the mass of transported matter. With the maintainance of the distance between the crests an increase of the intensity of the transportation must go hand in hand with an increase of the height of the dune. An increase of the travelling velocity instead of an increase of the volume should in its turn imply an increase of the distance between the crests of the dunes within the area where the *acceleration* takes place. Only if the erosion takes place above the place observed where the dune mode of traction exists, and only if the acceleration takes place simultaneously over the whole of this area, can an increase of the mass of the transported matter take place without changing the appearance of the dunes. Therefore, within the area considered, only transportation takes place. In the above-mentioned laboratory observations it was always found that movement in form of dunes occured below the places of erosion, the excavations, but never at the places where the erosion took place. There the matter moved with the same intensity over the whole area as a uniformly thick layer.

Deposition of a portion of the transported matter would, provided that the form of the dunes is maintained unchanged, cause a decrease of their height. A decrease in velocity must cause a compression of the dunes.

Another form of dunes corresponding to a smaller transport of matter also exists. In Fig. 29 all the matter above line 1 takes part in the movement, in that the whole sand-mass is transported. Erosion implies a lowering of this level line and deposition, a heightening. If the above-mentioned line is raised to level 2 and the surface in the meanwhile is levelled out, it may happen that the dunes become separated and move independantly of each other. This type of dune for a smaller transport of matter appears when the bottom layer has a different quality than the transported matter, and is solid or less moveable than this. In a laboratory it can easily be produced, for instance, by means of placing a sand-layer on a smooth metallic surface. By means of the effect of flowing water this dune-formation can appear, and if the existing mass of matter is not very large, the dunes become separated in the manner indicated above. This form of movement is, however, rather unstable. A very slight difference in the height of the dunes causes a change in their travelling velocity. According to EXNER's excellent paper on his studies of dunes on »Kurische Nehrung» (1928) the travelling velocity is reversely proportional to the height of the crest; therefore, the small dunes overtake the larger ones and combine with them. Moreover, these dunes most often have the form of barchans, that is to say, their sides are curved in the direction of the movement.

From these observations it is found, therefore, that the dune mode of traction signifies a state of equilibrium if the form of the dune remains unchanged; there is neither erosion nor deposition.

This rule is a corroboration, under previously stated conditions, of AHLMANN's more extensive proposition: »dass nähmlich die Furche die Form ist, in welcher das Geschiebe transportiert wird, und ihre Bewegung die Art, in welcher der Transport vorsichgeht» (1914 a, p. 22).

An assumption for the propositions above is, that the matter is present in abundance — preferably the whole river bed should have the same consistency. AHLMANN (op. cit. p. 31) makes the following important observation:

»In dem obenerwähnten Arpojokibach war dies mit grosser Deutlichkeit zu beobachten: Der Bach floss nähmlich erst über Moränenboden, wo alles feine Material wegerodiert, und der Boden gleichsam mit mittelgrossen Steinen gepflastert war; die kleine hier vorkommende Sandquantität wurde kontinuierlich einen langen Weg entlang geführt. An einer Stelle berührte das Wasser aber einen Sandrücken, der die Sandlast sehr vermehrte, was zu Folge hatte, dass sofort Transportdeltas entstande, obschon sowohl die Form des Bodens wie die Stromgeschwindigkeit dieselbe war. *Die Vorwärtsschaffung des Geschiebes mittels Transportkörper setzt somit eine gewisse minimale Materialquantität voraus.*»

Transportation by rolling and saltation.

When the velocity increases so that the finer ingredients of a mixed matter are transportated through saltation, the movement becomes more complicated. The dunes still remain, but above is found a layer with sand in saltation. The exchange between the layer of the rolling matter and the zone of saltation varies naturally with the velocity and the composition of the matter. If both of these remain unchanged the mass of matter which is transported in each of these modes of transportation is also constant. Then the form of the dunes is constant as well.

If erosion appears because of an increase in velocity, new matter passes at the same time, over into saltation or suspension. The form of the dune can not thereby be held constant; the dunes are swept away and the transportation occurs in a uniform layer. The opposite process, deposition, can hardly either happen without changes in the form of the dunes.

Transportation through rolling and saltation follows mainly the same laws as transportation through rolling alone. The kind of movement in question is a transition form to transportation of the moving bed-load as a uniformly extended layer.

Transportation of the bed-load as a uniform layer.

As has been mentioned earlier the coming into existence of the dune mode of traction is always connected with the influence of pulsations. They occur always, almost without exception, in running water, which, on the contrary, is not the case with the dune mode of traction of the bed-load. Why do then, under certain conditions, dunes appear, while in other cases, the bed-load moves as a uniform layer?

The answer is that a certain connection must exist between the pulsations and the nature of the matter, in order that the formation of these small submerged dunes may appear. If this condition is not filled, the movement takes place in a uniform layer.

At the formation of the dunes the sand was set in rapid motion over the bottom, by means of a pulsation. A gathering of sand took place at certain places with regular intervals, according to the waves in the boundary layer between the sand in movement and the water. A condition for the gathering together of the sand is, however, that the particles in the bed-load have resting-pauses in their movement. A pulsation increases the movement of the matter by means of an increase in its own velocity; when the velocity then decreases under its average value shortly afterwards, the grains must stop or else a dune will not be formed at all. If this is not the case the movement continues the whole time and will take place in the form of a uniform layer. It is easy to understand that existing obstacles can have an accelerated influence on the formation of these dunes.

If the resting pauses in question are to appear, the following conditions must be fulfilled:

1) The matter must not be too light, or else it follows the movements

of the water. Because of this, these dunes do not appear in running water over a bottom of clay.

2) The matter must not be too heavy either, or else it continues its movement because of its own momentum of inertia. Dunes of very coarse matter are not often to be found.

Thus it is essential for the appearance of dunes that the mean velocity is low enough so that the lowest instantaneous values fall below the lowest transportation velocity. The range of velocities between the value where the particles are set in motion by water and by other particles in motion, and deposition, must not be too great. It must not surpass the fluctuations in the velocity caused by the pulsations. It is shown by Fig. 17 that the velocity-interval in question is smallest for the grain-dimension groups 0.1 mm. It is also with this matter that the dune mode of transportation is most common.

According to KRAMER (1932, p. 27) KREY has in a hitherto unpublished investigation of the Elbe found that »die Reffelbildung sowohl von der Gleichmässigkeit der Korngrössen (Mischungsverhältnis) als auch von der absoluten Grösse der stärkeren Sandkörner abhängt». According to the observations of the writer the existance of rougher grains has a levelling effect upon the bottom. At the earlier mentioned (p. 301) observations of the velocity of the sand grains it was found that the rougher grains rolled continuously without pauses. They were influenced by the water even in lee of the crests of the dunes. But it was shown that it was not necessary to increase the velocity much over the velocity of the erosion in order that the dunes should disappear. The rougher matter put the finer matter in the crests in movement and the dunes were corroded away. In this way a zone was effected in the middle of the hydraulic channel with transportation of the material in a uniform layer, while on both sides the dune mode of traction occured. However, it was found that the bottom in the middle got lower and lower; *the bed was eroded at that part of the channel where the transportation in a uniform layer occured.* The other parts of the channel retained the same level; erosion was not present there. If stones or other obstacles which the water could not displace were placed on the bottom within the eroded area, some of the material was deposited behind these obstacles. There occurred, therefore, a longitudinal dune. At the sides and in front of the obstacles excavation occurred. All the forms of the bed were elongated in the direction of the stream. It is not always easy to decide if they are formed by accumulation or erosion. However, when the velocity is great, it seems as if these longitudinal forms were more often the result of erosion than of accumulation. The writer has made the same observations concerning the form-system of snow.

Similar observations can be made in natural streams when the water is sufficiently shallow or transparent. If the velocity is increased in an artificial way it is found that the dunes disappear, the matter passed over more and more into suspension, and the bed-load soon moves in a uniform layer. Pl. VI shows dunes in fine sand (0.2—0.4 mm.) formed in the small delta which the »Prostgårdsälven» builds where it empties into the Borssjön at Molkom, Värmland. The distance between the crests was on the average 15 cm., the water's velocity 30 cm. per sec. and that of the dunes about 3 cm. per minute. By damming up a little outlet-branch of the stream, the water-mass could be increased, whereby the velocity rose to about 70 cm. per sec. At this velocity erosion appeared at that place, illustrated by Pl. VI, the dunes vanished away, the sand was transported in a uniform layer and the bottom was lowered.[1]

These and other similar observations seem to the writer to justify the following conclusion:

At places where the water is eroding its bed the material is transported in a uniform layer.

The word »*uniform*» signifies the opposite to the dune mode of transportation, where the transportation has rhythmic variations according to the form of the dunes; however, it should not be taken too literally. In the boundary surface is even here found a tendency for wave-bilding, which, however, only expresses itself in variations with the thickness of the moveable layer. Illustrating figures are offered by BUTCHER (1919, p. 1933). This thickness can, indeed, be quite considerable.

This wave-formation in the saltation zone's upper boundary surface can be backward-moving (see TAYLOR, 1931, p. 500 and 516). Consequently the *anti-dune* motion appears, as described by GILBERT, CORNISH and others.

Conclusions.

A summary of the conclusions of the preceding pages may be formulated in the following manner.

The dune mode of traction with unaltered form of the dunes signifies equilibrium, without erosion or deposition. At places where the water is eroding its bed the material is transported in a uniform layer. The longitudinal forms seem to indicate erosion; they are — at greater velocities — caused by erosion and no such forms characterizing transportation exists.

If the mechanical composition of the material is uniform and the size of the particles is 0.5—4 mm. the presence of transversal dunes generally signifies a state of equilibrium without erosion or sedimentation; transportation of the sand as a uniform layer signifies erosion. — The process of deposition has no other form of its own than that of a delta.

[1] The figure is interesting because the surface-waves of the water are also visible. The dunes are, however, not caused by these waves, as they appear even when the water is calm, and exist even in the other outlet-branch, not exposed to wind or waves. (The system of white lines in the foreground is caused by refraction of sun-light.)

The capacity of a stream.

When a river deposites a part of its matter, this depends upon the fact that the actual velocity sinks below the lowest transportation velocity. If the material consists of particles of uniform size, all the quantity of material carried is deposited. But if there are particles of a wide range of sizes only a part of the load (load = »the actual quantity of material carried at any one time», TWENHOFEL, p. 42) may be deposited. This part then is most often the group of greatest grain-dimension; only in certain rare cases may the finer particles be deposited at first, while the greater particles still roll over the smooth surface.

One sometimes meets the more or less clearly formulated supposition that the deposition depends upon the fact that the stream is *saturated* (»gesättigt»). Energy is spent for transportation. In a river with a maximum load all the available energy is consumed for the transportation of mineral matter.

The writer has earlier pointed out (HJULSTRÖM, 1932, p. 252) that the expression »saturated» must be regarded as very unsuitable; this leads to the conception that the stream should be saturated with mineral matter in the same manner as a solution of salt can be saturated. Thus, it should not be able to carry a greater quantity of mineral matter. However, this is erroneous especially for the matter in suspension. A supply of matter lowers the velocity somewhat, it is true, (see JAKUSCHOFF, 1932 b, p. 18) and causes a sedimentation of the coarsest particles. We assume that these are found in a small quantity, while the matter on the whole is very fine-grained. As a result, an increase of the load may then be obtained. And if only a sufficiently fine-grained matter is selected, this increase in weight may be imagined to be of any magnitude whatever. It seems to be difficult to indicate an upper limit. At the same time, the water becomes more and more sluggish-moving. In nature all transitions between silt-carrying streams and mud flow (»Erdfliessen») should occur. RAYMOND C. PIERCE (1916) mentiones, from the San Juan River, that during a sudden heavy flood 75 per cent of the original volume of a sample was silt and red sand. But whilst in such cases water is mixed with silt and sand, the mud flow has from the beginning an opposite origin: that is to say, the soil has absorbed water.

According to GLUSCHKOFF (quoted from JAKUSCHOFF, 1932 b, p. 18) the river Murgab in Turkestan uses only 1 to 3 % of its total power of work for the transportation of suspended matter.

W. W. RUBEY, (1933 b) calculates that the energy consumed in supporting débris is closely (measured in ergs):

$$\frac{L(\varrho s - 1)}{\varrho s} \cdot g \cdot c \cdot t^2$$

where L = mass of debris passing a cross-section per unit time (in gr. per sec.).
g = acceleration of gravity.
ϱ = density of débris-particles.
t = time in sec.
c = the settling-velocities of both large and small particles.

RUBEY calculates that in 22 experiments by GILBERT, 97.5 %, on the average, of the total stream-energy appears to have been lost in friction and only 2.5 % spent in transporting débris. Unpublished data for the Colorado River indicate values of the same magnitude (RUBEY, op. cit. p. 503). The three cases for which calculations exist thus show unanimously an especially low energy consumption for silt-transportation.

A saturation of the stream should indicate that, because of a high percentage of transported matter, it has becomme so sluggish that its velocity approaches 0. Any such phenomenon has not been mentioned in geological or geographical literature. — When rivers carry very small quantities of matter and in spite of this do not erode, it is due to the fact that the velocity is too low in comparison to the size of the particles in the matter.

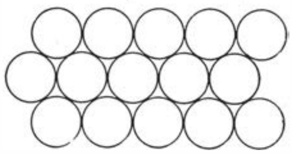


Fig. 30. Arrangement of spheric particles.

In connection with the term »saturated» there is also another term, namely, the *capacity* of a stream. By this term is meant the maximum load a stream can carry. According to the above this is a term which does not hold in case one imagines that the river has access to all kinds of grain-dimensions.

The term »capacity» has been brought forward by K. G. GILBERT in connection with his investigations concerning the transportation of débris by running water. These investigations concerned almost exclusively the transportation of the bed-load. It should now be noticed that for this kind of transportation — especially of coarse matter — a maximum load should exist. If the transportation consists only of rolling, the water can work upon the top-layer only, and only this layer can then move. A movement in layers lying one above the other as DU BOYS assumes, (see for instance SCHOKLITSCH, 1914) should be possible only in fine material, where a sheet of water round the particles plays some rôle. The existance of a movement of the indicated type has moreover been disproved by SCHOKLITSCH (1914, p. 16—17) concerning sand.

Under the condition that the particles are spheric $\left(\text{diameter} = d, \text{ weight } \frac{\pi}{6} \cdot d^3 \cdot \varrho\right)$ and arranged as in fig. 30, the maximum matter-transport per length unit of the dross-section becomes:

$$0.6 \cdot \varrho \cdot d \cdot U_1$$

where U_1 = the velocity of the grains.

If, besides, the matter exists in saltation it becomes more difficult to explain the occurrence of a maximum limit for transportation. But according to GILBERT's observations the velocity at the bottom is greatly lowered at the transportation of bed-load and, perhaps, because of this only a certain maximum mass may exist within the zone of saltation: this maximum mass increases with the size of the particles (GILBERT, p. 150—154).

Conclusion.

According to the above it appears that a river which has access to matter of all grain-dimensions down to clay and which possesses such a large velocity that even the clay may be eroded, lacks a maximum limit for its capacity of transportation. However, a stream which transports rolling matter without access to anything else can only transport a certain mass of this matter.

CHAPTER IV.

The degradation of the Fyris river basin.

Extent and plan of the investigation.

The previous chapters have treated the question of erosion and transportation from mainly a theoretical standpoint. The above-mentioned processes have, as a rule, been placed in connection with the velocity of the water. The velocity has been considered as the most important trait of character as to erosion, transportation and sedimentation of a river. The treatise has, however, shown the impossibility of making direct calculations of the erosion of a river without direct measurements. Important general laws can be laid down, and the physical explanation of several of the observed phenomena can be given. But the velocity depends upon many indeterminable factors, most important the water-mass which, in its turn, is determined by the hydrographical and climatological elements. Even if the velocity is presumed to be known, many unknown links in the chain of calculations for the obtaining of the extent of erosion remain. Among these incalculable factors the nature of the material should be mentioned. In Ch. III the difficulty of calculating the velocity of erosion for a given material was pointed out. If this is not altogether uniform, with the same size of the particles, the velocity of erosion cannot be regarded as known. Even after a determining of the velocity of erosion the difficulty still remains of determining how much material the river will transport. As has been pointed out in the preceeding pages this calculation cannot be carried out under certain conditions.

The knowledge of the eroding influence on the earth's surface of running water, must, therefore, be based on direct measurements according to one of the two methods — or both — which have been described on p. 225. Such measurements must be made for as many rivers as possible of different types and in different parts of the world. Every river has its own individuality in certain respects, and experiences concerning erosion in a river basin may be used as a basis for conclusions concerning other river systems only after very careful consideration. Furthermore, such measurements ought to be stretched over as long a time as possible in order that fluctuations in the climate will not have too great an effect.

The investigation which will now be described has been extended over 5 years, from the 1st of July, 1929 to and including the 30th of June, 1934.

The investigation was started with sample-taking as early as the end of October, 1928. During the time to the 1st of July, 1929, various methods for sampling and analysis were tested; the sample-series from that time has not been definitively arranged and is not included here. It is not entirely complete.

The chief object of the investigation was to determine the rate of degradation of the river basin of the Fyris, north of Uppsala. This was done by means of determining the amount of mechanical sediment and dissolved matter in the water passing a profile just north of the town. The quantitative measure of the rate of degradation which was thereby obtained was thought to be of some interest as only some scattered analyses for Swedish rivers existed earlier, and no detailed investigation of this type existed for a river so far up in the cold-temperate climate as at the 60th parallel.

Apart from this main object also the connection between the amount of matter carried by the river and the factors which influence this amount was to be sought.

Geographical conditions of the Fyris River basin.

The Fyris belongs to the Mälaren-Norrström drainage-system in the eastern part of Central Sweden. The sketch-map in Fig. 31 shows the situation of the Fyris River basin. The part of the river basin, the degradation of which has been investigated, is indicated. As is seen, the area is crossed by the 60th parallel.

The area is very low-lying; its average height amounts to about 30 m. above sea-level. It forms a part of the peneplane of Precambrian and Lower Cambrean age in Central Sweden. Figs. 32, 33 and 41 are intended to give a conception of the levelness of the area.

The largest plains within the territory are found around the head-river. The vast Uppsala-plain, Fig. 32, is the largest of these; it forms a fertile cultivated clay-plain with about 47,000 inhabitants, including the city of Uppsala with 31,560. Other cultivated plains of greater area are found in the parishes of Lena, Viksta and Vendel (Fig. 33) and around Gruvsjön, north of Dannemora. The vast marshes also form, of course, a level terrain. These have an especially large expansion within the northern, western and eastern parts of the territory and lie at a somewhat higher level above the sea than the cultivated clay-plains. Some of the marshes have been drained in recent years, as for instance the Bälinge marshes.

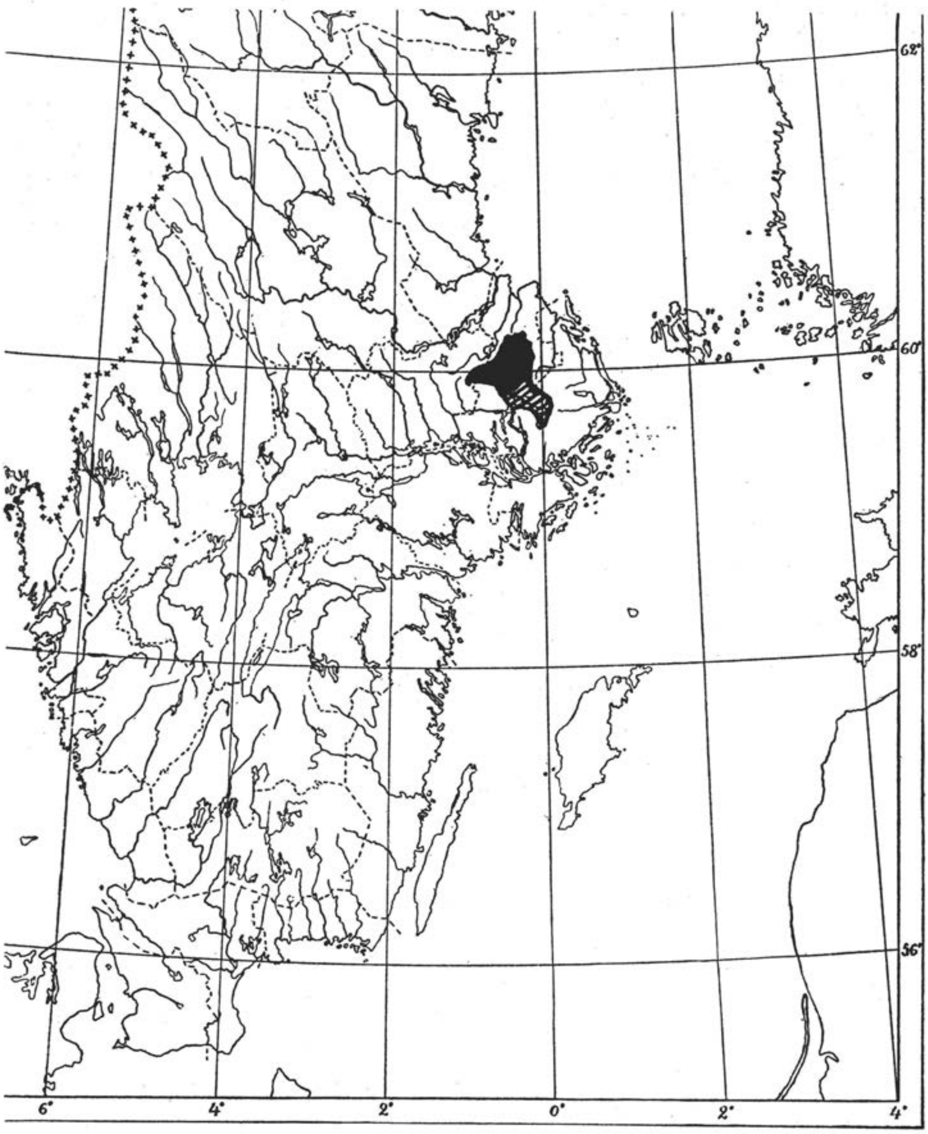


Fig. 31. Sketch-map showing the situation of the Fyris river-basin.

The mentioned levelness of the territory is to some extent conditioned by the loose earth which levels out the unevennesses of the bed-rock. In the bed-rock itself are found numerous depressions and fissures (WIMAN 1930, Fig. 91). In the rock-floor valley, caused by fissures in a north-west-south-easterley direction, in which the Uppsala-plain lies, borings have been made to a depth of 100 m. without encountering solid rock.

The bed-rock rises gently towards the West, and here are found the highest points of the territory. The water-divide here goes, at several places, over 100 m. and reaches at one point a height of 113 m. — the highest point of the river basin. (H. B. Ms).[1]

On the whole the water-divide is very level, especially in the north-western and northern portions, where it passes over low-lying lands which, at high-water, drain into the Fyris as well as into other near-lying water-courses. Lake Strömmaren sends, at high-water, a part of its water to the Fyris, but drains as a rule only into the Tämnar River (H. B. Ms).

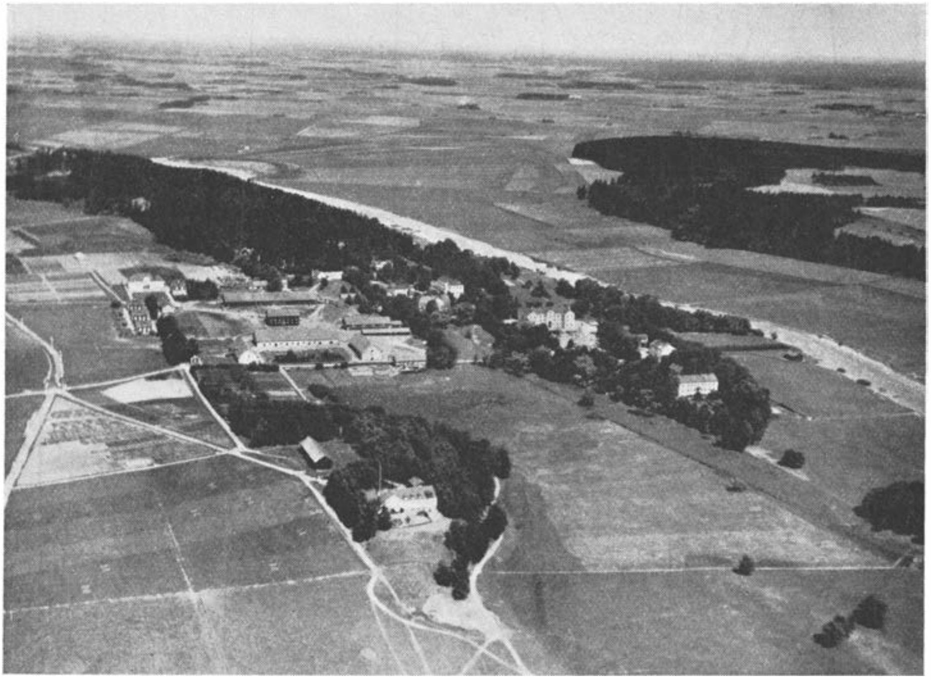


Foto Gösta Gustafsson.

Fig. 32. Air view of the Uppsala plain from the south. In the foreground Ultuna University of Agriculture and along the River Fyris the Uppsala esker. At the swell of the Fyris the River Sävja enters from the east.

However, eskers and out-croups rise over the level plain. The eskers go more or less continuously in a northerly and southerly direction; they are partly well developed and reach a height of 20—40 m. over the surrounding territory. The Uppsala-esker is the largest of these eskers. It has with its branch-eskers a large conformity to the Fyris and its tributaries. Thus the Vattholma-esker, on the whole, has the same course as the Fyris, while the Uppsala-esker itself rather follows the Björklinge-river. The Vendel-esker, however, has no river in its immediate vicinity. Apart from the Uppsala-esker with its branch-eskers short parts

[1] This abbreviation indicates an unpublished manuscript concerning the Fyris by the State's Meteorological-Hydrographical Institute in Stockholm, 1933.

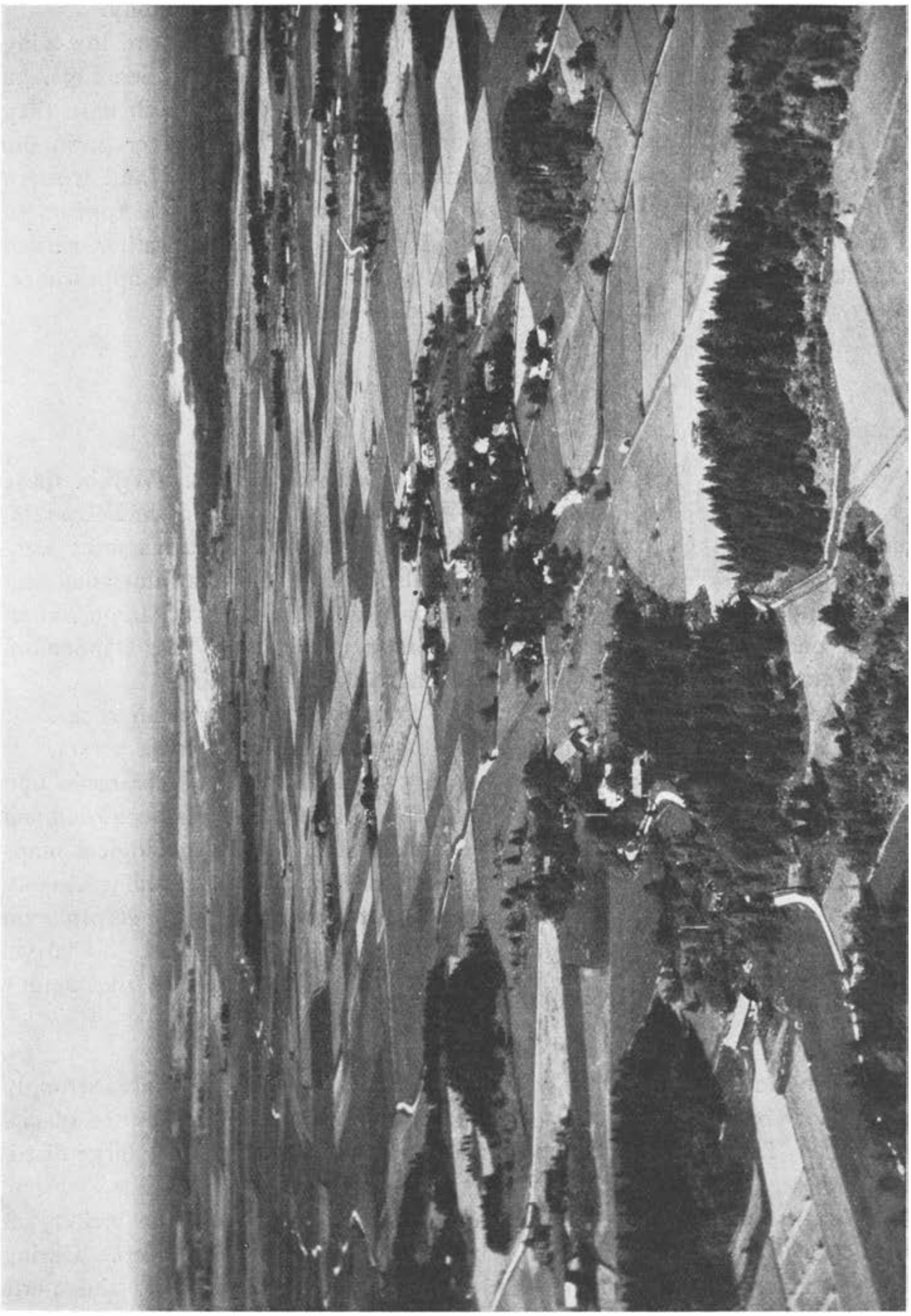


Foto Gösta Gustafsson.

Fig. 33. Air view of the Vendel plain from the south.

of others are also found within the drainage-system, the Järlåsa and Stockholm eskers, which do not stand out so much in the topography.

Outcrops also rise above the clay plains. In the more low-lying districts they stick up from the clay like isolated islands. See Figs. 32 and 34. They are entirely bare or morain-covered, in which case they are often forest-covered. In the northern section of the river basin the bed-rock is not so broken up as farther south. The eastern and western parts have a rather rough topography. Here naked bed-rock appears to a rather large extent. These higher lying areas stand in a rather marked contrast to the clay plains and have a completely different appearance. They form wooded morain-covered plateaus, often swampy.

Geology.

The rocks. The bed-rock consists mostly of granite. Within these granite-areas are found fields with hälleflinta and leptit which contain, among other things, iron ore. Here is found one of Sweden's most well-known mining districts, Dannemora. Also gneiss, diorites, limestone and other kinds of rock are found. Limestone is not found to a large extent in the bed-rock itself. The most important occurrences lie near Dannemora and Vattholma, where the limestone is an object for mining.

The bed-rock is composed almost exclusively of Archaean rocks. It is in this connection of little interest compared to the loose strata. It comes to the surface only within about 5 % of the whole river basin and 0,3 % of the drainage area above Uppsala. (This value has been obtained by means of surface-measuring with a planimeter on the geological maps on the scale of 1 : 50,000. Generally within districts with small rock outcrops these rock-areas are somewhat exaggerated as to their extention on geological maps. The percentage may, therefore, be somewhat too large). These areas form, of course, resistance territory in respect to the water's erosion.

The loose earth-layers. The nature of the loose material is strongly influenced by the quaternary glaciation and consists largely of glacial deposits. The post-glacial deposits have, however, also a very large distribution.

At the time when the ice-cap was receeding from the vicinity of Uppsala, the ice-sea must have been about 130—140 m. deep. During the following rising of the land which is still in process, the parts warping above the sea have been exposed to abrasion which has been of varying strength according to the exposure to the influence of the waves. The highest portions of the said area have, of course, been exposed to the strongest abrasion and have been washed clean of finer particles which are, instead, found deposited within the low-lying plains.

The most common kind of earth within this district is *moraine,* which, with an especially varied appearance, occurs within large parts of the territory. The composition of the morain shows that it comes from the bed-rock from the district lying immediately north. But even other matter is found, and among this is especially the limestone to be noticed, coming from the Silurian formation on the bottom of the Bothnian Sea. This occurrence of limestone in the moraine is most common in the northern part of the river basin; it decreases towards the south, and in the Uppsala district the moraine is almost free from Silurian matter.

After the moraine come, in extension, the clays. These have very different qualities, ways of formation, and age. The most frequently occurring clay within the district is the varved glacial clay, the Yoldia clay. This is generally calciferous with a decreasing percentage of lime towards the south -- in accordance with the moraine which is the cause of the clay's lime-percentage.

According to HÖGBOM (1892) the percentage of lime in the clay at Örbyhus is on an average 23 %, at Salsta 21.7 % and at Uppsala 18 %. The mechanical composition has been examined by ODÉN (1919) from samples from Uppsala (S:t Erik's tile-works). From his diagram of the composition it is found that only a very small quantity of the clay has a particle-dimension of over 15 μ. The fractions of lesser size of particles occur in about the same percentage down to 0.7 μ; those still smaller are found in great quantity, namely, 46 % of the weight of the clay. This clay comes to the surface in the vicinity of the sides of valleys and over wide areas of the large plains. In deep valleys and large depressions it is, however, often covered by younger clay-layers, *Ancylus*- and above that *Littorina*-clay.

The matter composing these clays comes from glacial clay and moraine clay; when the land rose so that the higher parts appeared above the surface of the sea a portion of the material was carried out into the sea by the action of rivers and waves and was deposited in stationary water free from currents. The same composition may, therefore, be expected with the post-glacial clays as with the glacial clays. They are not deposited in layers, that is true, but investigations show that they have many similarities in other regards. ODÉN and REUTERSCHIÖLD (1919) have given a detailed account of the mechanical and chemical composition of the »*Ancylus*»-clay. From this it is found, that they belong to the very finest grained of Swedish clays. The content of particles greater than 2 μ as a radius is only 12.5 % and consists partly of sand which does not belong to the clay but may be regarded as an impurity. Within the investigated interval of the grain-dimensions (r=0.17 μ—7 μ) there appears in the diagram of the mechanical composition a maximum with the equivalent radius of 0.23 μ. The finest particles are found in very large quantities; no less than 30.9 % of the clay consists of particles less than 0.17 μ. The average radius of these is about 100 μμ. Thus the small particles are by far the most predominant.

The »*Ancylus*»-clay is deposited in fresh water. When the sea was 65 to 67 meters above its present level (GRANLUND, 1931) the character of the water was changed; it was transformed into salt-water, and the clay deposited in that sea is called »*Littorina*»-clay. However, at this time a warm and dry climate prevailed (the subboreal epoch) and the streams and rivers which supplied the sea with silt had very little water (SERNANDER 1920). Only after the climatic transformation did the rivers carry a more abundant supply of water, and according to observations by SERNANDER (op. cit. p. 336) which the writer has found confirmed, mighty post-glacial, marine clays are found only from the present sea-level to 9—11 meters above sea-level. Above this line it is chiefly glacial clay that is found at the surface. According to STOLPE (1869) this is partially weathered. The *Littorina*-clay is highly mixed with organic matter but seems to be less calciferous than glacial clay. An examination of the mechanical composition has not been made, but very likely it does not differ very much from that of the *Ancylus*-clay. Because of the fact that the water was salty at the time of the formation of the clay, it could be expected that the clay would coagulate and therefore possibly be somewhat less fine-grained than the *Ancylus*-clay. Along the sides of valleys, especially in the vicinity of the eskers, the two postglacial clays change into sand.

The eskers are bounded on both sides by sandy ground, which in certain districts has a very great extent.

Vegetation and cultivation:

According to HÖGBOM (1905, p. 8) the total area of the Fyris, that is to say 1982 square kilometers, is composed of 22.8 % cultivated earth, 10.5 % meadow, 63.9 % forest and waste land and 2.8 % lakes. The given lake-percentage is too high, the figure should have been 2.1. The area of cultivated earth has by means of draining been increased at the cost of the waste land. The figures are, for the drainage-area north of Uppsala, approximately as follows:

cultivated land	33 %
forest (moraine)	55 %
marshes	10 %
lakes	2.4 %

The figures have been obtained from the area-statements in *Jordbruks-räkningen 1927*, Stockholm 1930, and, for the boundary parishes, by means of measuring with a planimeter. The figure for the lake-area was taken from H B Ms.

The American investigations of soil erosion have shown that »the character of the vegetative cover is the most pertinent factor in this connection» (BENNETT, 1934, p. 481). Forest and grass both give a practically complete protection from erosion on fine sandy loams. A thin cover of

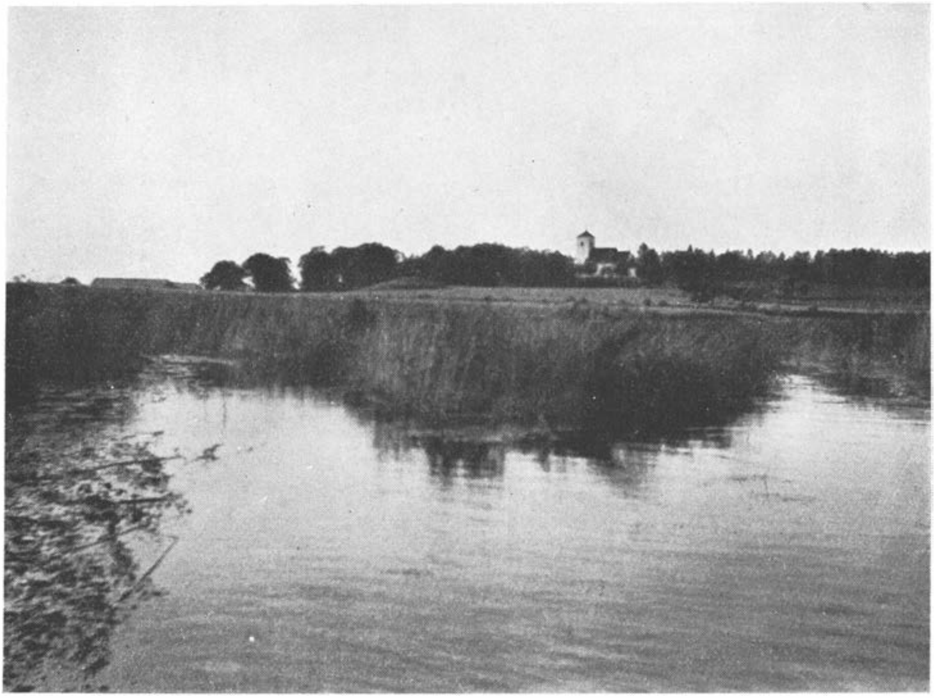


Foto FILIP HJULSTRÖM Aug. 1930.

Fig. 34. The junction between the Fyris and the Vattholma River. The Fyris to the left.

leaves in the woods is very protective. As is seen from the table the main portion of the river-basin is covered with grass or forest (as well as with marshy and mossy ground). The soil-erosion, or rain-wash, cannot have any greater effect than on parts of the cultivated soil, especially on the portion which is fallow. The greatest acreage is free of vegetation, and therefore soil erosion is the greatest during the autumn and spring plowing, which take place during the months of April and October—November respectively.

From the present point of view the different types of vegetation which appear within the area are of less interest. Of importance is only the vegetation which is found in the Fyris itself. The abundance of vegetation varies rather markedly in different parts of the course. In certain parts it is so abundant that the whole river seems to be overgrown during the latter part of the summer apart from a narrow canal in the middle. This is, for instance, the case at the junction between the Fyris and the Vattholma-river, where picture 34 was taken. Such a plentiful vegetation in the river is common within great parts of its course; but not everywhere. The Jumkil-river lacks vegetation of this kind almost entirely with the exception of a section close to its entrance into the Fyris. Pictures 35

Foto Filip Hjulström Aug. 1930.

Fig. 35. The Jumkil river west of Åkerby church.

and 41 were taken in August 1930 at the Jumkil-river immediately west of Åkerby church. It is quite remarkable that, within the Fyris river-bed there is no vegetation within those river-sections which have a meandering course or which in general have sinuous alignement — a fact which the writer will perhaps treate more closely in another connection.

The vegetation is formed by Equisetum-, Phragmites-, Glyceria- and many other associations. Elodea is also found in abundance. The vegetation is, therefore, often very thick; it checks the movement of the water. Sedimentation is, therefore, increased at places with abundant vegetation. The deposited material is then more strongly held fast by the vegetation, as is shown by Jakuschoff's report (1931) of the investigations by Russian scientists.

Climate.

The temperature-conditions within the Fyris River-basin are illustrated by Table 12 (from the State's Meteorological-Hydrographical Institute's year-book, volume XV, 1933, part I, Stockholm, 1934) and by Fig. 36. These apply to Uppsala but can be considered as representative for the whole river-basin, since the temperatures at different places within this river-basin differ from one another by only a few tenths of degrees (see for example HAMBERG, 1905).

February is the coldest month with an average temperature of —4.°3 Celsius, July the warmest with + 16.°5. The amplitude is thus on the average 20.°8. This rather high value indicates a certain continental characteristic in the climate, which can also be traced in the variation of other climatological elements.

The average temperature of the year is 4.°9. The temperature remains below 0° from the 16th of Nov. till the 31st of March, that is to say, 4 ½ months (WALLÉN, 1930, Table 6). The freezing over of lakes begins about Nov. 19th and the breaking up of the ice about March 23rd. The duration of the ice is therefore on the average 155 days.

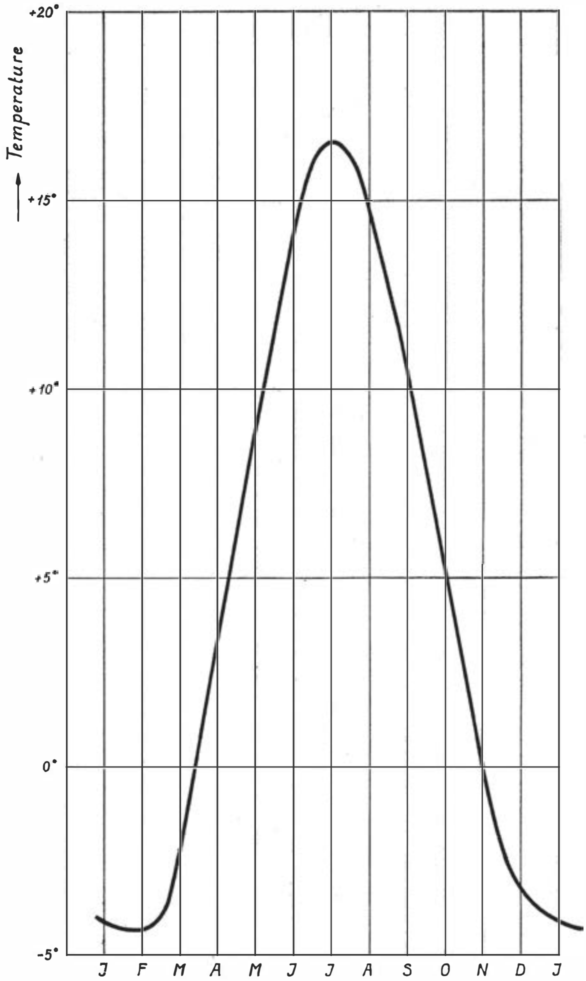


Fig. 36. Mean temperature at Uppsala.

The daily course of the temperature is greatest during the summer and least during the winter; according to HAMBERG 9.°1 in June and July and 1.°2 in Dec.

The importance of temperature on erosion consists mainly in its in-

Table 12.

Mean temperature at Uppsala (Period 1859—1925).

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
8 o'clock	−4.6	−5.5	−3.5	+2.6	+ 9.3	+14.7	+16.9	+14.8	+ 9.9	+4.2	−0.5	−3.6	+4.6
14 »	−3.1	−2.3	+1.1	+6.9	+13.1	+18.2	+20.6	+18.7	+14.5	+7.8	+1.4	−2.6	+7.9
21 »	−4.2	−4.5	−2.7	+2.0	+ 7.7	+13.1	+15.4	+13.3	+ 9.3	+4.5	−0.1	−3.3	+4.2
Mean	−4.1	−4.3	−2.2	+3.1	+ 8.8	+14.0	+16.5	+14.6	+10.5	+5.1	+0.1	−3.2	+4.9

Table 13.

Precipitation at Uppsala (Period 1836—1933).

Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
33.1	27.1	28.0	29.9	42.2	50.8	68.2	72.4	53.7	55.2	44.0	39.7	544.3

Table 14.

Mean precipitation in mm. (Period 1917—1931).

Station	Height a. s. m.	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
Lövsta . . .	25	42	18	23	37	32	51	65	65	64	49	33	51	530
Bro	25	39	16	19	37	40	59	62	80	65	52	34	49	552
Väsby	35	44	21	21	37	40	54	65	77	63	49	33	50	554
Östervåla . .	45	37	17	20	32	41	53	68	64	63	45	32	40	512
Örbyhus . . .	28	39	21	22	34	41	53	68	73	65	49	37	53	555
Österby . . .	35	36	17	19	30	33	54	63	74	60	50	34	45	515
Gimo	18	47	25	28	38	44	51	82	81	65	57	38	59	615
Vattholma . .	25	35	18	19	31	41	55	78	79	66	54	33	43	552
Drälinge . .	30	42	21	23	34	40	55	71	72	63	52	36	46	555
Husby . . .	25	37	17	18	31	33	48	60	65	58	48	29	45	489
Morgongåva .	65	37	21	20	31	42	51	80	72	62	57	47	36	556
Skattmansö .	45	39	16	18	37	41	51	81	71	68	55	35	41	553
Ultuna . . .	4	38	20	20	32	36	55	69	77	64	49	33	44	537
Frötuna . . .	15	36	18	16	33	29	49	65	71	63	48	30	41	499
Rånäs	20	47	24	24	33	38	58	65	79	67	54	42	52	583

Table 15.

Number of days with precipitation at Uppsala July 1929—June 1934.

	Year 1929					Year 1930				
	Number of days with precipitation					Number of days with precipitation				
	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0
January . . .						16	7			
February . . .						9	5	1		
March						11	3	2	1	
April						11	5	2		
May						8	4	2	1	
June						12	10	5	2	
July	16	13	6	1	1	15	10	5	3	1
August	16	11	6	1		18	10	5	2	2
September . .	12	9	3			21	13	6	3	1
October . . .	21	15	7	1		21	10	6	1	
November . .	14	8	2			14	12	5	1	
December . .	21	13	4			24	11	1		
Year	100	69	28	3	1	180	100	40	14	4

	Year 1931					Year 1932				
	Number of days with precipitation					Number of days with precipitation				
	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0
January . . .	25	16	3	1		14	8	1	1	
February . . .	21	8	2			18	3			
March	11	5	1	1		11	6			
April	12	5	2			19	11	4	2	
May	14	9	2	1		12	10	5	2	
June	15	8				17	8	3	10	
July	13	8	3	2		9	4	4	3	2
August	17	13	5	4		16	8	5	1	
September . .	16	8	2	2		14	11	3	1	
October . . .	11	9	4	2		14	8	5	2	
November . .	18	5				19	12	4	1	1
December . .	21	15	5	3		14	6			
Year	194	109	29	16		177	95	34	23	3

Table 15 (cont.).

	Year 1933					Year 1934				
	Number of days with precipitation					Number of days with precipitation				
	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0	≥0.1	≥1.0	≥5.0	≥10.0	≥20.0
January . . .	17	6	1			10	7	2		
February . . .	17	7	2			11	7	2	1	
March	7	3	3	1		21	15	5	1	
April	11	5	1			10	4	1		
May	11	6	3	1		13	9	1		
June	10	7	1			13	6	5	1	
July	19	14	6	3	2					
August	16	8	5	2						
September . .	15	9	3							
October . . .	14	8	2	2						
November . .	15	9	1							
December . .	19	4								
Year	171	86	28	9	2	78	48	16	3	

fluence on the water discharge. The temperature influences the evaporation and therefore the run-off decreases when the temperature rises; on the other hand the water is also held fast when the temperature goes below 0° due to the freezing. During those periods when the temperature ranges around 0°, it may be expected to have, from the present view-points, greater interest than during summer or winter, when it is rather constantly either above or below the freezing-point for long periods.

Precipitation. The Fyris river-basin is wholly situated within the precipitation-poor eastern part of Sweden, and has on the average a mean annual precipitation of 544.3 mm. During dry years the precipitation can (according to H B Ms) fall below 400 mm., but during wet years it may rise above 700 mm. According to WIGERT (1893) the extreme values for Uppsala are 312 mm. (1875) and 812 mm. (1866). The mean annual precipitation for Uppsala, mentioned above, is valid for the period 1836—1933.

The annual period is rather marked as is illustrated by Table 13. This is based on a Table accessible at the Met. Obs. Uppsala of the precipitation's total and mean for the period 1836—1925, to which has been added information for the last years from the Bulletin mensuel de l'Observatoire Météorologique de l'Université d'Upsal. In Table 14 the monthly and yearly precipitation averages are placed for a number of stations within or near the river-basin; they are calculated for the period 1917—1931 (H B Ms). As is seen they do not differ very greatly.

Table 16.

Number of days with covering of snow at Uppsala at noon.

Winter	Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	Winter months	Total
1929—1930			1	3	28	5	2		32	39
1930—1931			15	31	28	31	12		74	117
1931—1932	12	2	26	17	23	21	3		66	104
1932—1933			8	16	21	18	5		45	68
1933—1934		10	31	10	15	19	2		56	87
Average for										
1929—1934	2.4	2.4	16.2	15.4	23.0	18.8	4.8	—	54.6	83.0
1874—1890	0.8	6.9	20.0	24.7	19.2	21.3	7.4	—	63.9	100.3
Per cent of the time										
1929—1934	8	8	52	50	82	61	16	—	61	
1874—1890	2	23	65	80	68	69	25	—	71	

Table 17.

Number of days with covering of snow at Drälinge.

Winter	Oct.	Nov.	Dec.	Jan.	Febr.	March	April	May	Winter months	Total
1929—1930			3	3	28	8	4		34	46
1930—1931			13	31	28	31	23		72	126
1931—1932	11		28	21	22	27			71	109
1932—1933			9	14	16	22	9		39	70
1933—1934		7	31	19	19	25	5		69	106
Average										
1929—1934	2.2	1.4	16.8	17.6	22.6	22.6	8.2		57.0	91.4
Per cent	7	5	54	57	80	73	27		63	

From these tables it is seen that the precipitation has its maximum during August, when, in Uppsala, 13.3 % of the annual precipitation falls. Then the precipitation decreases until a minimum is reached in February, which has little more than 1/3 of the precipitation during August or 5.0 % of the annual average total. As is seen from the Tables most of the precipitation falls during the summer, when almost a double amount of rain falls than during the winter. Autumn is also a rainy period, and the percent of rainy days is then greatest.

Table

Thickness of covering of

Date	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Winter 1929—1930:															
December															
January															
February	2	2	2	2	3	11	11	10	10	7	6	6	6	4	0
March															
April															
Winter 1930—1931:															
December															
January	0	5	6	6	8	53	58	52	52	50	50	47	47	46	49
February	33	36	36	36	36	36	36	36	34	34	24	22	20	21	23
March	33	33	33	33	33	38	40	42	42	41	46	59	61	61	57
April	16	16	14	14	12	10	10	10	10	9	9	8	8	8	7
Winter 1931—1932:															
October															
December		2	2	1			7	7	10	10	16	16	12	8	8
January	52	52	49	49	49	39	34	32	33	33	31	29	28	26	25
February								2	2	1	1	11	10	9	8
March	1	1	1	1	1	1	1	2	2	8	14	14	21	20	21
Winter 1932—1933:															
December							1	2	2	2	1	1	1	1	0
January															
February	6	1	0												
March	14	13	13	12	12	10	9	9	9	8	5	1	0	0	
April				6	4	0									
Winter 1933—1934:															
November															
December	8	8	7	7	7	5	8	8	8	8	8	9	9	9	9
January	13	13	12	12	12	15	13	3	2	2	2	2	2	4	1
February									5	15	12	10	10	8	6
March	2	2	2	7	4	0	0			1	3	5	3	10	13
April						3	2	0		2	0				

18.

snow at Drälinge (in cms.).

16	17	18	19	20	21	22	23	24	25	26	27	28	29	30	31
									3	2	0				
													3	3	3
2	2	2	1	1	1	0	0	0	0	0	0	0			
			2	0	17	10	6	6	2	0					
			1	3	2	0									
2	3	3	1	1	0				9	11	10	8	5	1	0
48	51	46	46	45	45	45	45	43	29	23	30	32	32	32	33
23	25	25	25	25	24	22	20	20	20	30	30	32			
57	53	53	42	35	35	32	30	29	25	19	12	12	21	18	17
6	4	2	2	2	2	2	0								
					4	4	12	12	11	11	10	10	6	10	10
29	34	34	32	32	32	31	31	30	20	22	22	22	49	52	53
23	16	13	8	1	0										
9	8	8	7	6	7	3	1	1	1	0	2	1	1		
21	21	19	19	17	10	9	5	2	1	1	0				
		2	2	4	4	4	3	3	5	5	5	4	4	4	4
5	5	5	6	6	6	8	8	20	20	18	17	15			
			9	16	15	11	9	5	1	0					
		10	16	12	8	4	0								
								4	12	12	12	10	9	8	
9	9	9	9	9	9	9	7	7	7	7	10	13	11	15	15
1	1	1	0												
2	1	1	1	1	2	2	2	1	1	1	0				
9	2	0	1	0	0	1	0					10	4	1	1

According to a communication from Statens Meteorologisk-Hydrografiska Anstalt, Stockholm.

For the period July 1929—June 1934 the number of days with special values of precipitation, distributed monthly, has been given in Table 15. It is there found that, on the average, rain falls during 47 out of 100 days. Dec. has the greatest number of rainy days, 64 out of 100, and May the least number, 37 days.

The precipitation, therefore, shows that the climate is quite continental in type, because of the characteristic distribution with a maximum during the summer and minimum during the winter. WIGERT's statement of a maximum in the daily course of the precipitation to 1 o'clock points in the same direction.

Snow-cover. The quantity of precipitation which is stored up in the form of a covering of snow is of great importance to the run-off — and consequently to the erosion. WIGERT has determined for the period 1874—1890 the number of days with a covering of snow at noon to be on the average 100.3. In the Tables in the Appendix of this paper are for each month stated on which days a snow-cover was found in Uppsala at noon during the period which is of interest here, namely July 1st 1929—June 30th 1934. In Table 16 the number of days with a snow-cover has been given and the average calculated. As is seen, the variations are very great; from 39 to 117 days. In 1930—1931 the duration was exactly three times as great as in the proceeding winter which should be regarded as having an unusually small amount of snow. This winter lowers the average of the duration of the snow-cover to 83 days.

The first appearance of the snow occurs at different times during the autumn, in 1929 on the 25th of Dec., as against the 20th of Oct. in 1932. During the period in question the greatest amount of snow fell during the month of February, while WIGERT, for the period 1874—1890, found that most of the snow fell in Jan. The variations in the snow-conditions may be attributed to the influence of the temperature as well as the influence of the precipitation.

The variations in the amount of precipitation which is stored up in the form of snow are certainly still larger than for the duration of the snow-cover.

In Table 17 a similar comparison has been made for Drälinge within the central part of the Fyris river-basin. As may be seen the variations between the different winters are the same as in Uppsala, but the total duration of the snow-cover is somewhat longer, namely, on an average, 85.5 days as against 83.0 in Uppsala. This latter result corresponds to the increase in the snow-fall, northwards and westwards from Uppsala. Table 18 shows the thickness of the cover of snow at Drälinge. The contrast between the winter 1929—1930 and the following is there still more accentuated.

Tributary rivers and lakes.

As seen by the sketch-map, Pl. VII, the water system of the Fyris river is formed by a number of branches, whose length and basins do not differ very much from each other. In the topographical map, scale 1 : 100 000 Sheet 92, Östhammar, one of the tributaries, namely the Vattholma river, has been incorrectly called the Fyris river. The branch which flows through the Vendel lake, the largest lake of the system, has, however, the most water and ought to be considered, therefore, as the head-river. This is formed by two smaller branches, which rum from the Tegelsmora parish in Oland's district and flow together in the Tegelsmora lake. The source-river has at its head a height of 35.5 m. above sea-level while the Tegelsmora lake lies at a height of 25.1 m. above sea-level. The falling curve of the river (according to levelling, Table 22, by Statens Meteorologisk-Hydrografiska Anstalt) is reproduced in Fig. 37 with a greatly enlarged scale of heights. As is seen the fall of the river is in general quite small; the velocity therefore becomes very low. The average fall for the whole river (78.9 km.) is 0.5 ‰. From the picture it is seen that the slope is concentrated to some few water-falls, and the slope between these is quite negligible, below the Tegelsmora lake on the average only 0.1 ‰. The surrounding grounds are in many places low-lying and within large areas very swampy. According to information given by the agricultural engineer in Uppsala the total area of swampy ground along the Fyris and Vattholma rivers amounts to 72.8459 km², in which

cultivated earth	35.9748 km²
meadow and swamps	19.0603 »
lakes and waste land	17.8108 »

Because of these swampy lands it has been suggested that a new regulation of the river should be made for the draining off of the water. With the Swedish State's support a technical investigation of the Fyris has been made.[1] Because of the fact that levellings, profile-takings and mappings have been carried out on a large scale, the Fyris belongs to the morphologically best known rivers in Sweden. For the present investigation this valuable material has, however, no special bearing, and no account of the results will be given here. The Fyris is, as just mentioned, often surrounded by lowlying areas, Fig. 33, only at some places the river has dug itself deeper down into the clay-layers. Usually the bed is 4—6 meters deep, Fig. 38. It has between Uppsala and Vattholma an average breadth of about 25 m. The course of the Fyris is, as a rule, quite straight; it has no typical meanderings. Only in a few places it has for short stretches a somewhat sinuos alignement.

[1] By the agricultural engineer in Uppsala.

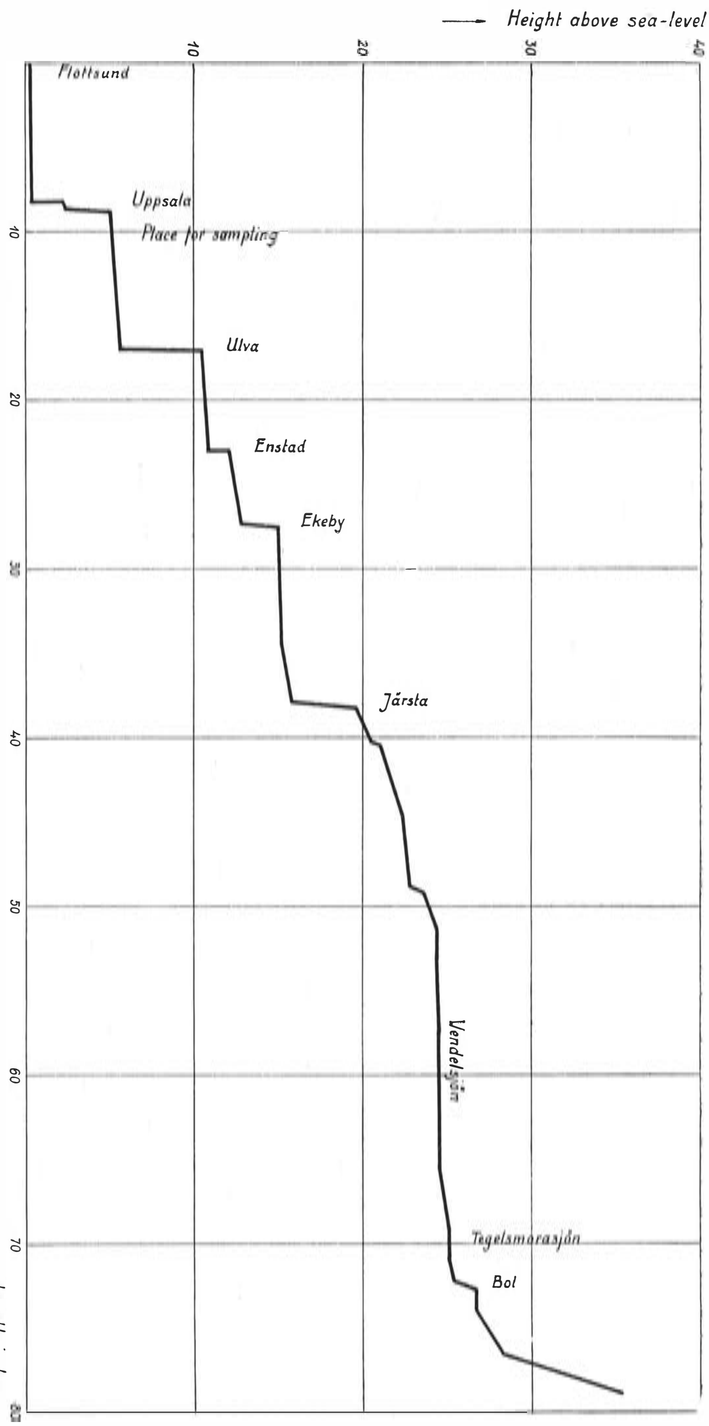


Fig. 37. The falling curve of the River Fyris. The scale of heights is very exaggerated, 1.000 times that of the lengths. The heights are expressed in meters.

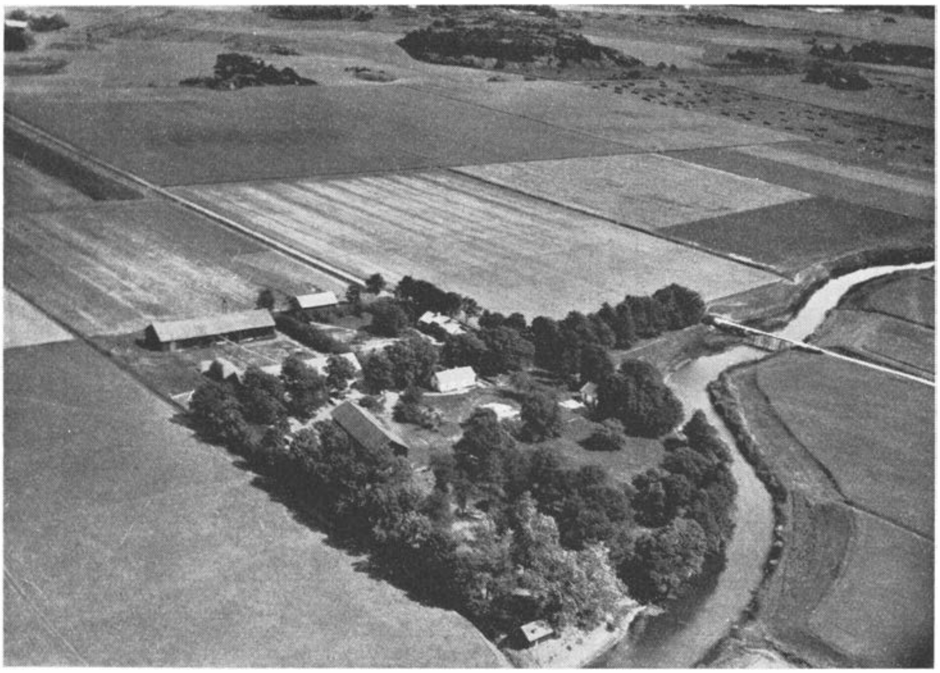


Foto Gösta Gustafsson.

Fig. 38. The River Fyris at Klastorp, north of Uppsala.

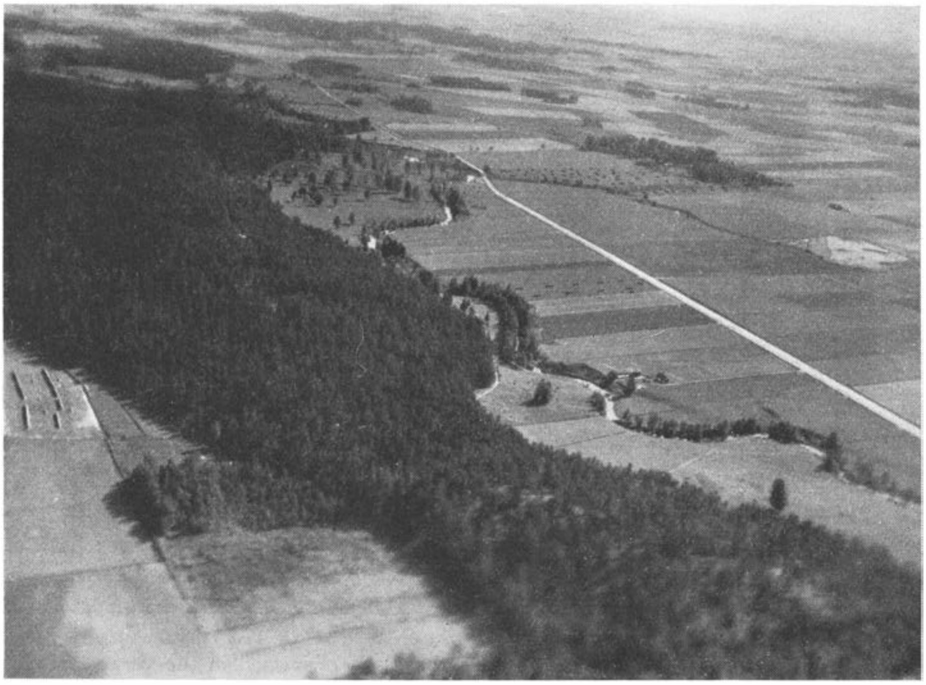


Foto Gösta Gustafsson.

Fig. 39. The Björklinge River 1 km. south of Drälinge. The river and the Uppsala esker for long stretches follow each others.

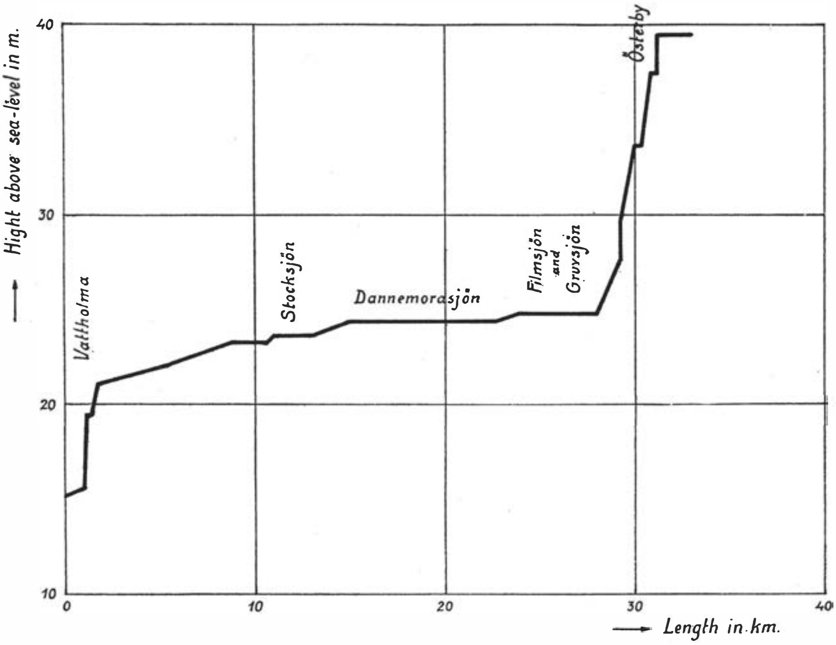


Fig 40. The falling curve of the Vattholma River.

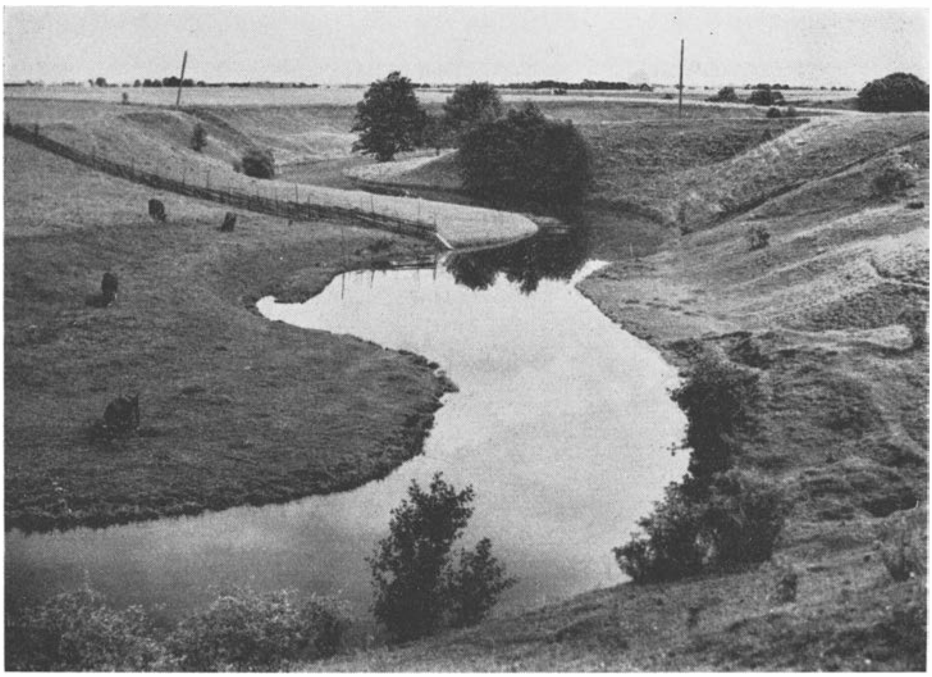


Foto Filip Hjulström aug. 1930.

Fig. 41. The Jumkil river at Åkerby. This river is here incised in the very plain surface and has a sinous alignement, at some places rather regular serpentines.

There is no meandering course in the biggest of the tributaries north of Uppsala, namely the Vattholma river. This comes from the Great Dam at Österby, and has a somewhat greater slope than the Fyris. Its length is 31.1 km., and its slope is 24.3 m.[1], Fig. 40. It flows through several lakes with low and marshy shores and has a very negligible slope between the water-falls.

The two other rivers, the Björklinge river and the Jumkil river, which come from the moraine and mossy ground areas in the west have a somewhat greater slope. The Jumkil river has cut itself down into the clay to a depth of 5—8 m. and shows a sinuous course which in places has the character of a well developed meander-course, as is seen from Pl. VII and the Figures 34 and 41.

The Sävja river is the largest tributary but comes into the Fyris south of Uppsala, and is, therefore, of no interest in this connection, as only that part of the river-basin which lies above Uppsala has been investigated.

Table 19 gives the size of the water-basins of the Fyris and its tributaries and the areas of the lakes in them (according to H B Ms).

Table 19.

Area of the river-basins and their per cent of lakes.

	Area of the river-basin km.²	Area of the lakes in km.²	Area of the lakes in %
Fyris at Uvlunge	263	6.8	2.6
» above Vattholma river	365	9.1	2.5
» below » »	651	22.1	3.4
» above the Sävja »	1226	29.4	2.4
» below » » »	1946	41.3	2.1
» at the river mouth	1963	41.6	2.1
Vattholma river at the river mouth	287	13.0	4.5
Björklinge » » » » »	221	4.8	2.2
Jumkil » » » » »	207	2.5	1.2
Sävja » » » » »	720	11.9	1.7

According to Statens Meteorologisk-Hydrografiska Anstalt Stockholm.

Hydrology.

Waterstages. The Fyris River belongs to that group of Swedish rivers which WALLÉN (1930) in his classification calls eastern rivers of the

[1] According to Statens Meteorologisk-Hydrografiska Anstalt, Stockholm. Table 22.

Central Swedish lowlands and characterizes it as follows: »the water variation assumes a more southern type, with a summer low-water usually lower than the winter low-water. The spring water-stage is distinctly the highest in the year and usually occurs in April. As a rule, there is an autumn flood. The magnitude of the variation varies greatly inasmuch as violent floods occur in rivers which are poor in lakes and flow over ground that is often clayey». (P. 56).

This description is to a high degree applicable to the Fyris river. Table 20 (according to H. B. Ms) shows characteristic water-levels as well as the variations for the different months at different stations within the Fyris river-basin. Everywhere where observations have been made over a long period, the highest water-stage of the year appears in April or May. The maximum usually appears earlier in plain-rivers than in forest surrounded rivers, since the melting of the snow during the spring takes place more quickly in the former areas. According to Statens Met.-Hydr. Anstalt (H. B. Ms) the spring-flood at Örbyhus appears at the earliest on the 12th of March, on the average on the 22nd of April and at the latest on the 20th of May. For Fundbo at the Sävja river the corresponding data are the 9th of March, the 16th of April and the 18th of May. The somewhat earlier appearance of the spring-flood is due partly to the fact that the Sävja river is a plain-river, partly to the fact that it lies towards the south-west in relation to Örbyhus, and that the breaking up of ice in the spring takes place earlier in south-eastern than in north-western parts of the river basin.

The lowest value of the water-stage usually appears in July or August. However, at the same time the precipitation becomes comparatively great, and when towards autumn the temperature decreases, the evaporation is decreased so that the water-stage reaches another maximum. This maximum usually occurs in November-December but is — as a rule — not so well marked as the spring-flood. During the winter a low-water stage occurs which is quite well marked.

The storage of water in lakes is not great and during the periods of low-water-stage the supply of water should to a large extent come from storage in marshes and ground-water. The eskers have special ground-water conditions, and the water-supply in the Uppsala esker is especially abundant. In its vicinity are found numerous wells which generally have an abundance of water. Within the Fyris river-basin are areas with a great number of wells. On the geological maps such an area is indicated 1 km. W. of Uvlunge.

In Table 20 the values of the mean water-stages per month for the period July 1929—June 1934 have been placed. As is seen, the average for this five year period is lower than usual — a fact which in part can be attributed to the condition that lake Mälar had an especially low water-

Characteristic water-stages in m. above sea-level at gauge-stations in the Fyris river-basin.

Period	Highest high-waterlevel m.a.s.	Normal high-waterlevel m.a.s.	Normal aver. waterlevel m.a.s.	Lowest aver. waterlevel m.a.s.	Normal low-waterlevel m.a.s.	Lowest low-waterlevel m.a.s.	Mean water-stage per months: Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Year
The River Fyris.																			
Bol . . . . 1917—23	27.82	27.41	26.70	26.64	26.52	26.47	26.73	26.74	26.76	26.82	26.75	26.60	26.60	26.65	26.66	26.65	26.68	26.67	26.70
Örbyhus stat. . . . . 1917—29	25.99	25.64	24.72	24.42	24.31	24.19	24.63	24.61	24.72	25.13	**25.16**	24.73	24.55	**24.53**	24.61	24.64	24.72	24.67	24.72
Örbyhus . . . . . . 1917—29	25.66	25.35	24.53	24.29	24.16	24.05	24.45	24.43	24.53	24.90	**24.92**	24.54	24.38	**24.36**	24.43	24.46	24.53	24.49	24.53
Uvlunge . . . . . . 1918—31	24.48	23.99	23.47	23.31	23.22	23.15	23.43	23.42	23.43	**23.66**	23.63	23.40	**23.33**	23.37	23.47	23.50	23.51	23.48	23.47
Viksta . . . . 1918—31	24.26	23.33	22.37	22.07	21.90	21.78	22.30	22.28	22.30	**22.73**	22.67	22.24	**22.10**	22.18	22.37	22.42	22.44	22.38	22.37
Lena . . . . 1889—99	16.8	16.3	15.6	—	15.2	15.1	—	—	—	—	15.70	15.56	15.42	15.46	15.46	15.51	15.55	—	—
Ekeby	(14.0)	—	12.8	—	—	(12.3)	—	—	—	—	—	—	—	—	—	—	—	—	—
Klastorp	(8)	—	5.5	—	—	(4.5)	—	—	—	—	—	—	—	—	—	—	—	—	—
Uppsala above Islandsfallet 1894—1900	3.32	2.86	2.32	2.21	1.78	1.57	2.39	2.36	2.29	2.41	2.12	2.16	2.31	2.30	2.29	2.35	2.42	2.43	2.32
Uppsala nedre . . 1894—1900	2.22	1.90	0.58	0.44	0.05	−0.06	0.45	0.41	0.54	1.22	1.14	0.75	0.46	0.40	0.33	0.31	0.39	0.54	0.58
» » . . . 1918—31	2.29	1.27	0.37	0.14	−0.09	−0.22	0.38	0.34	0.32	0.40	**0.69**	0.41	0.24	**0.19**	0.22	0.27	0.36	0.39	0.37
» » . . . 1877—31	2.72	1.51	0.47	0.14	0.00	−0.22	0.42	0.37	0.39	0.82	**0.88**	0.58	0.35	**0.30**	0.30	0.32	0.41	0.49	0.47
» » July 29—June 34	—	—	—	—	—	—	0.56	0.37	0.27	0.38	0.41	0.21	0.14	0.16	0.12	0.17	0.35	0.42	0.30
Ultuna . . . . 1918—31	2.05	1.16	0.32	0.11	−0.11	−0.23	0.34	0.30	0.28	0.36	**0.64**	0.37	0.20	**0.16**	0.18	0.23	0.32	0.35	0.32
The Vattholma River.																			
Österby . . . . 1910—31	40.08	39.86	39.47	38.89	39.07	38.26	39.48	39.48	39.48	39.61	**39.69**	39.58	39.45	39.36	**39.31**	**39.31**	39.39	39.45	39.47
Vattholma . . . . . 1917—31	22.06	21.57	21.14	21.02	20.94	20.84	21.15	21.14	21.16	21.31	**21.34**	21.09	21.00	**21.00**	21.06	21.12	21.16	21.17	21.14
The Sävja River.																			
Kuggebro . . 1919—24, 30—31	2.54	2.01	0.84	0.52	0.38	0.28	0.95	0.78	0.84	**1.20**	1.14	0.71	**0.57**	0.66	0.78	0.76	0.80	0.94	0.84

According to Statens Met.-Hydrograf. Anstalt, Stockholm, with some additions.

Table 21.

Measurements of discharge.

Date	Uppsala gauge	Stockholm gauge	Discharge cubic metres/sec.	Instrument
19 Jan. 32	194	418	56.5	OTT-meter
10 » »	110	411	22.5	»
8 Aug. 30	55	396	7.6	Float
14 May 30	53	396	7.0	»
8 Aug. 32	40	392	1.5	»
18 June 33	29	367	3.0	»
22 » »	25	368	2.0	»

level during this period, namely an average of 406 at the Upper Stockholm gauge station as against a normal 416. Because of damming, the level of Lake Mälar effects the level of the Fyris at Uppsala. In 1933 Lake Mälar reached its hitherto lowest observed value, with 383 as the year's average. Only in 1931 was the average somewhat above the normal, namely 421.

Discharge. An especially aggrevating circumstance for the present investigation was offered by the difficulty to establish a rating-curve for the relation between water-stage and discharge. This relation is not simple, so that a certain variation in the water-stage is corresponded to by a certain changing in the discharge. The water-stage is namely influenced by damming up. At Uppsala this is caused by Lake Mälar. The height of fall between the Uppsala gauge at the water-supply station (in Table 20 named »Uppsala Lower») and Lake Mälar is only 0.1 m. The variation of the water-level of Lake Mälar is on the average 0.57 m. and the difference between the highest and the lowest observed water-levels is 1.52 m. These variations, therefore, become highly noticeable in the water-level of the Fyris. If one, with the help of existing measurements of the discharge, tries to construct a rating curve for the Uppsala gauge-station, it will be the same as the one shown in Fig. 42. A cross indicates a measurement of the »Statens Meteorologisk-Hydrografiska Anstalt», published in its year-book, and a ring a measurement of the writer's according to Table 21. These measurements have in general been worked out in connection with the silt-percentage at different points of a cross-section, and have been executed at the »Sandkällan»; a few also at the mill below the gauge-station (Uppsala Ångkvarn). The velocity at low water-levels is so low that it sometimes cannot be registered by a common OTT-meter. In these cases the measurements were carried out with floats when there was no wind, and calculated according to BRAUER (1907, p. 200). Thus they are not very accurate.

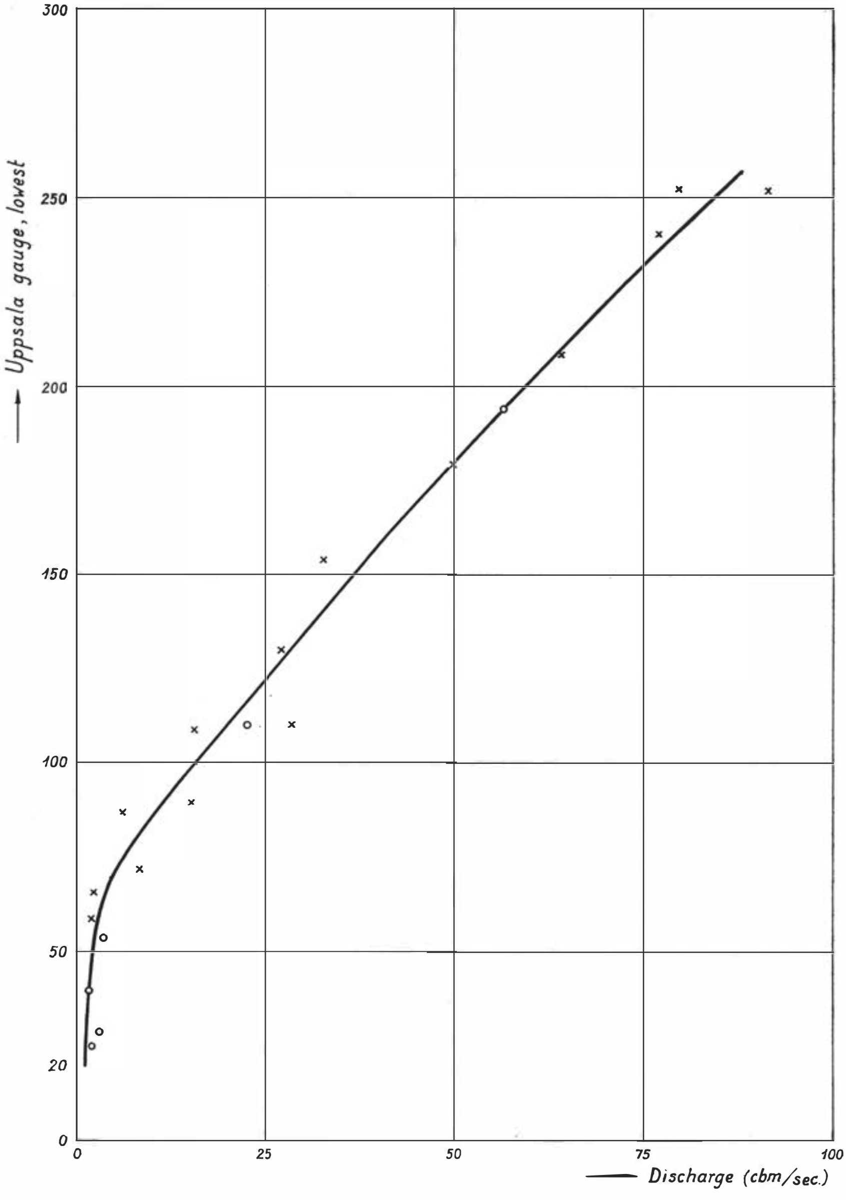


Fig. 42. Rating curve for the Uppsala Nedre gauge-station.

The simple rating-curve based on these measurements, is therefore very inaccurate. For other gauge-stations, for example Uvlunge or Vattholma, where no damming up occurs, there are reliable rating-curves and the water-mass at those places is therefore known. By multiplying this value with the relation between the drainage-basins, for instance Uppsala and Vattholma, a certain controll can be obtained on the realibility of the curve. It is then found that it generally gives much too high values, in yearly averages about 20 % higher, but for separate months up to four or five times higher or lower values, and for single days over ten times as much as the calculated values. Naturally, the deviation from the calculated values can be rather great, due to the differences in the local distribution of precipitation during short periods, due to variations in the thickness and melting away of the snow-layer and because of the differences in the general character of different parts of the river-basin. The percentage of lakes, marshes and clay-plains is not the same at all places. It is, however, improbable that the deviations from the calculated values should be so large as those just mentioned. The writer has therefore drawn up rating-curves for different water-levels. They are based upon the measurements which have been published by »Statens Meteorologisk-Hydrografiska Anstalt» and upon those which are reproduced in Table 21. Furthermore a number of points have been marked out, guided by the discharge at Vattholma. They are based on the following reasoning. Even if the difference between the values calculated and those read on the rating-curve for single days or shorter periods may differ much from each other, the average values for long periods cannot differ very much. The writer has therefore proceded from the published values of the mean discharge for different months at Vattholma and multiplied these water-masses with the factor 4,233 $\left(\text{the relation between the drainage-basins, } \frac{1215}{287}\right)$. The period 1928—1932 has here been used, but those months have been eliminated for which the water-level of Lake Mälar has been subjected to considerable variations (greater than 20 cm.). — However, greater importance has been placed on the direct measurements than on the points obtained in the above described manner. It is found that they all agree tolerably well at least for high water-stages in the Fyris. In the case of low water-stages, on the contrary, an important uncertainty is found. The direct measurements also show in this case an irregular distribution. Besides the water-level in Lake Mälar a large number of factors are certainly of influence in this regard, including among others, damming by ice and vegetation. It is probable that the variations in Lake Mälar's water-level also are of influence apart from the height of its water-surface. Furthermore, an error of a few centimeters can be found in the values used for Lake Mälar's water-surface because of the fact that a certain level-difference may be found between the upper Stockholm gauge-station and that bay of Lake Mälar, Ekoln, into which the Fyris flows.

Fig. 43 shows the rating-curve for the Uppsala Nedre gauge station, which has been obtained in this manner and which has been used for the calculation of the discharge. The writer wishes, however, to *strongly* point out the deplorable fact that because of the damming up it is impossible

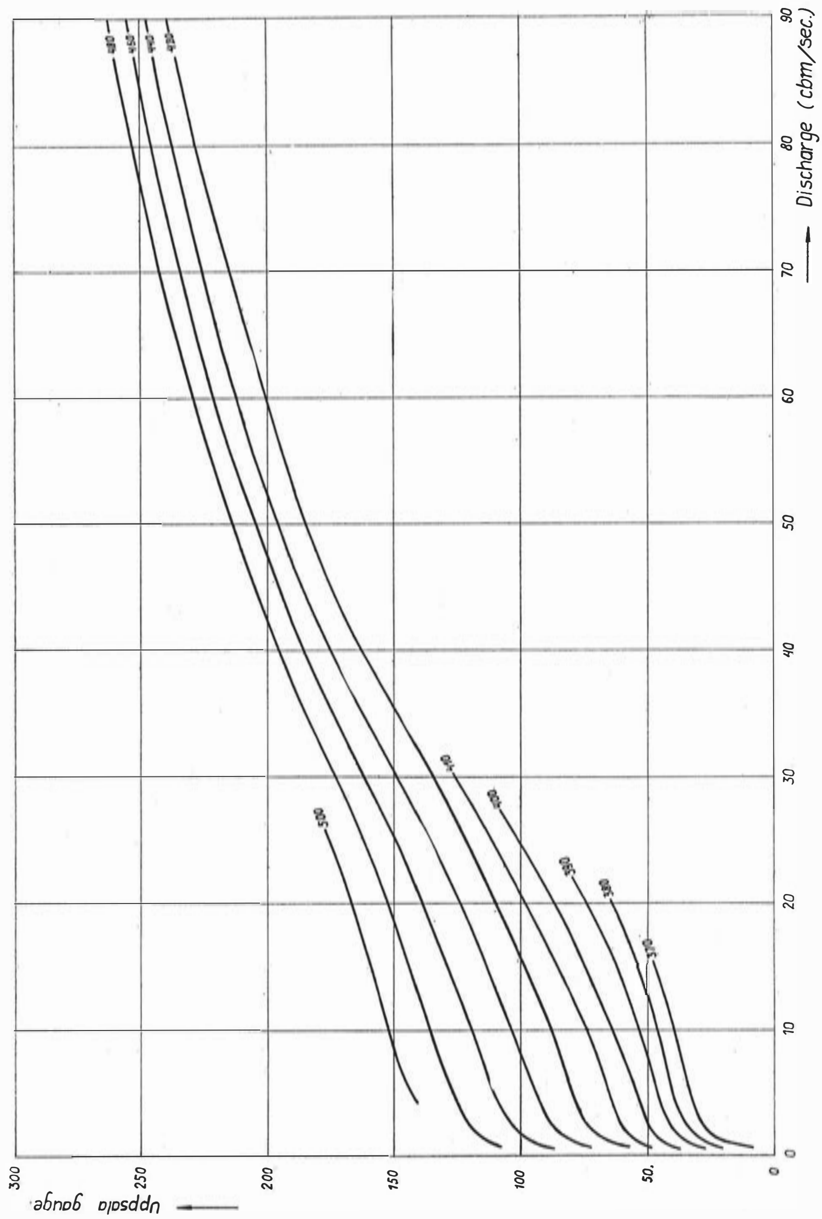


Fig. 43. Rating curves (Uppsala Nedre gauge-station) for different water-stages in the Lake Mälar. The numbers on the curves refer to the water-stages at Stockholm Övre gauge-station.

to obtain an exact rating-curve and that especially the values for low water-levels are very unreliable. For high water-levels it is, however, quite reliable.

At the same time, it ought also to be pointed out that this uncertainty in the discharge for low water-levels has very little influence upon the final result concerning the yearly denudation. At low-water the content of transported material is, in general, very small. An estimation of the error is made later on.

Table 22 gives, apart from areal- and altitude-data, also the discharge at different places. The Table has been drawn up by Statens Meteorologisk-Hydrografiska Anstalt, Stockholm, but with reservation for the stretch from Uppsala. It is, of course, to a high degree obtained be estimating and calculating, as the gauge-stations and rating-curves exist only for some of the places given in the Table. It is found that the relation between normal high-water- and low-water-discharge at Uppsala is very great, namely 32.1, and between highest high-water and lowest low-water-discharge no less than 158. These values are almost as high as for Norrland's forest-rivers which are generally characterized as greatly varying in water-discharge. Table 23 gives the values which the discharge attained during the five-year period, July 1929—June 1934, discussed further on. The greatest discharge was 72.7 m.^{3}/sec. which was reached in January 1932.

Precipitation and run-off. As the latter of these facts is not well-known, no calculation of its connection with the precipitation has been made. The writer, therefore, here cites Statens Meteorologisk-Hydrografiska Anstalt's manuscript on the Fyris river:

»For a comparison between the precipitation and the amount of the run-off, the calender-year is not well suited. A hydrographic year is used instead, with the turn of the year so chosen that the storage of the precipitation from the year before is as small as possible. Usually there is a certain time-displacement between the precipitation and the run-off. In agreement with WALLÉN in »Eau tombée, débit et évaporation dans la Suède meridinale», Geografiska Annaler, 1927, the run-off has been calculated from June to May and an average of the precipitation has been calculated for two months following each other, whereafter the precipitation-year has been calculated May/June—April/May. The precipitation has been calculated from the values of these stations lying within or in the neighbourhood of the respective districts. After a correction of the storing-up in lakes for each year has been introduced, the connection between precipitation and evaporation has been calculated. The calculation has been carried out only for Uvlunge and Vattholma.

Table 22.

Data concerning altitudes, areas and discharges in the Fyris river-basin.

	Distance from the river mouth	Area of the river-basin sqare km.	Normal mean water-level in m. a. s.	Height of fall in m.	Discharge in cubic metres per sec.				
					Low-water discharge		Mean discharge	High water discharge	
					Lowest	Normal	Normal	Normal	Max.
The River Fyris									
	78.9	0	35.3						
				7.0	—	—	—	—	—
	76.6		28.3						
				1.6	—	—	—	—	—
	74.0		26.7						
				0.0	—	—	—	—	—
	72.7		26.7						
Bolströmmen				1.3	—	—	—	—	—
	72.2		25.4						
				0.3	0	0.01	0.2	1	3
	71.0	22	25.1						
Tegelsmorasjön				—	—	—	—	—	—
	69.1	99	25.1						
				0.6	0.01	0.05	0.8	5	12
	65.5	119	24.5						
Vendelsjön				—	—	—	—	—	—
	56.2	195	24.5						
				0.5	0.02	0.1	1.6	9	21
	53.0	247	24.0						
				0.0	»	»	1.8	10	24
	51.3		24.0						
				0.4	0.03	»	2.0	11	26
	49.2	263	23.6						
				0.8	0.04	»	2.1	12	28
	48.8		22.8						
				0.4	»	»	»	»	»
	44.7	282	22.4						
				1.4	0.05	0.2	2.6	14	32
	40.4	325	21.0						
				0.5	»	»	»	»	»
	40.2		20.5						
				0.9	»	»	»	»	»
	38.2		19.6						
Järsta				3.8	»	»	»	»	34
	37.9	360	15.8						
				0.6	»	»	2.9	16	36
	34.5	652	15.2						
				0.2	0.4	0.8	5.2	25	61
	27.5	674	15.0						
Ekeby				2.2	»	»	5.4	»	62
	27.3		12.8						
				0.7	»	»	5.6	26	64
	23.0	914	12.1						
Enstad				1.2	0.5	1.1	7.3	35	77
	23.0		10.9						
				0.4	»	»	7.4	»	78
	17.0	956	10.5						
Ulva				4.8	»	»	7.6	36	80
	16.9		5.7						
				0.6	0.6	1.4	9.3	43	92
	8.8	1213	5.1						
Kvarnfallet				2.7	»	»	9.6	45	95
	8.6		2.4						
				0.1	»	»	»	»	»
	8.2	1215	2.3						
Islandsfallet				1.9	»	»	»	»	»
	8.2		0.4						
				0.1					
	0.0	1982	0.3		0.8	2.0	15.6	70	145

Table 22 (Continued).

	Distance from the river mouth	Area of the river-basin sqare km.	Normal mean water-level in m. a. s.	Height of fall in m.	Discharge in cubic metres per sec.				
					Low-water discharge		Mean discharge	High water discharge	
					Lowest	Normal	Normal	Normal	Max.
Vattholma River									
Österby Stordamm	31.1	36	39.5						
				2.0	—	0.05	0.3	1	3
	31.1		37.5						
				0.0	—	»	»	»	»
	30.8		37.5						
				3.8	—	»	»	»	»
	30.3		33.7						
				0.0	—	»	»	»	»
Österby {	30.0		33.7						
				4.1	—	»	»	»	»
	29.2		29.6						
				2.0					
	29.2		27.6						
				2.8	—	»	»	»	»
	28.0		24.8						
				0.0	—	—	—	—	—
Filmsjön—Gruvsjön	23.9	108	24.8						
				0.4	0.05	0.2	0.9	2	10
	22.6		24.4						
				0.0	—	—	—	—	—
Dannemorasjön	15.0	217	24.4						
				0.7	0.1	0.4	1.8	8	20
	13.0		23.7						
				0.0	»	»	»	»	»
Stocksjön	11.0	248	23.7						
				0.4	»	»	2.0	9	22
	10.6		23.3						
				0.0	»	»	»	»	»
	8.8		23.3						
				1.2	»	»	»	»	»
	5.4		22.1						
				1.0	»	0.5	2.3	10	25
	1.7		21.1						
				1.7	»	»	»	»	»
	1.3		19.4						
				0.0	»	»	»	»	»
	1.1		19.4						
				3.8	»	»	»	»	»
Vattholma	1.0		15.6						
				0.4	»	»	»	»	»
	0.0	287	15.2						

Table 23.

The discharge of the Fyris at Uppsala during the period July 1929—June 1934.

	Number of days with a discharge at Uppsala greater than										
	1	2	3	5	10	15	20	25	30	40	50 m.³/sec.
1929:											
July	31	29	29	23							
August	31	31	31	30							
September	30	29	28	19							
October	31	31	31	29	7						
November	30	30	30	28	7	1					
December	31	31	31	31	25	5					
July—December	184	181	180	160	39	6					
Per cent	100.0	98.4	97.8	87.0	21.2	3.3					
1930:											
January	31	31	31	31	31	13					
February	28	28	28	28	4						
March	31	31	31	31	4						
April	30	30	30	29	11						
May	31	31	31	25							
June	30	29	25	5							
July	31	17	9	3							
August	31	31	30	24	17	8					
September	30	30	30	30	22	10					
October	31	31	30	30	19	6					
November	30	30	30	30	30	25	10	5			
December	31	31	31	31	31	26	6				
Year	365	350	336	297	169	88	16	5			
Per cent	100.0	95.9	92.1	81.4	46.3	24.1	4.4	1.4			
1931:											
January	31	31	31	31	31	19					
February	28	28	28	28	25	6					
March	31	31	31	31	9						
April	30	30	30	30	16	13	11	9	8	5	
May	31	31	31	31	31	21	12	9	9	6	
June	30	30	30	30	19						
July	31	31	31	20	1						
August	31	30	30	24							
September	30	30	30	29							
October	31	31	31	31	2						
November	30	30	30	30	16						
December	31	31	31	31	28	23	7				
Year	365	364	364	346	178	82	30	18	17	11	
Per cent	100.0	99.7	99.7	94.8	48.8	22.5	8.2	4.9	4.7	3.0	

Table 23 (Continued).

	Number of days with a discharge at Uppsala greater than										
	1	2	3	5	10	15	20	25	30	40	50 m.³/sec.
1932:											
January	31	31	31	31	31	31	27	20	15	15	9
February	29	29	29	29	22	12	6	2			
March	31	31	31	31	5						
April	30	30	30	30	30	17	2				
May	31	31	31	31	30	9					
June	30	30	29	27	5						
July	31	31	31	26							
August	31	31	29	16							
September	30	29	28	14							
October	31	31	31	27	3						
November	30	30	30	30	25	9					
December	31	31	31	31	27	2					
Year	366	365	361	323	178	80	35	22	15	15	9
Per cent	100.0	99.7	98.6	88.3	48.6	21.9	9.6	6.0	4.1	4.1	2.5
1933:											
January	31	31	31	31	26						
February	28	28	28	28	12						
March	31	31	31	30	18	7	3				
April	30	30	30	27	20	11					
May	31	31	30	27	5						
June	30	19	15	3							
July	31	21	12	5							
August	31	31	30	20							
September	30	29	16	3							
October	31	23									
November	30	28	18	5							
December	31	12	3								
Year	365	314	244	179	81	18	3				
Per cent	100.0	86.0	66.9	49.0	22.2	4.9	0.8				
1934:											
January	31	28	23	17	4						
February	28	28	27	26	2	2					
March	31	31	31	3	31	15					
April	30	30	30	30	30	22					
May	31	31	31	31	7	1					
June	30	30	29	25							
January—June	181	178	171	160	74	40					
Per cent	100.0	98.3	94.5	88.5	40.9	22.1					
Per cent for the whole period July 1929—June 1934	100.0	95.9	90.7	80.2	39.4	17.2	4.6	2.5	1.8	1.4	0.5

The following values have been obtained:

	Precipi-tation	Run-off	Evapo-ration	Run-off %	Dry limit	Correlation coefficient
Uvlunge	552	255	297	46	355	0.96
Vattholma	540	261	279	48	250	9.91

Precipitation, run-off, evaporation and run-off-coefficient are practically the same for both regions, which is only natural as both regions are very similar. However, the dry limits are quite different which can hardly be correct. The correlation, especially at Vattholma, is rather poor and the obtained dry limits therefore uncertain. The evaporation is rather small. This may be due partly to the incompleteness and to the inaccuracy of the observations. However, the evaporation in these rather northerly regions with small precipitation is probably less than in most of the regions included in WALLÉN's abovementioned paper, for which the evaporation is 357 mm. on the average.

The year has been divided into summer, June—October, and winter November—May, and the values for precipitation, run-off, sea-storage, and evaporation have been placed in the Table below. No consideration has been taken to storage in the upper layers of the earth and groundwater, but the error obtained should be rather small.

	June—October			
	Precipitation	Run-off	Evaporation	Sea-storage
Uvlunge	304	71	237	−4
Vattholma	307	62	251	−6
Bol	310	85	225	—
November—May				
Uvlunge	250	183	63	+4
Vattholma	233	199	28	+6
Bol				

Summer-evaporation is 225—251 mm., which is about the values that are usually obtained for water-courses of Central Sweden. The obtained winter-evaporation, however, is very low, 63 and 28 mm. resp. The probably erroneous values should depend either upon the fact that the measured winter-precipitation is too low or to the fact that the winter watermass is calculated too high, or, perhaps, on both these causes.»

The method of investigation.

The closest investigations of erosion and transportation which had been published at the time when this investigation was begun, were the works of Prof. Dr LÉON W. COLLET and his pupils (1916, 1925, BOISSIER 1916). These works meant great improvement in comparison to earlier similar investigations.

During the time that this investigation has required, several important works dealing with similar investigations in other countries have been published. Many of these describe in detail the important question of the method of investigation. Viz. among others BAYERISCHE LANDESTELLE FÜR GEWÄSSERKUNDE 1929, HOWARD 1929, ÖSTERREICHISCHES NATIONAL-KOMMITEE 1930, LEPPIK 1930, EHRENBERGER 1931, JAKUSCHOFF 1932 a and b, MÜHLHOFER 1933. Much of interest has been pointed out in these treatises; especially the works of the Russian scientists (collected by JAKUSCHOFF 1932 b and LEPPIK 1930) in this field, seem to be especially noticeable. No alteration has, however, been made in the method used from the beginning.

Photometric methods of analysis.

An examination of the percentage of suspended particles can be carried out along two totally different lines. Perhaps it seems to be most convenient to make an analysis of a water sample which is procured in a suitable manner. There is, however, another method which seems highly convenient, as the sample-taking and the time-wasting analyses are wholly eliminated by it. It is based on light absorption or scattering of light by the particles (TYNDALL effect). JAKUSCHOFF (1932, a and b) describes suitable arrangements for the use of a light-source, the rays of which, after passing through a silt-containing water, are intercepted by a photocell. This produces an electric current, the strength of which depends on the intensity of the light falling into it, that is to say, on absorption which is read on a milliampèremeter. The mechanical composition has, however, a very great influence. »There is no simple relation between the size of particles, and light absorption and the scattering respectively, but it is possible to find, experimentally, certain empirical relations». (SVEDBERG 1928, p. 187). The variation occurs already, in the case of a unitary matter in a rather irregular manner, and it is especially complicated for a poly disperse system.

As will be shown further on the writer has conducted an investigation, by way of experiment, into the possibility of determining the percentage of silt by photometric measurements of the scattering of the light, and thereby escaping a weight-analysis. It was, however, found that sufficient exactitude could not be reached as concerned the water in the Fyris. By using a photocell the subjective measurement-errors are, indeed, eliminated, but in spite of this it is impossible to obtain sufficiently high accuracy. It is, of course, possible that the photoelectric method may be used successfully in other rivers. The mechanical composition of silt is a decisive factor and varies to a high degree in different rivers.

In the Fyris a simple method with sample-taking and analysis of the samples is used instead.

The procuring of samples.

The fundamental principle for procuring of samples has been to take a water-sample from a certain point in the profile which can give a representative average value for the prevailing percentage of solid and dissolved ingredients at the point in question.

At the investigation special stress has been laid on the obtaining of a representative *average* value. In this respect the method deviates in point of principle from the one which has been applied in other cases. One has instead tried to obtain a reliable value of the amount of silt which is present in a certain volume of water at the moment of sample-taking. For this purpose specially adapted apparatuses have been constructed. They usually consist of a horizontal cylinder through which the water can flow unhindered and which at a certain moment can be closed by means of a spring-connection, which should be placed on the outside of the cylinder. Different modifications of this type of apparatus are described by LEPPIK and COLLET (1925). An apparatus for sample-taking of this construction (Fig. 44), made in 1929, the writer has used for certain special purposes where it has been a question of obtaining momentary values (see p. 388). An apparatus, constructed by W. V. EKMAN, Lund, for oceanographical purposes, however, does not seem suitable for use in rivers, since the cylinder is vertical. At both ends of it eddies are formed and it is difficult to judge if the silt-content in the cylinder is representative for that of the water or not.

The apparatuses with momentary filling have, as LEPPIK points out, (1930, p. 9), the advantage that the natural flowing conditions are maintained rather undisturbed. But their characteristic quality of giving momentary values of silt-percentage, on the other hand, means a serious defect in the reliability of the result. The transportation of silt is not uniform, but depends, to a high degree, on the state of turbulence and of the pulsations. The concentration of the silt at a certain point in the river-profile can, therefore, vary within quite large boundaries, especially those fractions of the matter which are not sufficiently fine-grained to be uniformly distributed between the surface and the bottom. The silt may occur almost in the form of clouds in the water. A momentary value of the silt-percentage can therefore deviate considerably from the average. See p. 388.

Another requirement for water-samples, which are to be used for silt-analysis, has been advanced by Bayerische Landesstelle für Gewässerkunde (1929), namely »Die Wasserprobe muss so geschöpft werden, wie sie tatsächlich im Fluss dahingleitet». In order to reach this purpose a highly ingenious apparatus has been constructed (system HÖCHSTETTER). The sample-taker itself in this case hangs underneath a raft which floats on the water and follows the current. At a certain moment the vertically arranged

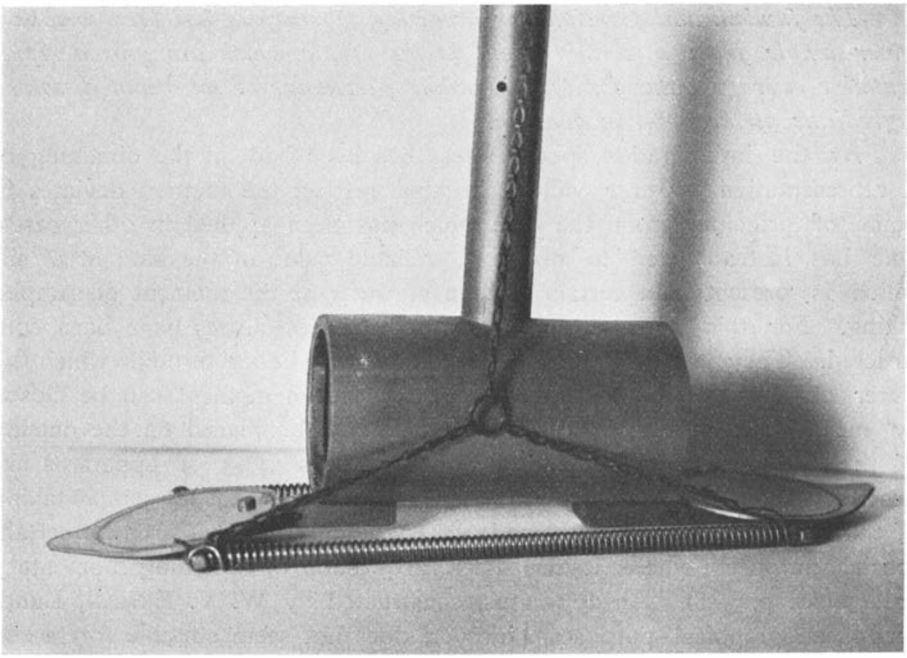


Foto FILIP HJULSTRÖM.

Fig. 44. Apparatus for procuring water-samples, used for special purposes.

cylinder with a cone shaped opening, which is the sample-taker, is disengaged and filled. The cylinder is the whole time in contact with the same water-mass; if the cylinder is not filled too rapidly and if the turbulence is not too weak new water-masses may, however, have time to come into close contact with the apparatus. Because of these facts it gives a more reliable value than the momentary samples. Otherwise it cannot be regarded as an advantage that, during the whole sample-taking, it is in contact with the same water-mass. If the apparatus happens to be placed in a surrounding of an especially high or especially low silt-percentage it remains there, and the sample is not representative as an average. An equalisation occurs only with strong turbulence.

Another inconvenience happens to be connected with the apparatus, therefore, that it is emersed open, although the opening is turned downwards. With the sinking of the apparatus, the air is pressed together in the sampler by means of increased pressure and water enters into the receptacle. If it is emersed to the depth d meters, the air is pressed together from v to

$$\frac{10.3 \cdot v}{10.3 + d}$$

liters, and at a depth of 4 meters the recepticle is $^1/_4$ filled with water, already before it is to be opened. The sample, therefore, contains water from the layers above and a mixture takes place.

In this respect this apparatus forms a transition to that method which was used by, among others, HOWARD (1929, p. 19) for the obtaining of average samples. A receptacle is sent to the bottom and opened there. »The bottle was then pulled up at a uniform rate, so as to be full when it came to the surface». Concerning the result it is said (p. 21): »For about 1 200 samples collected at Grand Canyon the quantity of suspended matter in the 'average' samples was nearly the average of the quantities in the bottom and surface samples».

It seems, however, as if in many cases one could expect a somewhat too high value for the silt-transportation, when this average value of the silt-percentage is multiplied by the water-mass. The water-mass flowing into the container is, at least in the beginning, a function of the pressure and thereby also of the depth $d = D - z$, where $D =$ the total depth of the river, and can be indicated by $f(10.3 + D - z)$. It is largest at the bottom. But at the same time the silt-percentage is also greatest there. The sample contains the silt-mass:

$$\int_{z_0}^{D} f(10.3 + D - z) \cdot s \cdot dz$$

where $z_0 =$ the height above the bottom of the opening at the moment when the samplers is opened. It is not given a priori that this silt-percentage, multiplied by the water-mass which flows over the part (of the breadth l) of the section, for which the sample is representative, has the real value

$$l \cdot \int_{0}^{D} s \cdot v \cdot dz.$$

HOWARD has also made an interesting investigation with »clear-water sample». »It consisted of a bottle of clear water fitted with a cap, which was broken when the bottle was at the bottom. The bottle was drawn up at the same rate as the 'average' sample» (op. cit. p. 19). »The clear-water samples contained considerable suspended matter that dropped into the bottles of clear water as they were raised to the surface. The quantities of suspended matter in some of the clear-water samples collected at Grand Canyon were as much as 25 % of the quantities found in bottom samples taken the same day» (p. 21). This indication is especially valuable since it shows the necessity of *the sampling being taken in a receptable which closes when filled*.

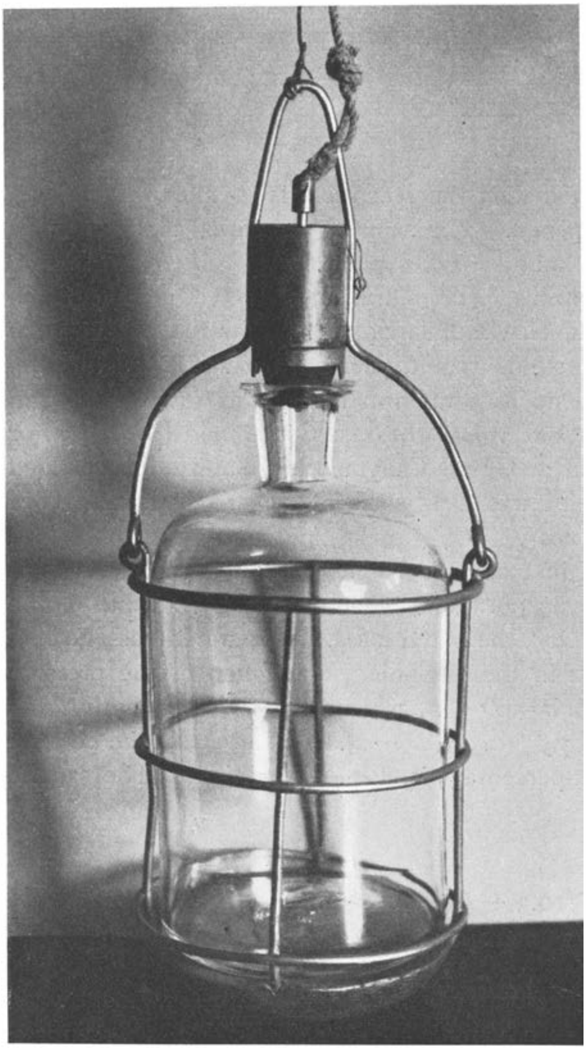


Foto *Filip Hjulström*.

Fig. 45. The apparatus generally used for the procuring of the Fyris-water samples.

It should be worth while to investigate if it might not be possible to determine the Austausch-coefficient with such a »clear-water sample» which at a certain depth is allowed to flow with the current, supported by a raft.

For the sampling a sample-taker of a simple type has been used in the present investigation, constructed at Statens Meteorologisk-Hydrografiska Anstalt in Stockholm, Fig. 45. It consisted of a two liters' bottle which was placed in a thick steel wire-frame with a heavy lead-bottom. The bottle-neck has a rubber-stopper which by means of a spring connection can open and close the bottle-neck, and which can be handled by a special line. The closed bottle can be immersed to a desired depth, opened there and, the bottle-neck having been closed with the rubber stopper, the bottle may be drawn up again containing the water-sample. With this simple arrangement two essential advantages are connected:

1) the emersing to a desired depth, as well as the drawing up of the sample, takes place while the container is closed.
2) since the sampling takes place slowly through the narrow bottle neck, a good average value can be obtained. At a depth of 1.5 m. the bottle fills in about 2.5 min.

The disadvantages consist in the fact that the sampler drifts with the current; thus the depth becomes less than the length below the water-surface of the line to which the bottle is attached. If the length of the line is l meter, and $\alpha =$ the angle between the line and vertical, the depth becomes $l \cdot \cos \alpha$ instead of l. At the low velocity which usually prevails in the Fyris, this deviation from the vertical line plays no important part at all, but in the case of higher velocities an estimation of the angle has been made. It has been found that, for example, at a velocity of 0.5—0.6 met. per sec α becomes about $45°$. In the case of higher velocities the sampler should have a larger lead-weight or be fastened to a rod instead of a line.

JAKUSCHOFF and LEPPIK have pointed out that with the use of samplers with bottles the natural flowing conditions are not maintained as undisturbed as in the case of apparatuses for momentanous sample-taking. Because of changes in direction and velocity the silt-percentage would not be properly reproduced at the point of the sample-taking. (JAKUSCHOFF, 1932 b, p. 19 in the separate). This is a proper observation and at higher velocities a certain displacement can take place so that the obtained value is more representative for the water layer which is a few centimeters below. When the bottle is equipped with a not too short neck, this influence does not become noticeable.

The disadvantages, just mentioned, are of no importance for the use of this sampler in a river of the character of the Fyris, and play no part in comparison to the essential advantages it offers. The sampler in Fig. 45, constructed by Statens Meteorologisk-Hydrografiska Anstalt in Stockholm, originally intended for chemical investigations of salts in water, (ERIKSSON, 1929) seems to be, when applied to slowly flowing rivers, especially suitable for silt investigations as well. The different samplers, constructed by Prof. GLUSCHKOFF and described by JAKUSCHOFF (1932 b), seem to the writer to be equally entitled to be used in this respect. These have not, however, been tested or used in the investigation of the Fyris. They do not have the same simplicity in construction as the samplers which were used there.

In order to judge the volume of the apparatus and the time for its filling the following experiment was deemed suitable. The sampler for momentous filling, Fig. 44, was placed at a 30 cm.'s distance from the FALK

Table 24.

Contents of silt in relation to the pulsations.

Contents of silt mg/liter	Velocity (mean 0.22 m/sec.)
15.1	high
16.0	»
16.1	»
14.9	»
15.2	low
16.2	»
15.0	mean
16.1	»

meter (cf. p. 254), and samples were procured at different velocities, at the highest, lowest and medium velocities. The difference in the contents of silt between the different samples was about 10 %, but no connection whatever with the pulsations could be noticed. Such a state can hardly be expected in a current which does not erode. Table 24 gives the values obtained. On another occasion (5/6 1934) a proof-series of 10 samples with 20 sec.-intervals was taken from a boat. The contents of silt for the samples were the following: 20.0, 24.4, 22.4, 22.2, 23.9, 21.4, 20.5, 23.0, 22.2, 22.1, that is to say no marked periodicity but rather rapid oscillations round the average value[1]. However, 20 seconds is, too long an interval to judge if eventually there are some »Turbulenzkörper» (see p. 248), and if these have any different characteristics as to their contents of silt. For such an investigation a photo-electric cell would surely give very good assistance. But in the case of the River Fyris the contents of clay, which is in this respect rather active, probably will not change much. The variations in the contents of silt seem to be due to greater particles, organic matter etc., which drift along in the water. A projected photo-electric arrangement for such investigations was therefore not used.

At times, when a special sampler cannot be included in the equipment, as for instance on research-expeditions, where it is important to have a minimum of equipment, a rather high degree of accuracy can be obtained through the use of simple aids. A bottle or a flask may simply by immersed in the water and the opening be pointed diagonally upward against the current. If the opening is wide, it should be diminished by placing, in the neck of the bottle, a rubber stopper or a cork, through which a narrow hole has been made, so as to cause the bottle to fill slowly. One then has a sampler which in principle is very much like that used in the

[1] With the sampler Fig. 45 the following values were obtained (interval 5 minutes): 22.2, 21.9, 22.3, 22.3.

present investigation. It differs from this only in the absence of an opening-mechanism. When it is a question of sampling at greater depths with bottles fastened to a rod, the opening must be closed, when immersed, with a cork provided with a string. It is more important that the opening is closed at the immersion than when it is drawn up. The mixture with water in the top layers, when the bottle is drawn up, is diminished because of the above-mentioned rubber stopper, being bored through.

In such cases the sampler, constructed by GLUSCHKOFF can be of great use. This consists of a rubber bladder which is fastened to a glass pipe which when sampling is pointed forwards, but otherwise backwards.

Besides the above-mentioned sampler, another device for the obtainance of samples has also been used during a shorter time of this investigation. This consisted in a pumping-up of the samples. Rather narrow glass pipes or rubber tubes of proper length were fastened to an especially constructed metal pump in which all the packing was of metal (constructed with great skill by the instrument-maker MATTSON, Uppsala). These were immersed to the desired depth, and the sample was pumped from this depth directly into the bottle. In order to prevent the glass pipes or the rubber tubes from drifting with the current they were fastened to a wire which had a lead weight at the end. It was necessary, however, to pump for a short while before the water could be led into the bottle to obtain a representative sample. For such highly disperse matter as is found in the Fyris, this method can be used, but if larger grains are present, sedimentation may appear in the conduit. In such cases it is, therefore, of essential importance that the dimensions of the pipe are small and the upflowing current strong.

This method for sampling was used for special investigations into the influence of pulsations upon the percentage of silt, p. 252, and for a short part of the sample-series (July—August 1929). This is, however, not as convenient as the above-mentioned sampling method, and was, therefore, soon abandoned.

Analysis of water-samples.

After having obtained, by means of a suitable sampler, a water sample from a chosen point within a cross-section, the analysis of the sample thus obtained remains, that is to say the determination of the weight of the silt. This is a procedure which in certain cases may cause very great difficulties.

The analysis of the suspended matter in a water-sample places varying demands on the method of analysis according to the degree of dispersity of the matter, the percentage of suspended and dissolved matter, the desired exactitude, etc. If an attempt is made to filter a water-sample taken from a slow-flowing river, through a common filter-paper, it is often found that the filtrate has an almost equally muddy appearance as the sample itself, while the filter-paper has become discoloured by the silt, and retained courser matter, as, for example, bits of vegetable-matter which may be found in the water. In other cases it may happen that the filter-paper becomes rapidly stopped up so that only a few cc. are let through in 24 hours.

In earlier investigations there is often no information at all to be found as to the method of analysis, but, presumably, in most cases filtering through common filter-paper has been done. The filter-papers have been weighed both before and after filtering, sometimes even the samples have been weighed after the combustion. The weighing of the filter-paper cannot, however, take place with greater exactitude without the taking of special precautions. Even if the matter which the river carries is of such a low degree of dispersity that filtering with common filter-paper gives rather an exact result, there still remains a source of error on account of the filter-paper.

This is subject to changes in weight as a consequence of atmospheric conditions, even in a dry climate. The error thus caused may be considerable, especially if the amount of silt to be measured is small (FORTIER and BLANEY, 1928, p. 12).

In many cases this source of error has been disregarded, but in other cases, attempts have been made to avoid it in different ways.

E. ÜTRECHT (1906) has, in his especially careful investigation of Rhône's ablation in Wallis during the year 1904—1905, used a method by which the weighing of the filter was avoided. He evaporated a filtered and an unfiltered sample, dried them in a drying-closet, and weighed and calculated the difference in weight. The method of filtering, however, was not given. This method is suitable when investigating the percentage of suspended and loose matter when the silt-percentage is large. If, on the other hand, this is small, the error-percentage becomes too large. In the Fyris, where the percentage of dissolved matter generally amounts to 160—260 mg. per liter and the silt-percentage to, on the average, 10 mg., this method cannot be used. Furthermore, this method requires too much time.

Another method had been suggested to the Second World Power Congress, Berlin 1930, by ÖSTERREICHISCHE NATIONAL KOMMITTEE. According to this suggestion, and, if one only seeks the total mass of, for instance, a whole month, all the samples must, one by one, be poured in a vessel for evaporation which should be weighed once a month. Here the percentage of salt seems to have been overlooked. In mountain-rivers in districts where the chemical denudation is negligable and the salt-percentage low but the silt-percentage very high, the error should not be so large, although a certain amount af salt is always found, among other things, from the precipitation. If the conditions are the opposite, the error nevertheless becomes great; in the Fyris a value should be obtained which might be 22—25 times too large.

In the modern American sediment-investigations one has tried, in many cases, to escape the inconveniences of the drying and weighing of the filter-papers. HOWARD has examined the best conditions for obtaining a uniform weight of the filter papers and used the weighed papers as checks during the weighing. In the *Sediment investigations on the Mississippi River and its tributaries* (1930—1931) a similar method has also been used. In this case colloids were floculated and settled by the addition of two or three drops of concentrated hydrocloric acid.

It lies close at hand to adopt some of the methods common in colloidal chemistry in order to bring about coagulation; in the first place by electrolytes. This method generally gives poor results when the concentration of the disperse system is low. Tests were made with different types of electrolytes, but it was found that their influence was unobservable, or at any rate, little. In the water are found previously dissolved salts of considerable concentration, among other humus matter, organic matter, which acts as a preventive measure against the coagulation of the colloidal clay (ODÉN 1919).

If, therefore, the concentration of silt in a river is too low, for greatly hastening the sedimentation by the addition of electrolytes for the bringing about of coagulation, one might think of using a finer filter. But the filtering time is thereby increased.

An attempt has been made to use membrane filters in the analyses according to ZSIGMONDY (see JANDER-ZAKOWSKI, 1929). As these filters appear in many different types and as they must be used in a special filtering-apparatus which stands in connection with a water suction-pump, the filtering time should possibly be brought down by this. It proved possible to gain very good results by means of a membrane filter. At the transferring of the small amounts of silt from a filter to, for example, a watch-crystal, it was found to be very difficult to get everything in. The filter itself cannot be weighed with any greater degree of exactitude. Furthermore, the method turns out to be quite costly and requires a certain amount of skill in the performing process. For these reasons this method was not chosen.

As a rapid and practical filtering process could not be easily carried out, a possibility for the calculation by another method was tested, namely, by optical means by using the scattering of light (TYNDALL effect) by particles in a colloidal system or a suspension (see above pp. 282—283). Thereby a convenient and practical apparatus was used for practical water investigations (mainly drinking water), an apparatus which had been constructed and described (1932) by Dr. OLOF DEVIK, Bergen, Norge. Dr. DEVIK very kindly placed the apparatus at the writer's disposal during the summer

Table 25.

Photometric measurements of the silt-content of Fyris-water.

Date 1930	Remarks	Shutter No. 2	Shutter No. 4	Forel-disk. Depth in m.	Silt-content	Date 1930	Remarks	Shutter No. 2	Shutter No. 4	Forel-disk. Depth in m.	Silt-content
April 22		46	36.5		4.6	June 4		67	49		14.0
23			80		55.0	5		45	42		10.6
	Filtrate	62	46.5			6		61	43		9.6
24			70		27.2	7		54	46		19.5
25			67		24.4	10		61	43		10.3
	Filtrate		57			11		66	41		11.9
26		76	53		14.8	12		46	40		15.7
28		58	43.5		4.1	13		67	52	0.85	13.3
29		54	42		10.7	14		65	48	1.0	12.7
30		49	36		4.1	16		62	47	1.1	9.8
May 1		52	40		5.6		1 m.	69	53		12.6
2		38	32		5.2		3 m.	76	55		18.5
3		50	40		5.6	18		70	53	0.8	12.8
5		41	32		4.9		1.5 m.	84	60		20.1
6		45	40		4.2		3 m.		64		26.1
7		45	35		4.1	19		69	50	0.75	11.6
8		48	40		9.0		1 m.	81	59		19.9
9		52	40		7.7		3 m.	83	60		22.9
10		42	37		5.3	20		73	51	0.80	10.6
12		35	35		4.9		1 m.	79	57		16.0
13		50	40		7.3		3 m.		66		25.6
14		52	35		5.2	21		63	50		(9.1)
15		49	40		14.4	23		52	41	1.05	6.0
16		50	38		7.5		1 m.	70	53		10.7
17		54	42		9.2		3 m.	64	48		10.4
19		51	36		14.9	25		57	44	0.80	0.1
20		56	41		9.8		1 m.	83	60		14.5
21		49	39		11.6		3 m.	68	51		15.1
22		54	42		10.3	26		65	48	0.90	11.1
23		59	44		9.9		1 m.	72	54		13.7
24		61	50		13.4		3 m.	73	53		17.4
26		65	48		12.3	27		52	44	0.95	7.2
27		69	48		17.2		1 m.	74	52		12.2
28		67	48		16.7		3 m.	78	58		16.7
29		55	45		21.5	28		58	42	1.0	9.3
31		54	44		9.5		1.5 m.	66	51		13.1
June 2		54	43		4.5		3 m.	74	53		14.9
3		66	52		14.2	30		52	40	1.0	10.0

of 1930. In this apparatus the intensity of the scattered light is compared with the intensity of diffusely reflected light from the same source of light. The intensity of the diffusely reflected light can be regulated by means of a shutter which is graduated. As to the details of the construction the attention of the reader is here called to DEVIK's description of the apparatus (1932). In that description there is also found a diagram which shows some of the values obtained by the writer. They are also presented in Table 25. The concentration has there been determined according to a method which is described below. As is seen from the table the relation between the concentration and the number of the scale of the shutter can be explained in more than one way. The number 40 on the scale, for example, corresponds to the value of the concentration which varies between 4 and 16 mg. per liter. This extension of the error boundaries was too great for this investigation; so this convenient method unfortunately had to be abandoned. In rivers of another mechanical composition of matter this method may very well prove to be advantageous. With lower claims for exactitude it might even be used for the Fyris-water. It is also possible that after the simple filtering away of the rougher constituents of the water sample, the apparatus could be used successfully for the determination of the silt-percentage of the filtrate.

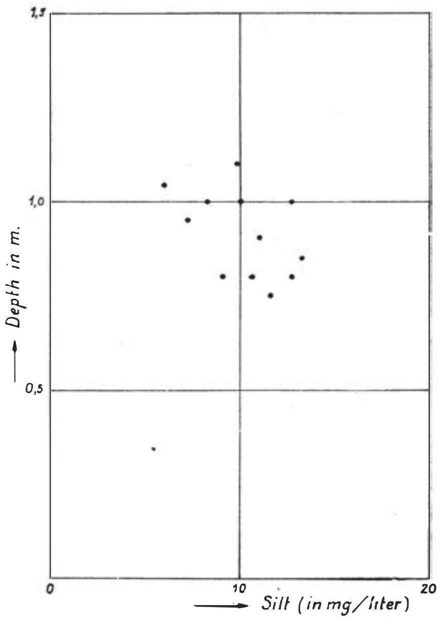


Fig. 46. Determination of the silt contents by means of a FOREL-disk.

Another optical method which has come into use for the rough estimation of the percentage of silt in water is the so called FOREL-disk. It consists of a white circular disk and is used in the following manner. It is immersed in the water and the depth at which it seems to disappear is observed. This depth was named by FOREL (1901) »Sichtbarkeitsgrenze». It is fixed by the absorption and scattering of light which passes through the water. The FOREL-disk has attained very wide-spread use for the determining of the silt-percentage, especially in lakes and seas and sometimes also in rivers. The writer tested it initially in order to determine the degree of accuracy of the method. This cannot be expected to be high, but when it was used in the Fyris it was found to be so low that it could not be used at all because of the consistency of the water. Table 25 and Fig. 46 shows the result.

Asbestos method.

A practical method must be so simple and so reliable that analyses can be performed without difficulty by a person inexperienced in chemical analysis, and they must give exact results. Absolute mathematical exactness is naturally not necessary, but as, at the calculation of the water-mass, errors cannot be avoided, it is important that the other calculations are made as reliable as possible. The demand for simplicity excludes the electrical methods and chemical precipitation methods as well, founded on absorption through an induced deposition. The great amount of loose matter complicates the application of, among others, these principles.

The method of analysis used is a combined filtering and adsorption-method, quite simple in principle and application. It consists of an addition of a certain amount of fine asbestos to the sample, which, after effective shaking, is filtered through a Gooch-crucible with an asbestos packing.

The use of Gooch-crucibles with asbestos-packing has proved effective and obtained a widespread use when filtering suspensions with fine matter (KIMBERLEY and HOMMAN, 1906) in different works of analysis. Sometimes the Gooch-crucible is avoided because of the fear of the asbestos-fibres coming loose in the filtrate, and porcelain filters of various kinds have been used instead. This fear is entirely unjustifiable in careful procedure as experience has shown. The writer has often controlled the crucibles by filtering destilled water or a known mass of clay, and on no occasion has he obtained a loss in weight. Furthermore, porcelain filters cannot be used here, as the ignition loss of the matter should be determined. At the ignition the crucibles split to pieces whether they consist of glass or porcelain.

The effectiveness of asbestos packings as filters may partly be ascribed to electrical powers. As to the conditions at clay-filtering OSTWALD and PICKENBROCK have pointed out that the mass obtained on a filter has a much smaller degree of moisture and ignition loss than sedimentary clay. The former hardly absorbs the moisture out of the air. According to the above-mentioned authors the particles swollen more or less through the water absorption are separated at the filtering; those particles which contain more water remain on the paper while those containing less water penetrate the paper. Perhaps two facts have then an influence, namely the decrease of the charging of the particles and at the same time of their water-percentage which is more or less marked in different cases. Asbestos has a lower negative charge than paper; the decrease of the water-percentage which occurs at every neutralization of chargings should therefore be less in contact with asbestos than in contact with filter-papers.

A simple filtering of the sample through a Gooch-crucible proved in many cases to be quite satisfactory. In certain cases, especially at low water, there is a tendency for the particles to flock together, which of course facilitates the filtering. On other occasions, on the contrary, especially at high water, the colloid-percentage was high and the filtrate somewhat muddy. Even in such cases a clear filtrate could, however, be obtained by adding — before the filtering — a weighed mass of asbestos and then shaking thoroughly. Such absorption-methods are often used in chemistry for the clarifying of impure solutions. As absorbing agents different types of matter were used; coal is usual, also cellulose which in the form of tablets is for sale. The writer tested cellulose-tablets manufactured by SCHLEICHER und SCHÜLL on an occasion when the Fyris-water contained a rather high percentage of difficultly filtered colloidal clay, and obtained a completely clear filtrate. Cellulose is less befitted for quantitative calculations for the same reason as filter-paper. It is then necessary to enclose it in a hermetically shut weighing-vessel. The choice of asbestos as an absorbent is conditioned by the small hygroscopicity of this matter. This use of asbestos as both a filter and an absorbent has proved to be especially effective; even solutions with a very high colloidal percentage become clear by means of the use of asbestos.

The analysis of a water-sample according to this method takes place in detail in the following manner. After being heated to red-heat and cooled off in a desiccator, 0.3 gr. asbestos is weighed in a platinum-crucible; when the water is very muddy a little more asbestos is added. The asbestos consists of common amphibole-asbestos which is for sale under the name of »asbestos for Gooch-crucibles». It has, beforehand, been cooked with strong hydrocloric acid and then carefully washed, and all the hard lumps have been removed and the asbestos loosened with a pair of pinchers so that it is uniform and loose. After the asbestos has been transferred into the water-sample, this is shaken energetically for 20 min. and then filtered through a weighed Gooch-crucible. In the present case, in the analysis-series, a platinum Gooch-crucible and 7 quartz-crucibles, transparant as glass, have been used. On the bottom has been placed a rather thick and hard-compressed layer of loose and uniform asbestos, through which *at least* 1 liter of water has been passed in order to wash away all the loose particles in the asbestos layer. In order that the crucible itself should show the same weight at the various weighings it had already, before the first weighing (before the filtering), to undergo the same treatment which it should undergo before the following weighings. Thus it was heated to red-heat for 15 minutes after the filter had been placed and washed off. After cooling off in the open air about 300 cc. of destilled water were filtered, this partly in order to cause the asbestos to absorb water, partly for the removal of particles and loose matter made free during the heating. After this the crucible was left to dry in a drying closet at a temperature of 110° Celsius for 2 ½ hours, after which it was allowed to cool in a desiccator for 45 min.; finally it was weighed.

The filtering was carried out with the help of a water suction-pump connected to a suction-bottle, according to O. N. WITT, supplied by Membranfilter-Gesellschaft, Göttingen. According to JANDER-ZAKOWSKI there is a description of the bottle in Zeitschrift für analytische Chemie *42* (1903) p. 111. So as not to be forced to fill the crucible as soon as

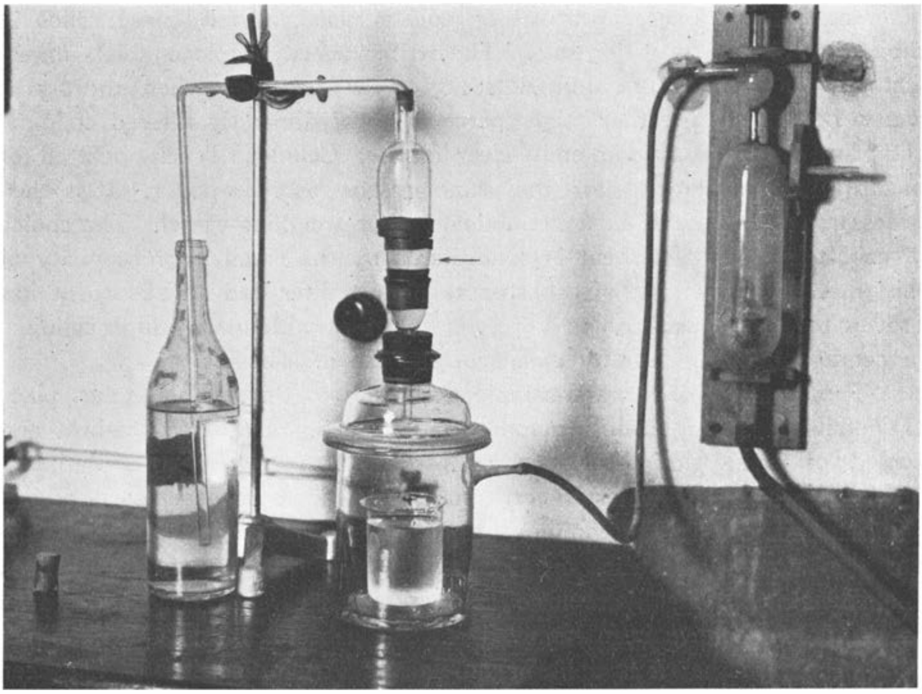


Foto Filip Hjulström.

Fig. 47. Arrangement for the filtration of the water-samples. The crucible is indicated by an arrow.

it was emptied, (its volume was about 40 cc. and that of the water-sample was 900 cc.) it was, by means of a rubber bottle without bottom but with rubber packing, put in air-tight connection with a glass tube which led down into the water-sample. An automatic emptying of the water in the crucible was thereby obtained. Fig. 47 shows the arrangements for the filtration. After the main part of the water-sample had been transfered in this manner into the filter-crucible, the suction-tube was removed and the bottom substance brought up by means of a pipette. The bottle with the water-sample was washed out carefully with destilled water, at least three times and often more, until no solid particles stuck to the sides of the bottle.

After the filtering the crucible is dried 2 ½ hours in a drying closet, cooled for 45 min., and then weighed. The total mass of suspended matter can then be calculated. It becomes, of course, the weight after the filtering less the weight before, if this is increased with the weight of the added asbestos.

For determining the ignition loss the crucible is placed on a platinum cover which is incompletely covered by another cover and is then brought to a gentle glow for 15 min. After cooling in the open air a few drops of a $(NH_4)_2CO_3$ and NH_3 solution are added whereby possible existing carbonates, which at the heating are transformed into oxides, again change to carbonates. The solution has in accordance to the rules of OHLMÜLLER-SPITTA (1921, p. 64) for ignition-loss determinations, been obtained by a solution of 20 gr. ammoniumcarbonate in 80 ccm. of destilled water with an addition of 20 ccm. of ammonium solution with a specific weight 0.96. With the water suction-pump this solution was sucked up after a few minutes, whereby at the same time some destilled water filtered through — for the removal of the already mentioned carbonate solution, and so that the asbestos should be able to adsorb the water which had departed at the ignition. The crucible was allowed to dry in a drying closet at a temperature of 110° Celsius for 2 ½ hours, thereafter being allowed to cool in a desiccator before it was weighed. The ignition loss could now be determined. This ignition loss might be considered to correspond very well to the percentage of organic matter. It is true that also other kinds of matter may depart at the ignition but in the suspended matter these should not be present. The determining of the ignition loss represents the percentage of organic matter much more exactly for the suspended matter than for the matter dissolved.

All the weighings were made on a balance which was accurate to 0.1 mg. In the routine work of the analysis-series the weight of the crucible was always estimated beforehand as well as possible — after some practice to an accuracy of 0.01 gr. — and the weight was placed on the scale before the crucible was taken out of the desiccator. So the time for the weighing could be reduced to a minimum and the very small increase in weight due to the moisture in the air was hardly noticeable. In series-analyses it is possible to work with several tests at the same time, and the time for one analysis can be reduced to 30 minutes. The filtering requires the longest time; its velocity depends upon the character of the suspended matter and upon the thickness of the filter.

Sources of error.

Of the imaginable sources of error which could lower the exactitude of the analysis, two originate from the qualities of the asbestos, namely the percentage of water and the percentage of iron. Heated asbestos weighs less than dried asbestos. This source of error is avoided by handling the asbestos in an entirely similar manner before the weighing. Repeated controlling tests have shown that through this a constant weight is obtained. Concerning the percentage of iron it can perhaps be imagined that the iron's valency should increase from 2 to 3 through oxidation, thereby causing an increase in weight to appear. The asbestos also assumes at intensive ignition a somewhat brownish colour-tone. No weight-increase whatever could, however, be noticed. Another source of error which could only influence the calculation of the ignition loss, could be imagined to occur with the addition of a carbonate solution to the ignition sample. The solution may possibly cause a peptization of the silt after which this, in the following sucking-through of destilled water, should appear in the filtrate. Control samples showed, however, that this was not the case. The destilled water proved namely, after it had passed the filter, to contain only ammonium carbonate which completely volatized during heating.

The sources of error of the analysis are therefore of a vanishing character, and when determining the degree of accuracy of the analyses the weighing-errors become decisive. The weighing was carried out with an accuracy of 0.1 mg., and in the case of only filtering through Gooch-crucibles two weighings were required, and so the combined weighing-error was 0,2 mg. By the addition of asbestos to the sample the number of weighings becomes 4 and the combined weighing-error 0.4 mg. These errors form the total analysis-error, if the filtrate is completely clear. This has generally been the case; only in the case of high-water has it appeared that the filtrate has shown opalescence or clouding, and then the procedure has always been repeated. On these occasions it has always been found that the weight of colloidal clay which caused the opalescense was very small. It has generally been below 1 mg. A simple calculation shows that if the size of the particle is 2 μ which, according to ODÉN (1916), corresponds to the upper boundary for clay, and if the specific weight is 2.7 almost 10^8 (about 90 million) particles are demanded for a mass-weight of 1 mg. Therefore, also small mass-weights are clearly noticeable, and an error caused by insufficient filtering is improbable.

Method for determining the bed-load.

The bed-load, however, offers even greater difficulties than the suspended material when attempting to determine the total mass of transported sedimentary material. Up to now no accurate and reliable method has been fully worked out for such investigations. However, in recent years the matter has been given much attention, and by investigations, by

EHRENBERGER, MÜHLHOFER and Russian scientists, especially APOLLOF, the solution of the problem no longer seems to be so remote.

At the beginning of this investigation into the silt-transportation in the Fyris, it seemed to the writer necessary to obtain a method for direct measurements of the amount of bed-load transported, since the formulae appear to be too uncertain and hypothetical. In 1929 no direct similar measurements were carried out except for those of KURZMANN's (1919) and SCHOFFERNAK's (1923), both with catch-baskets. The writer, however, in 1931, in a hydraulic flume with a movable sand-bottom at Karlsruhe Flussbau-laboratory, had the opportunity of testing a few simple models, carried out on a small scale with sheet-iron or wire-netting, in apparatuses which were able to catch the amount of bed-load which passed a certain cross-section of a profile. The problem turned out to be very difficult; all inroads in the river-bed and all objects which were placed in it caused a change in the transportation of the sand. Furthermore, the mode of transportation had an effect, especially the contrast dune mode of traction contra transportation in a uniform layer.

When an object was placed on the bottom it was found that the sand's movement was stopped in front of this object, if in any way it formed a hindrance for the movement of the water. The movement of the sand curved aside and became instead much more intensive at both sides of the object. The writer tested several different models of catch-apparatuses, especially different types according to the principle which LÜDERS later, in 1934, has presented so ingeniously in his »Sandfalle». The water and the sand is here led to a container where the sand is deposited and its quantity can be measured. Rather small changes in the models can cause considerable changes in the course of the stream-lines, and all the types had this in common that the sand curved aside before the apparatus and passed by at the side instead of being caught. The writer therefore entertains a doubt concerning the reliability of the absolute values which are obtained with LÜDERS »Sand-falle», although relative measurements can certainly give good results.

Furthermore, catch-baskets of wire-netting were tested. If these were not entirely too tight the sand ran, in the beginning, into them and was deposited at their front ends. As soon as a deposition had appeared the transportation in the apparatus ceased and the sand ran past the side. From this it was evident that this type could be used for the determination of the *occurance* of sand-transportation along the bottom.

The only apparatus which did not cause changes in the sand-transportation was APPOLOF's which was described in 1931 by LEPPIK.[1] It is very simple: the sand is made to run over a plate from which side-walls

[1] Die Wasserwirtschaft, Heft 6—7, 1931.

may be folded up. No hindrance of the flowing of the water nor of the transportation of the sand takes place when this apparatus is used, as was proved by experiments with a simple model. The difficulty in using APPOLOF's apparatus lies in the rythmical sand-transportation in the dune mode of traction. Only an average value based on several measurements is then reliable.

In the Fyris the writer has used only a catch-basket consisting of an iron frame into which a kind of catch-basket or box of brass-wire-netting may be placed. It was found that there was no transportation at all of bed-load. The writer has made examinations at all high-waters since September, 1932, but without ever being able to determine any such transportation. Not even during the great high-water in October—November, 1934, when the water rose to 225 at Uppsala gauge — higher than July 1929—June 1934 — did any such transportation appear in the Fyris at Uppsala. One can therefore establish the fact that *no transportation of bed-load takes place at Uppsala.*

The Fyris runs over a bed of clay, and only within certain districts over moraine, sand or gravel of glacio-fluvial origin.

Certain signs can, however, be found which indicate that motion of bed-load occurs within the tributaries, for example the Jumkil river and the Björklinge river, which run over moraine within large areas.

In the Fyris at Uppsala transportation occurs only in suspension and in solution; we return, therefore, to these methods of transportation.

The collected material.

Samples and analyses. The samples for July 1st—December 18th 1929 were procured from a boat at Sandkällan, a short distance north of Fyrisbadet at Uppsala. The same applies for June 10th—July 21st 1930 and for July 16th—July 20th 1932. During all the rest of the time the procuring of the samples was made from the river at Fyrisbadet, north of Uppsala, Fig. 48. The sampling was carried out by Mr GÖSTA ROOS except during the above-mentioned periods. Usually two liters of water-test were taken daily; during the winter months at times of intense cold, of small silt-percentage and of small variations in the same, tests have not been taken daily. Until March 1933 tests had not been taken on Sundays other than in special cases. The samples have as a rule been taken at 8 o'clock, never later than 9 o'clock. The reading of the Uppsala gauge also occurred at 8 a. m. During certain periods samples were taken several times a day as is shown by the Table in the Appendix which contains the results.

The samples have been analysed within 14 days after the sampling; only in a couple of cases has the time been more than a month and the water for November and December, 1931, was first analysed in June, 1932. Of the two samples for each day, the one has been analysed according to the asbestos method, the other has been filtered through a common filter-paper (From J. H. Munktells Pappersfabriks-A.-B., Grycksbo, Nr. O). During a part of the year 1931—1932 the filtering was carried out by the writer's wife,

Foto Gösta Gustafsson.

Fig. 48. Air view of Uppsala from the north. In the foreground to the right the bridge over the Fyris at Fyrisbadet, from which the water samples were procured. To the right in the back-ground the Ekoln, the arm of Lake Mälar, into which the Fyris falls.

a part by Mr ERIK KARLSSON, but the largest part by the writer. The latter samples were wrapped in paper and preserved as a reserve in case of an unsuccessful analysis. A part of them has been burned to ashes and weighed; they are given in the Tables in the Filtration column. This ashing and weighing has been carried out partly by the writer, 1929, partly by Kemiska Kontrollbyrån, Stockholm and partly by Fil. Dr. N. SAHLBOM. The great majority of the analyses according to the asbestos method have been carried out by the writer. A total of 80 analyses have been carried out by Mr ERIK KARLSSON during the year 1930—1931.

Everyone of the sample-bottles was provided at the sample-taking with a label for the date. This label was placed so that it indicated the level water-surface in the bottle. After filtering, the bottle was filled with water up to the same mark, and the volume of this water was determined in a measuring-glass.

The filtrate of certain samples was preserved and was evaporated in a platinum bowl on a water-bath protected from dust. Generally 250 ccm were evaporated.

The mechanical Composition of the Matter in Suspension.

The question of the mechanical composition of the material is of great importance for deciding the distribution of the silt at different heights above the bottom, as well as for an understanding of the mechanical denudation within the river basin. A number of measurements have been carried out in connection with this, with the aid of the sedimentation apparatus, constructed by WERNER and HEDSTRÖM, for the determination of grain-sizes. The apparatus gives good values down to the grain-size of 2 μ (as radie); the composition of the colloid clay cannot thus be determined. A condition i. a. is that, even the specific gravity, (measured by means of a pyknometer to 2, 57) is the same for all grains — a condition which is not quite fulfilled. Loam also contains vegetable matter which is able to remain suspended on account of a high water percentage and a low specific gravity. This fact shows that the largest grain-sizes, according to the results, are smaller than in reality. However, it is the settling velocity which is of importance here; the influence of the aforementioned fact is therefore small.

The grain-size has been determined at high-water and at low-water and in the case of the former at 2 different depths. On account of the small contents of silt which are generally to be found in the Fyris-water, great volumes must be procured for these measurements, e. g. carboys of 60—80 litres. The procuring of surface water samples was easy, but water from greater depths had to be pumped up. Great volumes had likewise to be taken for the chemical analyses. A little ammonia was added to the samples in order to prevent coagulation. The samples were allowed to stand about a month for purposes of sedimentation, after which time the water was poured off and the sediment analysed. For the samples of high-water a period of one month did not prove sufficient as the water then showed signs of opalescence. These samples were, therefore, allowed to stand a further two months. Before the analysis took place the samples were shaken at least one hour in a shaking-apparatus.

Table 26 contains results of most of the measurements carried out. For low-water percentages a few more analyses have been carried out but as these do not vary very much, the results of the 30th of June 1933 may be looked upon as being typical. The great difficulties met with when

Table 26.

Mechanical composition of some silt-samples (in weight-%).

Date	Depth	Greatest particles	> 40 μ	40—30 μ	30—20 μ	20—10 μ	10—5 μ	5—2 μ	< 2 μ
8.8. 1930	0 m.	90 μ	2.2	3.6	2.9	5.6	4.3	20.3	61.0
8.8. 1930	3.1 m.	108 μ	6.4	9.7	5.5	6.8	3.6	17.1	50.9
8.3. 1934	0 m.	81 μ	7.4	5.5	5.9	4.0	4.7	10.4	62.1
30.6. 1935	0 m.	50 μ	1.9	6.0	4.3	6.1	18.8	32.8	30.1

taking the samples of these vast quantities of water, as well as the time-consuming processes of sedimentation resulted in only a few mechanical analyses being carried out. These analyses have, however, been chosen only in-so-far as they are considered as being typical. A daily examination of the composition of the material — such as JOSEF STINY (1926) has carried out for the Mur (Steiermark) — was not possible in this case.

It will be seen from the Table that, for different depths, the contents of the finest particles did not vary very much. The percentage of contents becomes lower but if reduced to mg/litre the value is about the same. The silt content was, on the 8th of August 1930, at the surface 201.0 mg and at the bottom 241.5, the depth being 3.1 metres; the sample was procured at 0.3 metres above the bottom. The percentage of coarse particles has, as is to be seen, increased somewhat. The largest particles at the bottom have a grain-size of 108 μ against 90 μ at the surface. The major part of the increase consists of the grain-size groups > 5 μ: this analysis is for the highest contents of silt which have been measured during the period between July 1929—June 1934. This high value appeared after a particularly heavy downpour of rain in the late summer and when the temperature was rather high.

An analysis was even carried out of the silt content of the spring flood, viz. on the 8th of March 1934. The samples from the spring flood are difficult to procure, as a boat cannot be used on account of the ice, which is, at the same time, not strong enough to bear the weight of man. This sample, was however, taken at the bank of the river in the vicinity of the Fyris-badet. As is to be seen, the percentage of clay-content is somewhat greater than at high-water in summer-time. It is also more difficult to filter this water than the water procured during summer as an opalescence is more easily seen in the filter

Neither the low-water of the summer nor that of the winter had the same high content of colloidal clay: here the grain-size group 5—10 μ was larger. Perhaps coagulation had taken place here. In her studies of the sediments of the North Baltic and adjoining seas, STINA GRIPENBERG (1934) found that

»sea-water diluted to a salinity of 0.25 ‰, corresponding to a normality of 0.0004, causes slow coagulation, which after a night's standing has completely changed the distribution of the suspension» (page 74). This concentration is just that which appears in the water of the Fyris, although, in this river organic matter is also included 25—30 %, which, in similar cases, acts as a preventative against coagulation. According to GRIPENBERG, »with progressing coagulation the suspensions become more and more sorted» (page 75); and, »observations often made in the course of the mechanical analysis», show that, »more or less coagulated suspensions are characterized by one dominating size group». Similar circumstances prevail here, although the sorting is not very pronounced as is to be expected in a river. SCHÜRMANN (1916) says of the suspended matter in the Neckar at low-water stages, »sie sind ausgezeichnet durch eine beträchtliche Neigung, sich zusammenzuschliessen und Aggregate zu bilden, die trotz ihrer zuweilen bedeutenden Grösse eine ausserordentliche Schwebefähigkeit besitzen». (Page 22). The same applies to the Fyris water. When the samples from the periods of low-water have been allowed to stand for some time, e. g. one month, the silt has collected in small clots at the bottom of the bottle. These clots are, however, very mobile and with the least movement of the water they break up and spread. And, furthermore, they form one common abode for the micro-fauna. According to a report from the Borough Engineer of Uppsala, the number of in gelatin vegetable micro-organisms was, in a sample of the 29th of July, 1930, about 47 thousand colonies per cc. The fresh-water plankton ought, on account of its own power of motion, not to be reckoned to the suspended matter, but is, of course, included in the obtained values as it cannot be parted from the mineral matter during the process of analysis.

In the summer-time the water has a more brownish colour but during the spring it is of a yellowish brown. At high-water stages it is light yellow owing to the presence of clay.

The percentage of colloids of different kinds is subject to great variations as is to be seen from the mechanical analyses. It is the material's high-dispersed form that makes the analysis so difficult, and excludes the use of the ordinary paper filters. By a combination of the asbestos method and filtration through the same, one should expect to get an idea of the percentage of the presence of high-dispersed matter in the sample. But, however, only a rough estimate, as it is not possible to give an exact limited size of particles for that part of the silt which passes through the filter. When the richly clay-containing water is filtered the pores of the filter gradually become stopped up, the filtering proceeds slower, and the particles of limited sizes sink. But, on an average, particles less than 3 μ pass through an ordinary paper filter. (See SVEDBERG, 1928, page 183). In the Tables of the Appendix there is a column headed »Filtration», covering several months, which gives the values of the combustible parts remaining in the filter. It is interesting to compare these figures with those obtained by the asbestos method (column Silt Contents minus Ignition loss). It will be seen that the difference at low-water is inconsiderable, and only corresponds to the general fluctuations which are always to be found between water samples that are taken at the same place immediately after each other. At times the figures are higher but more often they are a few percent lower. At low water-stages and poor silt content the percentage of colloidal matter is small. This result is partly caused by the aggregation of the silt particles in the bottle prior to filtration. To a great extent this result is thus fictive and shows only the flocculent tendency of the particles.

When the silt content is high the difference between both results of the two methods is extremely great. That of the 8th of August 1930 gives, for example, 438 mg/litre, i. e. 18.5 %. For the spring flood of April 1934 the filtering result is likewise poor. High silt-content coincides usually with great quantities of water caused by the melting of snow or by heavy rainfall in summer and autumn. On these occasions the percentage of dissolved matter is less than at low-water as the ground-water leaves a greater percentage of the discharge. The measurements show quite clearly that the flocculence is not so far advanced in these cases.

The Distribution of Silt in a Cross-Profile.

The demonstrated fineness of the greater part of the material, as is shown in Table 26, makes it possible for the running water to be easily transported. The velocity need not be great to enable the turbulence to keep the particles suspended, and they are not deposited at the mouth of the Fyris in the Mälar Lake; the Fyris has no delta. See Fig. 49. The silt is held in suspension for long distances and is deposited gradually. It is to be observed from an aeroplane that the path of the River Fyris continues about one kilometre into the lake and that the spreading of the particles does not take place until there.

Owing to the grain-fineness of the silt one may also expect an even distribution over the profiles.

For the deciding of this question:

1) series of samples have been taken at different points of a cross-profile and the velocity has been measured where it has been of measurable size, and

2) samples have been procured vertically at different depths for each day of several periods.

Table 27 shows a typical example from the former measurements. The measurement is from Sandkällan and was taken on the 23rd of July

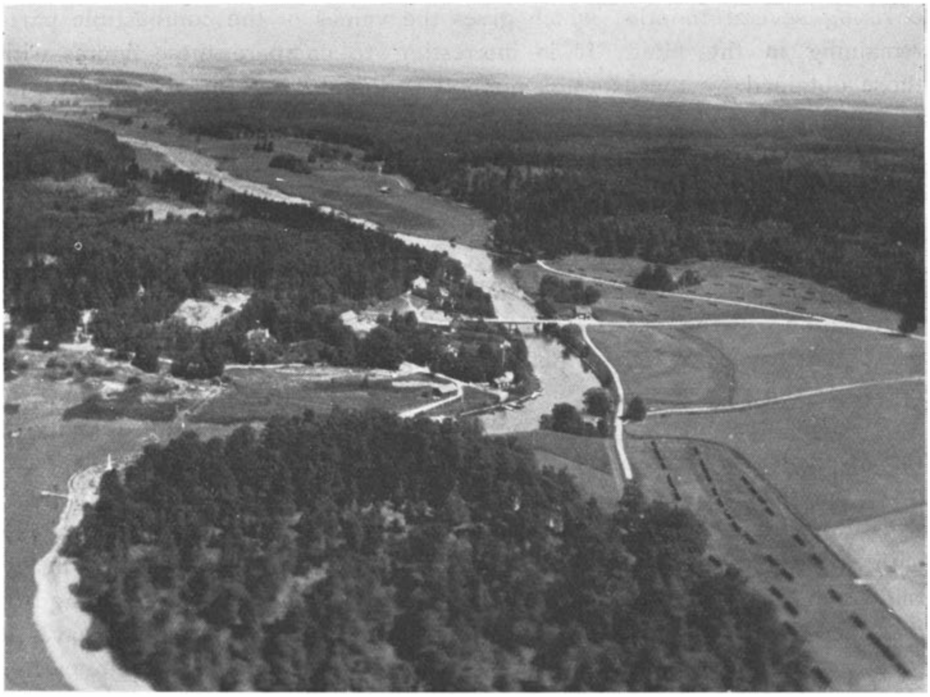


Foto Gösta Gustafsson.

Fig. 49. The Fyris River mouth in the Lake Mälar at Flottsund. The Fyris has no delta.

Table 27.

Distribution of the silt in different points of a profile.

Depth for sampling \ Total depth	I 1.8	II 2.9	III 3.3	IV 3.6	V 3.7	VI 3.6	VII 3.5	VIII 3.0	IX 1.9
0 m.	15.6	16.0	15.0	15.8	16.3	16.5	13.4	19.3	14.0
1 m.	—	13.4	18.8	16.0	16.9	14.9	18.2	18.1	24.8
1.5 m.	16.1	15.0	15.6	15.1	17.2	16.7	12.1	18.1	19.6
2 m.	—	18.1	16.1	19.0	18.1	19.1	18.1	15.4	—
3 m.	—	—	17.1	19.1	19.1	19.4	18.1	—	—
0.3 m. above the bottom		19.8	18.1	20.0	20.7	19.8	18.5	19.1	19.6

The distance between the vertical lines is 2.5 meters; the breadth of the river is 25 meters. The vertical lines are enumerated from the western bank.

1929 between 12 and 13 o'clock. The velocity was registered at the same time by an OTT-meter. In accordance with the COLLET Method (1925) the discharge has been estimated, and the total quantity of silt transported by the river calculated. The discharge was 8.1 m^3/sec. and the load 0.2 kg/sec., i. e. 8.1 tons per twenty-four hours.

The calculation of the total quantity of suspended matter, L tons/24 hours, may be given in the following formula:

$$L = 0.0864 \cdot k \cdot Q \cdot s,$$

where k = a coefficient

Q = the discharge in cubic metres per second

s = the silt-content in mg/litres, at a certain point of the profile.

The coefficient k has different values at different points. By procuring a whole series of samples it is easy to estimate this factor. At a depth of 1.5 metres in the middle of the river it is, in this case, 1.19.

The corresponding distribution of the silt was obtained for the 14th of May and the 8th of August 1930. The factor k was in both cases respectively 1.11 and 1.21.

An other example was taken from a high-water stage during the spring flood, viz, the 23 of April 1931. In this case the silt is more uniformly distributed over the profile. This is probably explained by the turbulence being increased owing to the comparatively high velocity. According to Table 26 it will be seen that the contents of coarser particles are not so large on such occasions as might be expected. The factor k has the value, 1.17.

Finally, a series of samples has been taken from a low-water stage, viz, on the 22nd. of June 1933. On that occasion the differences of silt were not great. At this point the velocity could not be estimated other than with a floating object. The factor k was estimated at 1.17.

As is to be seen from Table 27 the distribution of the silt in profile is rather irregular. Such regular increase, as is shown in Fig. 12, for the contents of salt in the experimental channel is not to be found. These irregularities appear even conspicuously in the series of samples procured at different depths of one vertical for each day of a longer period. This is to be seen in the Tables of the Appendix.

A closer study of this Table gives a rather peculiar change in the distribution of the silt for different concentration. *In the case of a high percentage of silt the value is, as a rule, greatest at a depth of 1.5 metres, i. e. in the middle of the river.* This is clearly seen in Fig. 50. The writer has not been able to give any other explanation for this peculiar phenomenon than that it must depend on local irregularities in the stream at that place where the samples were procured (Sandkällan). At the bottom of the river there are no marked irregularities. The river has an almost straight course. It winds somewhat so that vertical IX is to be found at the outer bend, but this bend is very slight. At normal tur-

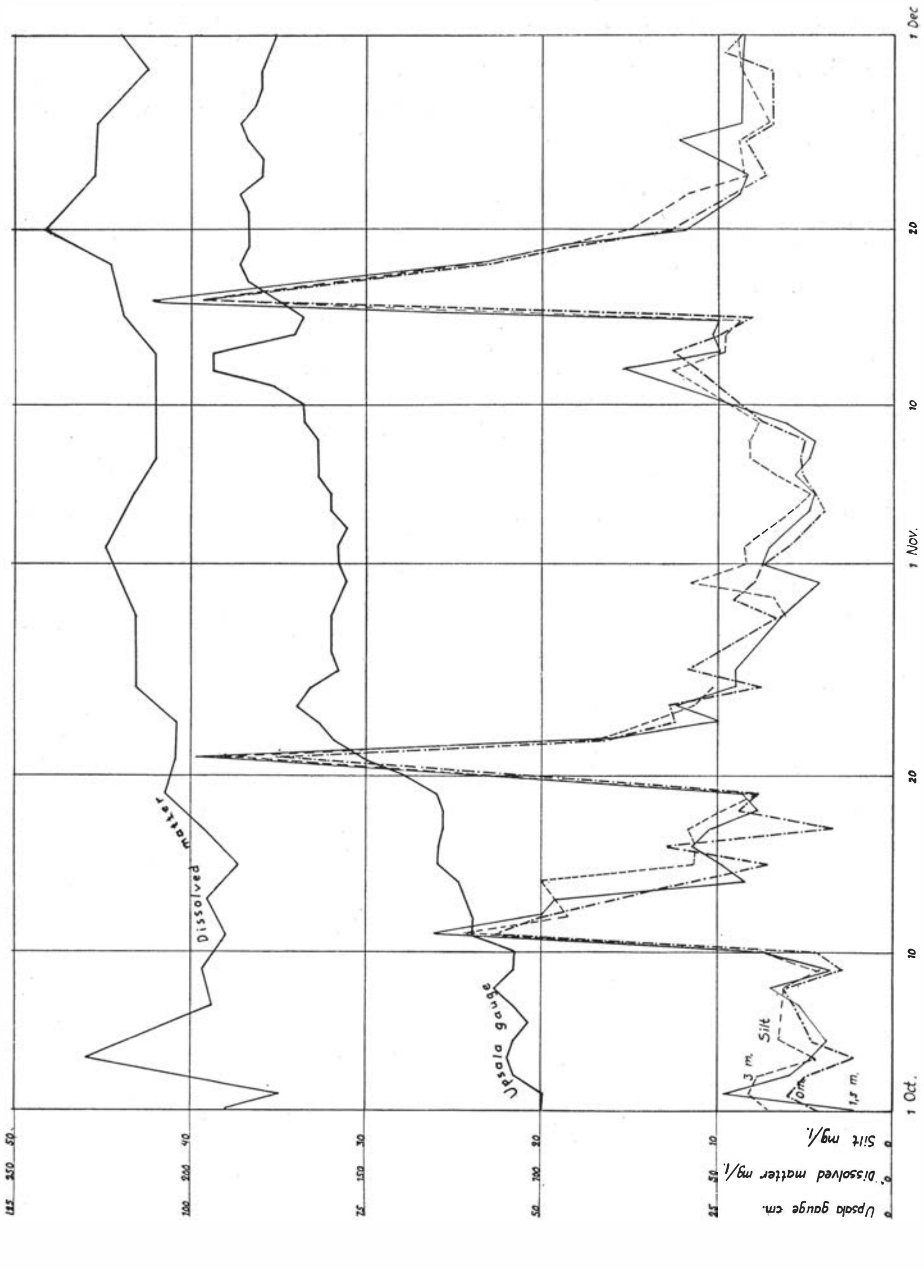


Fig. 50. The transportation of suspended and dissolved matter in October and November 1929.

bulence and normal distribution of the silt this phenomenon cannot be brought into harmony. By normal turbulence the silt can practically adopt constant concentration in all points of the profile. But, on the contrary, an inversion in the silt-content cannot take place. Such an inversion can only be explained by strong transversal movements, or by erosion above the place for sampling; (see page 290). It was, however, not possible to observe any transversal movements, and marked erosion is not probable. Any change in the configuration of the bottom was not noticable by sounding.

No record of similar observations is mentioned from other rivers. The increase in concentration of the silt generally takes place in the ordinary way. The question has been discussed at length by COLLET (1925), GRUNSKY (1930), STRAUB (1932), and several others, so that if the phenomenon had been the rule some mention would have been made of it.

One influence of turbulence-distribution as is to be seen in Table 6 and Fig. 15, may be traced even if it is not so obviously conspicuous. In the verticals III, IV, VI, and VII, which flank the middle line V the silt is more regularly distributed than in the middle and at the sides, thus indicating more intensive turbulence. This distribution would, perhaps, be more clearly marked if the previously mentioned irregularites did not exist.

A calculation of the condition between the concentrations for 0 m., 1.5 m., and 3.0 metres brings about an average of 1: 1.44: 1.62.

As an average of those measurements of which Table 27 is an extract, the value of 1.15 has been obtained for the factor k[1]. If this is included in the formula for L the following is obtained:

$$L = 0.1 \cdot Q \cdot s_{1.5}.$$

For measurements taken from the bridge a connection must be sought between $s_{1.5}$ at that place and at Sandkällan. It was seen that the difference kept within 10 and 15 %, and on an average, no difference was to be found within the limits of error. This allowed for the same convenient formula being used for all tests.

The Turbulence. From the formula deduced by SCHMIDT (see page 272), and also MORROUGH P. O'BRIEN (1933)

$$-c \cdot s - A \frac{ds}{dz} = 0$$

one finds for constant A:

$$A = \frac{\cdot c \cdot z}{\log \frac{s_m}{s_z}}$$

if s_m = the contents of silt (characterized by c) at the height z_m.

By applying this formula for measurements according to Table 26 one finds that for the 8th of August 1930 A on an average was 75.

[1] For samples procured at the surface $k = 1.44$, at 1 m. depth $k = 1.27$.

The variations in the contents of silt at different periods.

Weather conditions during the period of July 1929—June 1934. Before discussing the results obtained, it is advisable, at first, to insert the following as regards the weather conditions and the discharges during the period in question, in addition to what has been pointed out previously.

The period embraces years with widely diverging weather conditions, and it is, therefore, possible to obtain certain fixed points for estimating the influence which some climatic changes have on erosion.

During the autumn of 1929 there was a rather heavy rainfall and the temperature was, on an average, high. The following winter was likewise milder than normally and the snowfall was insignificant. As a result of this there was practically no spring flood. The whole year of 1930 was unusually warm. The low-water of the River Fyris during the summer was extremely pronounced. But, however, the rainfall during the autumn was great and the discharge in the Fyris was remarkably high. During the following winter there was, as previously pointed out, a very heavy snowfall in contrast to the winter before. The spring flood was particularly pronounced.

The summer and autumn of 1931 were colder and the rainfall was less than normal. The low-water of the summer, was, however, less pronounced.

The latter half of the period differs very little from the normal. The Tables in the Appendix as well as Pl. VIII, clearly show the variations. There were two stages of high-water during the winter of 1931—1932. In December there was a heavy snowfall but in the following month the snow melted away and brought about a mighty high-water. During the subsequent months the rainfall was insignificant until a heavy snowfall in March followed and brought about a cover of snow which gave rise to a new but less marked high-water in April and May.

In 1933 the rainfall was the lowest recoded in Uppsala during the period 1929—1934, being only 444.1, i. e. practically 100 mm. below the average. At the same time the temperature was higher than normal; on the 9th of July the temperature was 38°.0 in Ultuna, this being the highest temperature that has, with certainty, been recorded in Sweden. The run-off also was insignificant in the River Fyris.

The variations in the contents of silt. A closer study of the Tables in the Appendix as well as of Pl. VIII. shows that the transportation of silt in its entirety is particularly irregular and spasmodic with rapid intensifications and equally as rapid depressions. It shows, in this respect, the same appearance as other published measurements of this kind: see HUMPHREYS and ABBOT 1861, ULLIK 1880, BAËFF 1891, COLLET 1916 and 1925, UETRECHT 1906, FORTIER and BLANY 1928, and HOWARD 1929 and others.

These maxima in the silt-content show striking similarities among themselves. When the discharge increases because of rain or melting snow the silt-content rises very rapidly to its maximum. This maximum soon appears when the discharge begins to increase, and long before the latter factor reaches its maximum. From its highest value the silt-content generally sinks less rapidly to a lower value again. This peculiarity in the course has been alluded to by the previously mentioned authors in connection with other rivers, and it is even particularly and regularly developed in the Fyris — much more by rain than by the melting of snow. Examples are at hand for practically every month; even for a rain-maximum August 1930 gives a good illustration, and for the melting of snow April 1931 and 1932, together with February and March of 1934.

The explanation might be that which was first given by UETRECHT: — »dass bei starken Regengüssen der Staub schnell abgespült und der Flüsse zugeführt wird. Regnet es nun weiter, so nimmt doch die Abspühlung etwas ab, weil der Boden schon rein abgewaschen ist» (page 51). Thus the material is loosened by different weathering processes and then transported away by rain-wash. The silt-content at rain or the melting of snow is, therefore, dependent upon

1) the intensity of the rain-wash, and
2) the work which the weathering processes have managed to carry out after the previous clearing away of the material.

The latter factor is, for its part, dependent upon the interval of *time* between the maxima and of the intensity of the weathering processes (the resistance of the material and the forces at work).

The supposition behind this explanation is that the river's own erosion of its bed is not of the greatest importance. If the erosion of the bed in which the stream flows constituted the most important part of the work of erosion and transport, it would, of course, be greatest when the discharge had its maximum.

Thus we arrive at the following conclusion. By making a comparison between the transportation of sediments before, during, and after a maximum in the discharge, it is possible to judge if the direct fluvial erosion is more important than the inter-fluvial, or on the contrary. In the meantime, it ought to be noted here that, strictly speaking, this only holds good for the suspended material. With the presence of the bed-load circumstances are certainly more complicated; this has, as mentioned above, a lower velocity than the water.

For the River Fyris, as already mentioned, the maximum of the silt-content comes before that of the discharge. *The direct erosion of the River Fyris is, therefore, of less importance than the inter-fluvial erosion by weathering processes and rain-wash.* As will be dealt with later, this conclusion has been confirmed by direct measurements.

Table 28.

The content of silt in the Fyris-water at Uppsala during the period July 1929—June 1934.

	Number of days with a silt content in mg./liter greater than													Max.
	2	5	10	15	20	25	30	40	50	75	100	150	200	
1929:														
July	31	30	24	14	10	3	1							37.8
August . . .	31	30	16	5										18.7
September . .	30	23	7	2	1									20.0
October . . .	30	26	12	6	4	2	1							39.9
November . .	30	26	9	15	3	2	2	1						42.1
December . .	31	30	17	12	8	4	4	2	1					56.1
July—Dec. . .	183	165	85	54	26	11	8	3	1					
Per cent . . .	99.5	89.7	46.2	29.3	14.1	6.0	4.3	1.6	0.5					
1930:														
January . . .	29	26	12	5	3	1	1							38.4
February . .	28	24	4											12.0
March . . .	31	31	21	5	3	2	1							34.7
April	30	26	12	4	4	1	1	1	1					55.0
May	31	27	12	4	1									21.5
June	30	29	23	8	1									20.1
July	31	31	15	3	1									25.7
August . . .	31	31	22	11	9	9	5	4	3	2	2	2	1	237.7
September . .	30	28	12	8	3	2	2	1	1					66.8
October . . .	31	30	16	12	8	5	3	1						41.8
November . .	30	30	26	18	9	6	5	2	1					64.7
December . .	31	31	15	8	5	4	1	1						44.2
Year	363	344	190	86	47	30	19	10	6	2	2	2	1	
Per cent . . .	99.5	94.2	52.1	23.6	12.9	8.2	5.2	2.7	1.6	0.5	0.5	0.5	0.3	
1931:														
January . . .	31	22	6											13.4
February . .	28	28	2											11.5
March . . .	31	31	4											14.5
April	30	30	24	15	14	13	13	11	5	3	2			129.9
May	31	30	18	6	5	1	1							35.1
June	30	29	4											13.3
July	31	31	3											11.4
August . . .	31	30	8	2	2									20.4
September . .	30	29	2											11.7
October . . .	31	28												8.2
November . .	30	29	8	1										15.3
December . .	31	30	2											10.9
Year	365	347	81	24	21	14	14	11	5	3	2			
Per cent . . .	100.0	95.0	22.2	6.6	5.8	3.8	3.8	3.0	1.4	0.8	0.5			

Table 28 (Continued).

	Number of days with a silt content in mg./liter greater than													Max.
	2	5	10	15	20	25	30	40	50	75	100	150	200	
1932:														
January . . .	31	31	22	18	17	9	4	3	3					64.1
February . .	29	17												8.0
March . . .	31	28	11	3										18.2
April	30	30	30	28	20	15	12	5	1					72.5
May	3	31	31	22	15	7	2	1	1					69.2
June	30	30	23	3										16.6
July	31	29	12	2										19.5
August . . .	31	29	2	1	1									21.2
September . .	29	12	1											12.9
October . . .	31	21	7	2										18.4
November . .	30	29	17	7	5	5	4							37.1
December . .	31	31	9	1										18.6
Year	365	318	165	87	58	36	22	9	5					
Per cent . . .	99.7	86.9	45.1	23.8	15.8	10.0	6.0	2.5	1.4					
1933:														
January . . .	31	20	13	9	2									22.3
February . .	28	22	1											12.5
March . . .	31	29	28	27	23	15	10	6	4	3				87.8
April	30	29	7											10.9
May	31	30	9	2										17.3
June	30	28	6											14.3
July	31	31	16	8	2									21.9
August . . .	31	31	1											10.2
September . .	30	29	2	1	1	1	1							35.6
October . . .	31	23	6	2										18.0
November . .	30	28	8	5	1	1								28.4
December . .	31	31	16	4	2	1								26.4
Year	365	331	113	58	31	18	11	6	4	3				
Per cent . . .	100.0	90.7	31.0	15.9	8.5	4.9	3.0	1.6	1.1	0.8				
1934:														
January . . .	31	28	14	2	1	1								29.4
February . .	28	22	12	4	4	4	4	4	4	2				77.4
March . . .	31	31	26	25	21	17	14	11	5	1	1	1	1	221.5
April	30	30	24	12	3									24.4
May	31	31	17											13.1
June	30	28	13	3	2	1	1							33.7
Jan.—June . .	181	170	106	46	31	23	19	15	9	3	1	1	1	
Per cent . . .	100.0	93.9	58.6	25.4	17.1	12.7	10.5	8.3	5.0	1.7	0.6	0.6	0.6	
Per cent for the whole period July 1929—June 1934 .	99.8	91.7	40.2	19.4	11.7	7.2	5.1	3.0	1.6	0.6	0.3	0.2	0.1	

The same conditions are to be found in glacial streams. Glacial erosion works uninterruptedly and grinds away the surface of the rock; the fine material is transported away when the run-off increases, but the river cannot usually erode the surface of the rock to the same extent as the glaciers. See, e. g. Rhône and Drance according to UETRECHT 1906 and COLLET 1916.

A closer study of the Tables in the Appendix as well as of Pl. VIII. shows that the variations in the silt-content have a somewhat different character during different periods of the year. Table 28 shows the duration of different contents of silt. It is greatest during autumn and spring, small in summer and least during winter. As regards the transportation of silt, we may divide the year into the following periods:

1) the cold period,
2) the melting period.
3) the warm period.
4) the autumn rain period.

During the first of these periods, *the cold period,* the ground is generally frozen and covered by snow. Loose particles on the surface of the ground are then effectively bound and only the bottom and sides of the river are in contact with running water. In the meantime, this surface is not eroded to any great extent, at least not by the insignificant velocity at the bottom which prevails during the cold period. The silt-content is less than 10 mg. per litre: during shorter periods it sinks to a few mg. per litre. The water, however, is not quite clear, i. e. completely free of silt, due no doubt to the following causes.

The temperature of the water is now 0° under the ice and has a high specific weight, thus enabling the solid particles to be more easily transported than when the water is warm. This is dealt with more in detail on page 275. During the winter the contents of dissolved salts are greater than usual, whereby the specific gravity is further increased over and above the influence of the temperature. It is quite possible that these salts have even a physico-chemical influence and thus produce dispersion of colloidal clay. This process, however, is of no great importance during the cold period. In the river bed there is also organic material which is subject to uninterrupted decomposition by which particles are released and transported further. As soon as a thaw has prevailed some days the silt-content increases to 10 mg. per litre or more. The rainfall during this period has no influence at all, and no substantial maxima exist. It is possible that the depth of the snow has a certain influence, in-so-far that during shorter thaw periods no marked increase of the silt-content takes place if the thickness of the snow is great. The temperature now seems to be most important, above all, the regelation with transition from plus to minus degrees (centigrades) is very important. As a rule, an uninterrupted decrease in the silt-content during cold periods is observed, but this increases as soon as the temperature rises above zero. According to Pl. VIII. the curve of the silt contents is very even during the cold period.

The next period, *the melting period,* shows, on the other hand, particularly great variations, the culminating point being reached during *the spring flood*. The highest values of the silt-content usually appear at this time.

During this period the silt-content is nearly connected with the discharge. The thickness of the snow cover and the course of melting snow are, therefore, decisive. The snowfall was very poor during the winter of 1929—1930. (See Table 16—18). There was no spring flood and the melting snow brought about no higher silt-content than 13 mg. per litre. The following winter registered the heaviest snowfall for the whole period, the thickness of the cover of snow being 61 mm. During the spring flood there was about 130 mg. silt per litre. It very often happens that the cover of snow does not remain from autumn until spring; warm periods without snow intervening with the cold periods. In such a case there are several high-water stages, examples of which are to be seen in the winter of 1931—1932. In January as well as in April the silt-content reached 72—73 mg. per litre.

March 1934 gives an example of how a sudden thaw may have a greater influence than the thickness of the cover of snow and the discharge. After a cold period accompanied by snow the temperature quickly rises. A depth of snow 13 cm. deep melted away in three days, and at the same time the silt-content of the River Fyris at Uppsala increased from 3.7 mg./litre on the 13th of March to 221.5 mg./litre on the 18th of the same month. The silt-content is, on the whole, subject to considerable variations during this period, inter alia, there is even a daily variation. Several samples were taken daily at different periods during the *melting periods* of January and April 1932. As is to be seen the silt-content is, as a rule, greater at 15 o'clock than at 8 o'clock. The thaw during the morning and at noon has, usually, caused an increase in the discharge, and the water from the melted snow has carried the material to the river. See LÜTSCHG 1926.

A measurement from the 27th of April 1931, Table 29, is particularly illustrative. In this example there is a general tendency of the silt contents to sink, and besides, there are daily variations notably conspicuous. At noon there is a definite increase and during the night a decrease. In the meantime, the value from 8 o'clock is representative. The difference is, however, to a great extent dependent upon the temperature, and very often the contents of silt are constant or vary very irregularly, as is to be seen

Table 29.

The silt-contents at different times of the day during melting periods.

Time	April 27, 1931	January 20, 1932
8 o'cl.	31.6 mg./liter	60.0 mg./liter
10 »	33.7 »	
12 »	31.9 »	69.0 »
14 »	33.3 »	
15 »	33.4 »	72.7 »
16 »	33.4 »	75.6 »
17 »	28.5 »	70.6 »
19 »	27.0 »	75.3 »
21 »	25.5 »	69.1 »
24 »	22.1 »	69.6 »
Method	Filtration	Gooch-crucible

by the values of the 20th of January 1932 in Table 29. These values have been obtained by filtration through a Goach-crucible. No kind of correction has been made for the daily course of the silt percentage other than in that which was obtained by direct measurement. The silt-content has always been supposed to be constant until the next measurement was taken.

The frost in the ground, the »tjäle», has also some influence, chiefly by its loosening activity when disappearing. The measurements of the temperature at Uppsala and Ultuna, published by the Statens Meteorologisk-Hydrografiska Anstalt show that the frost penetrated 0.5 but not down to 1.0 meter during the years 1929—1934. When it penetrates deeply, as in 1934, its retreat was delayed until the beginning of April ($^7/_4$). In 1930 there was in Ultuna at a depth of 20 cm. a temperature of 0° or lower up to the 22nd of February; the winter of 1930—1931 only up to the 28th of December, in 1932 up to the 31st of March and 1933 up to the 27th of March. During that period when the frost disappears from the ground the rainfall is of great importance. Before then the run-off is very great and likewise the erosion as no infiltration in the ground can take place, i. e. for the transportation of silt. If rain, or snow which quickly melts away, falls, there is an increase of the silt-content in the water of the Fyris as the particles are easily washed down from the loosening and loose ground. See e. g. April 1932, the end of March 1933 and April 1934.

In April the spring ploughing begins on the farms whereby the ground is still further loosened within parts of arable land. These parts are, therefore, open to soil erosion, in the case of heavy rainfall, until the vegetation has had time of develop, viz., in the middle or at the end of May.

Table 30.

The precipitation for different months at different stations in the Fyris river-basin.

	Jan.	Febr.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Sum.
Vattholma 1929							93	39	54	66	26	51	329
1930	14	8	21	24	25	40	132	98	95	81	56	32	626
1931	41	22	16	9	42	14	71	127	41	42	16	88	529
1932	9	10	12	48	82	69	28	69	42	52	69	10	500
1933	17	25	27	15	34	7	106	53	31	46	34	11	406
1934	14	34	51	23	33	54							209
Average	19.0	19.8	25.4	23.8	43.2	36.8	86.0	77.2	52.6	57.4	40.2	38.4	519.8
Drälinge 1929							76	79	48	69	37	51	360
1930	14	20	20	20	30	66	115	126	79	78	75	35	678
1931	63	30	29	18	46	17	71	96	43	53	16	106	588
1932	27	11	25	60	66	54	50	78	39	55	68	14	547
1933	19	28	29	16	40	21	94	56	39	44	46	13	445
1934	19	43	64	27	38	73							264
Average	28.4	26.4	33.4	28.2	44.0	46.2	81.2	87.0	49.6	59.8	48.4	43.8	576.4
Husby 1929							84	40	39	66	26	51	306
1930	14	11	40	25	35	54	82	102	49	74	53	35	574
1931	58	25	15	11	38	26	28	124	48	49	13	95	530
1932	20	11	18	31	69	45	38	41	45	45	60	15	438
1933	16	29	25	22	32	10	77	63	25	39	26	14	378
1934	21	30	48	18	31	46							194
Average	25.8	21.2	29.2	21.4	41.0	36.2	61.8	74.0	41.2	54.6	35.6	42.0	484.0

(Communicated by Statens Meteorologisk-Hydrografiska Anstalt, Stockholm.)

At this point *the warm period* makes its entry, and remains until about the 1st of October. The silt-content in the water is now very inconsiderable, particularly during June and July; next to the winter months these months have the lowest silt-content.

The temperature of the water rises rather high; for long periods it remains between 20° and 23° as the measurements at the Fyrisbadet show. Chiefly on account of the low viscosity the settling velocity of the particles is now greater, and the particles are not so easily held in suspension as at lower temperatures. The other climatological conditions, however, have a much greater influence than the temperature. It is not possible, at least in detail, to trace any direct influence of the temperature of the water. For a short period in 1929 the temperature of the water was measured by a reversing deep-sea thermometer at a depth of 1.5 meters, but as no influence could be traced no further measurements were taken.

The particles of soil are now bound fast by the vegetation and the rain does not, to any great extent, increase the transportation of the silt. The beginning of August 1930 shows, however, that particularly heavy rainfall can be of very great importance. From the 4th to the 9th of August there was 82.9 mm. rainfall in Uppsala. And in other parts of the river-basin there was a heavy rainfall as was generally the case in South and Central Sweden. Among other places there were floods in Uppsala. These particularly heavy rains brought about extreme rain-wash and the silt-content rose to 237.7 mg./liter. That which is decisive for the rain-wash is torrential down-pour. The run-off is then extremely great. If the intensity of rain is low the run-off is, on the contrary, less. During the warm period numerous thunderstorms take place. These storms have often a high intensity of rain, but are of short duration and do not cover wide areas. During the summer months they are responsible for the rainfall being subject to greater variations between the different places within the area than is otherwise the case. Table 30 shows the rainfall for three stations within the area during the period in question. As is to be seen the differences are greatest during the month of July. These local thunderstorms have very little influence on the silt-content of the River Fyris, as is seen in the Tables of the Appendix and on Pl. VIII. In both places, the rainfall in Uppsala is given, and in those cases where it is of a local character the influence on the silt-content is very little. Hereupon are the 13th of July 1930 and the 18th of August 1932 examples. On both these occasions heavy rainfall in Uppsala was registered in connection with thunderstorms but no particular increase in the silt-content was the result in the water of the Fyris.

There was no daily course in the silt-content other than in connection with the variations of the rainfall. Measurements of this are to be found under June 1932 and the 17th of July 1933. The variations are not great.

The fourth period is *the autumn rain period.* It is characterized by considerable changes in the silt-content. The maximum of rainfall appears under August, but the following months also register heavy rainfall. In October the autumn ploughing commences and, as in the spring, the ground is not protected against heavy rains and rain-wash. The rainfall is heavier during the autumn than in the spring, consequently the erosion is considerable. Plate VIII shows the influence which rain has upon the contents of silt during this period. The often repeated difference between freezing and thawing, which appears during the latter part of this period, contributes to the loosening of the ground. Considerable frost in the ground — as indicated by temperatures $\leq 0^\circ$ at a depth of 20 cm. at Ultuna — occurred during the winter of 1929—1930 February the 2nd,

Table 31.

The Contents of silt in the Fyris-water (mg./liter).

	1929	1930	1931	1932	1933	1934	Mean.
January		12.9	7.8	30.3	11.1	11.9	14.8
February		8.3	9.8	6.1	7.0	26.4	11.5
March		14.8	9.5	10.5	32.8	39.7	21.5
April		15.1	55.7	32.8	9.6	16.3	25.9
May		10.4	17.0	25.1	10.4	11.3	14.8
June		15.8	9.5	13.3	10.3	11.3	12.0
July	20.4	11.1	9.5	10.8	15.2		13.4
August	12.7	28.9	10.9	8.4	8.6		13.9
September	10.1	17.3	8.3	5.7	9.0		10.1
October	13.6	18.9	7.2	7.9	8.4		11.2
November	15.2	23.3	10.5	16.5	11.4		15.4
December	20.7	16.2	9.1	10.5	11.9		13.7

the winter of 1930—1931 December the 24th, the winter 1931—1932 January the 1st, the winter of 1932—1933 January the 23rd, and the winter 1933—1934 on December the 4th.

And finally, in Table 31 a summary is given of the average values of the silt-content for the different months. The figures have been obtained by a division of the mass transported by the river divided by the volume of water which has passed the profile during one month. The Table denotes the difference between the different periods.

The total transportation of sedimentary matter by the River Fyris.

The load of the River Fyris has been calculated according to the formula on Page 409 and its value is to be found in the Tables of the Appendix. They are, however, published with reservation made for that uncertainty which multiplication by the discharge involves.

If one assumes that the values of the discharge are trustworthy if they reach 5 m.^{3}/seconds, but under that confirmed with 50 % error, an idea of the error of the total amount of matter transported can be obtained in the following way. According to Table 23 the number of days with a discharge less than 5 m.^{3}/sec. (on an average 3 m.^{3}/sec.) is 19.8 %. These days have, naturally, at the same time the lowest silt-content. Table 28 shows that if 19.8 % of the number of days with the least silt-content are chosen silt-contents up to a value of 6 mg./litre must be included. On an average the silt-content is here put at = **4** mg. By doing so it is easy to estimate that *the error in the total sum will be 3.3 %.*

Table 32.

Precipitation, run-off and load of sedimentary matter for different months during the period July 1929—June 1934.

Month	Precipitation, mm.	Run-off cbm/sec.	Load tons/month	Month	Precipitation	Run-off	Load
1929:				**1932:**			
July	82.8	6.3	344.0	January	35.0	38.8	3150.2
August	65.7	7.7	260.3	February	11.3	14.7	225.7
September	37.6	5.1	135.2	March	18.3	8.1	228.9
October	73.5	8.7	318.4	April	56.9	15.8	1340.0
November	32.3	8.6	340.9	May	69.3	13.3	895.7
December	58.7	12.9	714.5	June	65.1	7.6	261.2
				July	79.1	6.7	193.0
1930:				August	54.1	5.2	117.4
January	20.9	14.5	501.0	September	47.1	5.0	74.9
February	16.7	8.4	167.6	October	52.5	7.5	159.4
March	20.8	8.3	330.6	November	68.3	12.7	542.1
April	21.0	9.7	378.1	December	16.1	11.5	322.0
May	24.0	7.0	193.9				
June	67.8	3.7	150.9	**1933:**			
July	92.7	2.7	79.3	January	26.0	11.7	347.2
August	145.2	11.1	861.9	February	26.5	9.7	163.9
September	73.5	13.0	583.0	March	29.0	11.6	1020.4
October	71.1	11.4	579.8	April	19.6	12.1	299.2
November	55.8	18.8	1137.6	May	34.9	7.4	207.5
December	36.8	17.5	758.9	June	25.1	3.0	80.6
				July	105.1	3.0	121.9
1931:				August	56.7	5.6	129.5
January	63.4	15.4	320.8	September	39.0	3.7	86.2
February	30.2	13.1	309.3	October	45.0	2.4	53.1
March	21.0	9.3	237.4	November	26.3	3.6	105.8
April	24.4	19.5	2821.1	December	10.9	2.0	64.8
May	39.2	23.5	1067.1				
June	18.2	10.6	260.2	**1934:**			
July	45.2	5.9	151.0	January	24.8	5.7	181.0
August	101.2	6.1	177.3	February	33.8	6.6	421.4
September	45.5	7.5	160.7	March	65.0	14.9	1580.1
October	47.6	7.7	148.0	April	22.6	15.9	673.5
November	12.6	9.5	260.1	May	33.0	9.3	282.3
December	88.7	17.0	413.3	June	58.1	6.6	192.3

Table 32 gives a comparison of the total quantity of transported material per month and year. The final result of the investigation is, as is to be seen, *that on an average, the River Fyris transports 5,540 tons of sedimentary material per year past Uppsala.*

The drainage area is 1,200 sq.km. according to the »Arealstatistik för Mälaren—Norrström» by Statens Meteorologisk-Hydrografiska Anstalt, Stockholm 1934, therefore, from each sq. km. 4.6 tons is eroded per year. For the mechanical erosion of a layer 1 metre thick it would take 326 thousand years if the specific gravity is put at 1.5.

The variations. The variations of the amount of suspended matter are given in detail in Tables 32—34.

Table 33 shows the duration of different loads. On some occasions it has exceeded 200 tons per twenty-four hours, but, however, only during the spring flood and for short periods, only 0.4 % from July 1929 to June 1934. The lowest values appeared in April 1931 (maximum 530 tons per twenty-four hours) and in January 1932. On the 20th of January 1932 there appeared the greatest amount of sedimentary material in 24 hours which was observed during the whole period, viz. 584.1 tons. This high value depends upon the discharge being extremely great on this occasion: the silt-content was not abnormally high, 60—70 mg. per litre. The maximum of silt-content (237.7 mg. per litre on the 8th of August 1930) corresponds to a considerably less load as the discharge was rather small at that time. On certain occasions, chiefly during the summer at low-water the load sinks to 1 ton per twenty-four hours: the most frequent values being 5—10 tons per twenty-four hours.

The annual course of the transportation of silt is very marked, as is to be seen in Table 32. For longer periods, as for whole months, it closely follows the discharge: the previously mentioned digressions between the appearance of the maxima in the percentage of silt and in the discharge have no great influence then.

Besides the discharge the silt-content is also included in the formula for the calculation of the load. As regards this factor it has been previously pointed out that it is very different during different periods of the year, and that four chief periods may be distinguished. The same thing is noticeable in the silt-contents. If the load is plotted against the precipitation according to Table 32 one obtains a peculiar picture as is seen in Fig. 51. The points lie grouped according to the periods mentioned on p. 414 and coincide somewhat with the seasons of the year, so that the fields can be divided into different sections according to the seasons. The widely diverging weather conditions which prevail during different years are the cause of certain transitory months being reckoned to the one or other of the seasons. October has, for example, at times more the character of summer than of

Table 33.

The load of silt in the Fyris River during the period July 1929—June 1934.

	Number of days with a load in tons per day greater than														Min.	Max.
	0.5	1	2	5	10	15	20	30	50	75	100	150	200	300		
1929:																
July	31	31	30	24	15	8	3	1							1.3	38.3
August . .	31	31	31	30	7										2.6	14.4
September .	30	30	27	9	2										1.6	11.2
October . .	31	31	29	24	11	7	4	2							1.2	34.7
November .	30	30	30	23	10	5	5	2							2.3	42.1
December .	31	31	31	31	19	16	13	7	4	1					5.9	81.9
July—Dec. .	184	184	178	141	64	36	25	12	4	1						
Per cent . .	100.0	100.0	96.7	76.6	34.8	19.6	13.6	6.5	2.2	0.5						
1930:																
January . .	31	31	29	27	19	13	7	4	1						1.0	68.0
February . .	28	28	28	20	1										2.0	10.7
March . . .	31	31	31	31	13	3	3	1							5.0	33.7
April . . .	30	30	30	22	12	5	5	2	1						2.7	67.1
May	31	31	31	17	4										3.1	12.7
June	30	30	28	12	1										1.5	11.5
July	31	30	20	1											1.1	5.3
August . .	31	31	31	27	22	15	12	8	5	2	1	1			2.4	180.7
September	30	30	30	28	18	12	9	6	1	1	1				3.9	132.3
October . .	31	31	31	29	14	12	9	8	3						4.5	62.7
November .	30	30	30	30	30	27	22	16	6	2	1	1			11.2	155.3
December .	31	31	31	31	31	12	9	8	3	1					11.5	98.6
Year	365	364	350	275	165	109	76	53	20	6	3	2				
Per cent . .	100.0	99.7	95.9	75.3	45.2	29.9	20.8	14.5	5.5	1.6	0.8	0.5				
1931:																
January . .	31	31	31	27	10	8	1								2.6	23.0
February . .	28	28	28	28	19	4									5.1	17.7
March . . .	31	31	31	29	3										4.5	14.5
April . . .	30	30	30	30	22	14	14	13	13	13	10	8	3	2	6.6	530.0
May	31	31	31	30	27	22	14	9	7	5	2				3.9	147.1
June	30	30	30	30	9	1									5.0	19.0
July	31	31	31	10	1										3.3	11.3
August . . .	31	31	31	18	2	1									2.4	15.9
September .	30	30	30	18											3.3	8.3
October . .	31	31	30	12											1.6	9.0
November .	30	30	30	26	7	2									3.4	16.2
December .	31	31	31	30	24	11	4								4.8	24.8
Year . . .	365	365	364	288	124	63	33	22	20	18	12	8	3	2		
Per cent . .	100.0	100.0	99.7	78.9	34.0	17.3	9.0	6.0	5.5	4.9	3.3	2.2	0.8	0.5		

Tab. 33 (Continued).

	Number of days with a load in tons per day greater than														Min.	Max.
	0.5	1	2	5	10	15	20	30	50	75	100	150	200	300		
1932:																
January . .	31	31	31	31	31	28	25	25	16	9	7	5	4	3	12.6	584.1
February . .	29	29	29	27	9										3.6	14.4
March . . .	31	31	31	23	5	1									3.8	19.3
April . . .	30	30	30	30	30	30	28	21	11	2	1				18.7	138.0
May	31	31	31	31	31	28	24	10	1	1	1				12.4	117.6
June	30	30	30	29	9	1									3.2	15.2
July	31	31	31	20	2										2.5	11.5
August . .	31	31	28	4	1										1.3	12.7
September .	30	28	19	1											0.5	7.6
October . .	31	31	31	14	2										2.0	13.1
November .	30	30	30	30	21	13	7	4	2						5.3	61.6
December .	31	31	31	31	16	2	1								5.3	20.5
Year . . .	366	364	352	271	157	103	85	60	30	12	9	5	4	3		
Per cent . .	100.0	99.5	96.2	74.0	42.9	28.1	23.2	16.4	8.2	3.3	2.5	1.4	1.1	0.8		
1933:																
January . .	31	31	31	27	13	12	5								2.3	23.6
February . .	28	28	28	15	1	1									3.1	15.5
March . . .	31	31	31	30	28	23	20	13	8	1					3.6	92.6
April . . .	30	30	29	24	12	7									1.9	19.3
May	31	31	31	24	2										3.1	10.7
June	30	28	16	4											0.7	6.9
July	31	28	20	8	2										0.8	13.1
August . .	31	31	29	9											1.2	7.3
September .	30	29	22	3											0.9	9.6
October . .	31	26	9												0.8	3.8
November .	30	30	20	4	2	1									1.3	16.2
December .	31	30	13	1											0.8	5.0
Year. . . .	365	353	279	149	60	44	25	13	8	1						
Per cent . .	100.0	96.7	76.4	40.8	16.4	12.1	6.8	3.6	2.2	0.3						
1934:																
January . .	31	30	25	12	4	1	1	1							0.8	42.3
February . .	28	28	28	12	5	4	4	4	2	2	2				2.3	118.4
March . . .	31	31	31	30	28	26	24	20	11	6	2	1	1		4.1	270.2
April . . .	30	30	30	30	30	26	19	3							11.6	41.5
May	31	31	31	30	9	3									4.7	18.1
June	30	30	30	20	5										2.1	13.8
Jan.—June .	181	180	175	134	81	60	48	28	13	8	4	1	1			
Per cent. . .	100.0	99.4	96.7	74.0	44.8	33.1	26.5	15.5	7.2	4.4	2.2	0.6	0.6			
Per cent for the whole period June 1929—July 1934 . . .	100.0	99.1	93.0	68.9	35.7	22.7	16.0	10.3	5.2	2.5	1.5	0.9	0.4	0.3		

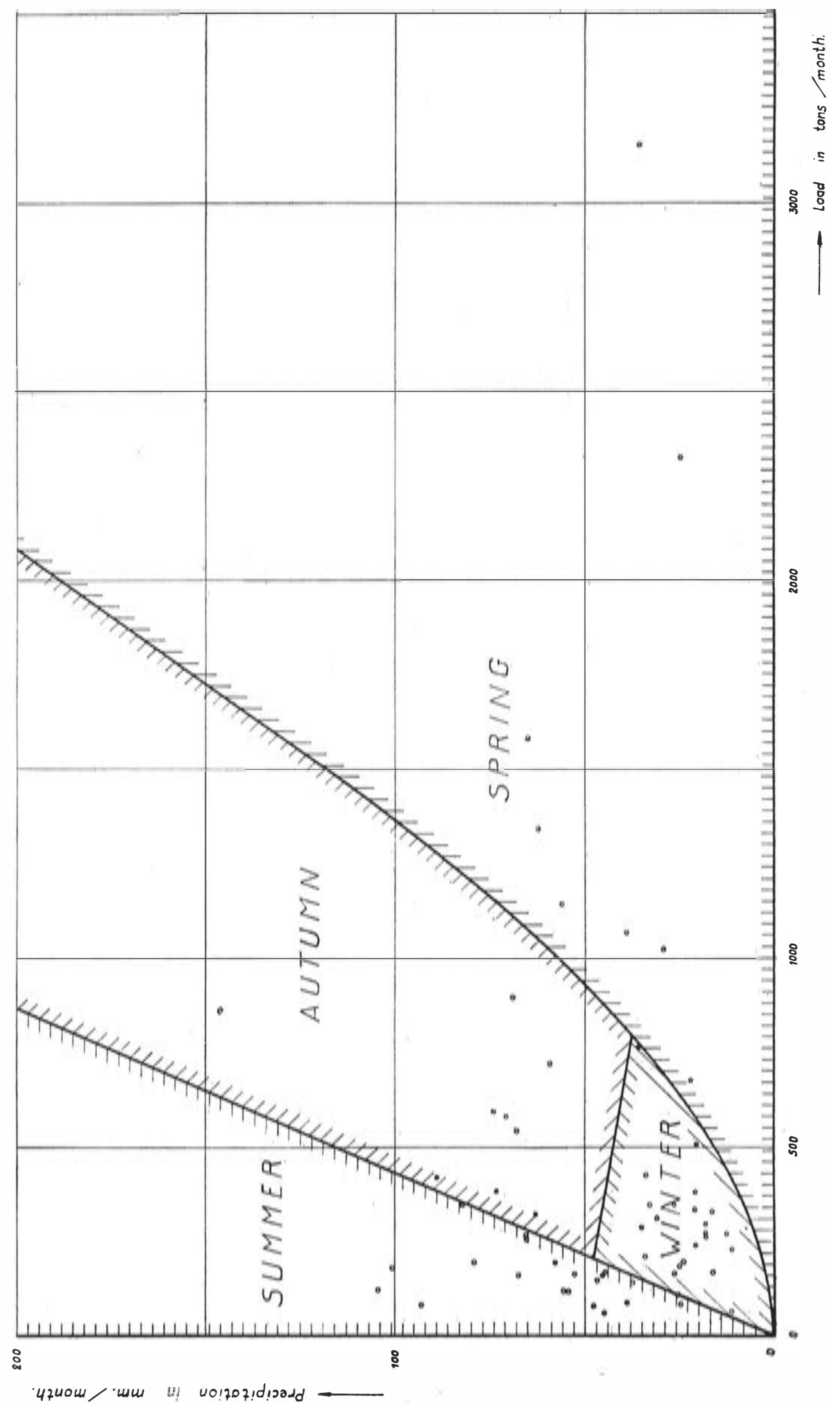


Fig. 51. The load of suspended matter in relation to the precipitation.

autumn. The greatest number of points within each section belong, however, to just that season which is marked in the field. Thus, one sees that the summer is characterized by insignificant transport even if the rainfall is heavy. In the autumn the erosion is more intense at the same time as the rainfall is heavy. A certain amount of rainfall has, however, an effect many times greater during November than during June or July. In the winter the amount of rainfall is less: but the melting of snow during a thaw is of greater importance than this factor. Therefore, the transportation is often somewhat greater than during the summer.

As regards erosion and transportation the most important period is, however, the melting period — the spring. The load is then much greater than even in the autumn, although the line of demarcation between these two periods in Fig. 51 has been very difficult to draw. Table 34 shows the average values for the months and seasons as calculated from Table 32. The abnormal weather conditions during January 1932 make the result somewhat erratic. As regards the viewpoint in question this month belongs to the spring months but, as a matter of fact, the Table gives a clear picture of the transportation of the sedimentary material. HETTNER (1928) has put forward the question of the importance of the low-water periods. »Die Erosionskraft eines Flusses wechselt zeitlich mit der Wasserführung. Für die Gesamtwirkung scheint hauptsächlich das Hochwasser massgebend zu sein; aber ganz ohne Einfluss kann auch die Wasserführung des übrigen Jahres nicht bleiben, und Untersuchungen darüber wären auch von geographischer Bedeutung, weil der jährliche Gang der Wasserführung in verschiedenen Klimaten und bei verschiedenen Gestein verschieden ist» (page 30). The transportation of the sediment at low-water periods for the River Fyris (discharge less than 10 cbm/sec.) is, according to Table 32, 25 % of the total.

In Table 35 the transportation has, for each and every one of the five years' investigation, been placed in connection with the temperature and the rainfall. From the 1st of July 1929 to the 30th of June 1930 the year was particularly warm and dry; the degradation of the river-basin was comparatively small. The following year was quite the opposite; less warm[1] and damp. The erosion was considerable. The period of 1931—1932 was warm and damp with great erosion. The following year again was warm and dry with particularly insignificant erosion. The year 1933—34 was like the foregoing. That characteristic of the first four years corresponds rather well to that, in the BLYTT—SERNANDER scheme for the post-glacial climatic periods, which was originally given to the following periods as they now appear in due order: the Boreal, the sub-Atlantic, the Atlantic, and the sub-Boreal. Table 35 gives us an idea of the activity of the rivers during these different periods. The first and fourth ought to

[1] Though, as all the years, warmer than normal.

Table 34.

Mean values of the load of sedimentary matter.
(For the period July 1929—June 1934).

January	900.1 tons.
February	257.6 »
March	679.5 »
April	1102.4 »
May	529.3 »
June	189.0 »
July	177.8 »
August	309.2 »
September	208.0 »
October	251.7 »
November	477.3 »
December	454.7 »
Spring	2311.2 tons.
Summer	676.0 »
Autumn	937.0 »
Winter	1612.4 »

Table 35.

Precipitation, temperature and load for the different years.

	Precipitation mm.	Mean temperature	Load of sedimentary matter, tons per year
July 1929—June 1930	521.8	+7.05	3835.4
» 1930— » 1931	671.5	+5.15	9016.4
» 1931— » 1932	596.7	+5.38	7412.3
» 1932— » 1933	478.3	+6.20	3527.4
» 1933— » 1934	520.3	+6.54	3891.9
Mean July 1929—June 1934	557.7	+6.06	5536.7
Mean for longer periods	544.4	+4.9	

have been distinguished by inconsiderable transportation of sedimentary material but the other two by an abundant transportation. The series is, however, far too short for more detailed conclusions to be drawn from it as regards the climatic variations. In that case, a BRÜCKNER period would, at least, be necessary. Table 35, shows how the divergence from the average of the load can be very great; 1932—33 it was up to 55 %. At the same time the divergences of the climatological factors are very great; for rainfall 25 %. When the discharge varies very much the transportation of the sediments varies very much also, a fact which must be marked in the deposits of the river.

PHILIPP KRAPF (1919) who for twenty years has carried on an investigation into the sediment-transportation by the Rhine into Lake Constance found still greater variations, viz. between 13,7 and 1.7 million tons per year. The variations are, naturally, particularly great in those areas where there are glaciers but, it is quite certain that the River Fyris also has greater variations than those appearing during this five-year period.

The chemical composition of the silt.

From a geographical-geological point of view, the amount of sedimentary material transported is surely of the greatest interest. But, the question also arises: what is its composition? Is there any selection among the loose particles on the surface?

The sedimentary material naturally consists of fine weathering-products and to some extent also of unweathered particles of the original material. The relation of these depends on the character of the erosion and of the ground. In an area recently covered with ice the latter type may be yielded to the water to a great extent. (MATTSON 1932, p. 232). If there is no enrichment of certain ingredients in the soil, the sum total of dissolved and solid material must have the same composition as the surface affected by the water, when the salts added from the rains are abstracted. On account of the podzolization processes there is some such enrichment of different ingredients in different layers. As TAMM (1920) pointed out, this process is, however, very slow.

A study of the soil and the soil processes within the river-basin was not included in the present investigation; but regularly, the percentage of organic matter was determined and a sample of the suspended matter analysed.

The chemical analysis of the suspended matter was carried out by Fil. Dr. NAIMA SAHLBOM. The sample was procured during the high-water of November 22, 1934 at a water-stage (falling) of 188 cm. The silt was dried at 100° C. The result was the following:

$H_2O^{+100°}$	1.86 %
SiO_2	6.96 %
Al_2O_3	2.69 %
Fe_2O_3	1.32 %
CaO	48.51 %
MgO	0.12 %
Na_2O } K_2O }	0.80 %
CO_2	37.80 %
	100.06 %

The percentage CO_2 is determined as ignition loss minus the water; organic matter is included which probably forms the main part.

The most remarkable feature of the result of the analysis is the high percentage of CaO. The lime is not only, in a great amount, carried in solution (HOFMAN-BANG 1903), but even in suspension, and the washing away of the lime is thereby still more accelerated. Though the silica is generally present as colloids, the percentage of SiO_2 only amounts to nearly 7 %. Al_2O_3 forms 2,69 % of the silt; usually it is included in 7—14 % of the clays.

In his theory of the isoelectric weathering SANTE MATTSSON (1932) discusses at length the transportation of colloid matter. The isoelectric weathering represents, however, the result of a long duration in a humid climate, rich in precipitation, so that, for instance, the lime is carried away. In Sweden the soils are, however, rather young. — The pH of the water ranges from 7.2 to 7.7, as measured by means of a BJERRUM-ARRHENIUS colorimeter; the reaction is, therefore, basic and not acid as in old soils in high latitudes. The ratio $\frac{SiO_2}{Al_2O_3 + Fe_2O_3}$ is 1.73 — a low value for such a high latitude. The $\frac{SiO_2}{MO + MO_2}$ ratio is 0.14 for the colloidal matter and 0.12 for the dissolved salts (computed from HOFMAN-BANG 1903), both very low values, caused by the high contents of lime. The analysis shows, however, that the River Fyris is very intense in its work of carrying away the lime and trying to establish the conditions usually existing in such a climate as prevails.

The content of CO_2 is rather striking. As mentioned above, the organic matter is also included here.

The organic matter. In each silt-analysis a determination of the ignition loss was included. According to the description on page 397 it is carried out in such a way, that the result should as far as possible correspond to the percentage of organic matter. In the Tables of the Appendix the values obtained are included. An examination of these Tables will show, that the ignition loss has rather great variations in detail, but that, on an average, the following may be concluded. Generally, the ignition loss constitutes 25—50 % of the silt contents. If, however, the contents of silt increase, the percentage of organic matter will not increase proportionately. For August 8, 1930, when the value arose to 237.7 mg/liter the percentage of organic matter (ignition loss) was less than 10 %. This feature appears generally, as soon as the contents of silt increase. The transportation of organic matter is more regular than that of the mineral matter.

The transportation of organic matter in suspension, on an average about 25 % of the total load of silt, constitutes 1385 tons per year.

The dissolved matter.

During parts of the period in question the filtrates of some samples were also evaporated on a water-bath for the determination of the total amount of dissolved matter and its ignition loss. The dissolved matter in Swedish rivers is comparatively well known by the numerous analyses carried out by Statens Meteorologisk-Hydrografiska Anstalt (ERIKSSON, 1929) and by HOFMAN-BANG (1903) and only the *amount* of the salts and the ignition-loss were determined. Only a few words are needed as an explanation for the analysis-data.

The results are to be seen in Table 36. It is seen, that the content of dissolved matter is considerably greater than that of suspended matter. The greatest concentration of dissolved salts appears in February and March with about 250 mg. per liter, a very high value, compared with the contents of silt. The minimum with 160—180 mg. per liter occurs usually in August. The mean concentration is 210 mg. per liter. — Most of the analyses are from 1929. In Pl. VIII the salts are not plotted but in Fig. 49 some features as to the variations may be seen. The variations are not so great as for the suspended matter but there are, however, some changes. The content of dissolved salts is, as a rule, greatest when the silt-content is least, and vice versa. It is worth mentioning that when there is an increase in the silt-contents, caused by precipitation, an increase in the concentration of the dissolved material appears also, but only some days later. One easily gets the impression that the rain-water, which percolates into the ground there is enriched in salts, which are then supplied to the Fyris-water. The same tendency is to be seen from other measurements (see JOUKOWSKY, 1928) but this does not seem to have been pointed out before. During a rain-period the different maxima, therefore, make their appearance in the following course:

Tab. 36. The contents of dissolved salts.

July 1929

Concentration			Load	
Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	203.2	54.1	July 1	114.1
2	199.6	64.0	» 2	84.5
3	191.2	50.8	» 3	71.0
4	190.0	48.4	» 4	83.7
5	187.0	51.0	» 5	69.5
6	208.0	54.0	» 6—7	134.8
8	194.0	56.0	»	16.8
9	195.0	54.0	» 9	20.2
10	193.0	80.0	» 10	91.7
11	184.0	71.0	» 11	146.3
12	192.0	84.0	» 12	149.3
13	197.0	75.0	» 13	143.0
14	200.0	56.0	» 14—15	235.8
16	199.0	74.0	» 16	134.1
17	204.5	68.5	» 17	102.5
18	200.5	67.0	» 18	100.5
19	200.8	68.0	» 19	109.3
20	197.0	63.0	» 20—21	195.7
22	199.0	67.0	» 22	139.3
23	194.0	63.0	» 23	135.8
24	204.0	65.0	» 24	77.6
25	195.0	62.0	» 25	131.4
26	200.5	57.0	» 26	162.8
27	189.0	69.0	» 27—28	269.4
29	189.0	68.0	» 29	117.6
30	195.0	74.0	» 30	134.8
31	194.0	65.0	» 31	127.4

Sum for July 3298.9
Average 106.4 tons per day.

August 1929

Concentration			Load	
Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	191.0	67.0	Aug. 1	127.1
2	195.0	71.0	» 2—4	424.6
5	190.0	64.0	» 5—6	297.1
7	185.0	78.0	» 7—8	265.3
9	210.0	66.0	» 9—11	361.1
12	203.0	69.0	» 12—13	266.6
14	188.0	67.0	» 14—15	242.0
16	188.0	62.0	» 16—19	529.5
20	173.0	77.0	» 20	61.3
21	176.0	70.0	» 21—22	232.7
23	173.0	74.0	» 23—25	367.7
26	186.0	75.0	» 26—27	233.0
28	179.0	64.0	» 28—29	223.5
30	184.0	60.0	» 30—31	225.7

Sum for August 3857.2
Average 124.4 tons per day.

September 1929

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	184.0	60.0	Sept. 1	82.7
2	189.2	68.0	» 2—3	210.9
4	191.2	60.4	» 4—5	211.5
6	174.8	53.2	» 6—8	184.3
9	196.8	66.4	» 9—10	132.6
11	187.6	56.8	» 11—12	95.6
13	202.0	54.4	» 13—15	235.6
16	189.2	55.2	» 16—17	170.0
18	192.0	56.8	» 18—19	207.4
20	188.4	43.2	» 20—22	289.7
23	196.0	34.8	» 23—24	166.0
25	179.6	57.6	» 25—26	181.6
27	188.0	54.4	» 27—29	279.4
30	200.0	39.2	» 30	81.2

Sum for September 2528.5
Average 84.3 tons per day.

(Tab. 36, cont.)

October 1929

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
	200.0	39.2	Oct. 1	105.4
2	175.6	47.2	» 2—3	220.0
4	229.2	70.0	» 4—6	473.3
7	194.0	56.0	» 7—8	338.6
9	197.0	43.5	» 9—10	282.5
11	190.4	56.8	» 11—12	297.8
13	195.2	62.4	» 13—14	258.0
15	186.4	52.4	» 15—16	228.7
17	196.8	52.0	» 17—18	292.5
19	207.6	62.0	» 19—20	380.3
21	204.4	62.0	» 21—22	365.6
23	204.8	58.4	» 23—24	437.1
25	216.0	60.8	» 25—28	733.4
29	216.0	77.2	» 29—30	279.9
31	220.4	54.8	» 31	70.5

Sum for October 4763.6
Average 153.7 tons per day

November 1929

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
	220.4	54.8	Nov. 1	83.8
2	224.4	56.8	» 2—4	310.2
5	216.8	68.0	» 5—6	209.8
7	210.4	61.2	» 7—8	241.8
9	210.0	54.8	» 9—12	802.0
13	210.4	62.4	» 13—14	398.1
15	219.2	62.8	» 15—17	575.7
18	223.2	87.2	» 18—19	408.8
20	242.0	67.2	» 20—22	633.5
23	228.0	80.0	» 23—25	516.1
26	226.8	50.0	» 26—28	515.4
29	212.4	40.8	» 29—30	256.9

Sum for November 4952.1
Average 165.1 tons per day.

December 1929.

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
	212.4	40.8	Dec. 1—2	302.8
3	227.2	59.2	» 3—4	288.6
5	224.4	52.0	» 5—6	339.3
7	230.0	60.4	» 7—10	1029.4
11	234.0	56.4	» 11—12	594.4
13	244.8	63.2	» 13—15	937.0
16	240.0	68.4	» 16—17	574.4
18	258.8	63.2	» 18—20	930.2
21	244.4	65.2	» 21—25	1262.7
26	242.4	83.6	» 26—31	1773.9

Sum for December 8032.7
Average 259.1 tons per day.

January 1930.

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
	242.4	83.6	Jan. 1—3	1101.6
4	243.6	62.0	» 4—8	1757.4
9	243.6	42.8	» 9—12	1378.6
13	228.4	57.2	» 13—17	1405.0
18	224.4	40.8	» 18—22	1339.7
23	228.8	61.6	» 23—29	1678.3
30	232.8	63.6	» 30—31	442.5

Sum for January 9103.1
Average 293.6 tons per day.

February 1930.

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
	232.8	63.6	Febr. 1—4	879.0
5	243.2	62.4	» 5—11	1233.4
12	250.0	53.6	» 12—24	2317.7
25	254.8	58.0	» 25—28	535.0

Sum for February 4965.1
Average 177.3 tons per day.

(Tab. 36, cont.)

March 1930

Concentration			Load	
Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	(254.8)	(58.0)	March 1—4	561.4
5	256.0	62.4	» 5—9	849.3
10	232.4	50.4	» 10—14	915.6
15	224.4	38.8	» 15—19	851.1
20	250.8	60.0	» 20—25	1042.3
26	222.0	44.0	» 26—31	1118.2

Sum for March 5337.9
Average 172.2 tons per day.

April 1930.

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	222.4	44.8	April 1—4	747.5
5	222.0	39.6	» 5—16	1162.4
11	220.4	40.4	» 11—14	830.3
15	212.0	44.4	» 15—20	773.0
21	202.0	43.2	» 21—24	773.0
25	203.6	53.2	» 25—29	934.1
30	210.8	48.0	» 30	176.7

Sum for April 5357.0
Average 178.6 tons per day.

May 1930.

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	210.8	48.0	May 1—4	595.6
5	209.6	49.2	» 5—11	1092.0
12	204.4	60.0	» 12—16	566.9
17	210.4	56.0	» 17—20	530.8
21	207.6	72.0	» 21—26	566.8
27	196.8	56.0	» 27—31	518.6

Sum for May 3870.7.
Average 124.9 tons per day.

June 1930.

Concentration			Load	
Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	196.8	56.0	June 1	102.0
2	214.8	109.6	» 2—5	274.7
6	212.0	60.8	» 6—9	331.5
10	142.4	35.6	» 10—15	337.1
16	211.6	48.4	» 16—19	223.0
20	229.2	61.6	» 20—24	378.7
25	229.2	62.8	» 25—30	344.6

Sum for June 1991.6
Average 66.4 tons per day.

July 1930.

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	184.8	26.4	July 1—4	111.8
5	160.8	34.8	» 5—9	116.7
10	161.6	29.6	» 10—14	111.7
15	248.8	62.0	» 15—20	395.5
21	180.4	42.4	» 21—24	149.6
25	218.4	67.2	» 25—29	388.7
30	180.8	38.4	» 30—31	159.3

Sum for July 1433.3
Average 46.2 tons per day.

August 1930.

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	180.8	38.4	Aug. 1—4	245.3
5	156.8	54.8	» 5—9	395.6
10	134.4	42.8	» 10—14	1100.8
15	138.2	44.0	» 15—19	946.9
20	141.2	37.2	» 20—24	723.4
25	136.8	10.8	» 25—29	573.2
30	162.0	48.4	» 30—31	258.9

Sum for August 4244.1
Average 136.9 tons per day.

(Tab. 36, cont.)

September 1930

Date	Concentration Total mg/liter	Ignition loss mg/liter	Load Time	Tons
	162.0	48.4	Sept. 1—4	600.5
5	178.0	43.2	» 5—9	765.9
10	153.6	44.4	» 10—14	599.9
15	214.8	46.0	» 15—19	1254.6
20	203.6	35.6	» 20—24	1586.7
25	206.8	38.4	» 25—30	1679.5

Sum for September 6.487.1
Average 216.2 tons per day.

January 1931

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	238.0	50.4	Jan. 1—9	2547.8
10	243.6	47.2	» 10—14	1488.0
15	198.4	41.6	» 15—25	2939.8
26	208.8	39.6	» 26—31	1993.5

Sum for January 8969.1
Average 289.3 tons per day.

February 1931

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	208.8	39.6	Febr. 1—8	2321.8
9	246.4	68.0	» 9—28	5051.9

Sum for February 7373.7
Average 263.3 tons per day.

March 1931

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	246.4	68.0	March 1—8	1573.9
9	256.8	42.4	» 9—31	4777.0

Sum for March 6350.9
Average 204.9 tons per day.

April 1931

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
	256.8	42.4	April 1—3	625.7
4	210.8	44.4	» 4—30	10159.3

Sum for April 10785.0
Average 359.5 tons per day.

July 1931

Date	Concentration Total mg/liter	Ignition loss mg/liter	Load Time	Tons
1	220.0	38.4	July 1—31	3478.5

Average 112.2 tons per day.

August 1931

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
3	197.2	—	Aug. 1—31	3199.8

Average 103.2 tons per day.

September 1932

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
8	208.0	47.2	Sept. 1—15	1367.6
21	198.8	50.4	» 16—30	1286.5

Sum for September 2654.1
Average 88.5 tons per day.

October 1932

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
6	200.0	45.2	Oct. 1—31	4026.2

Average 129.9 tons per day.

November 1932

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	220.1	51.3	Nov. 1—30	7220.6

Average 240.7 tons per day.

December 1932

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
1	238.4	69.6	Dec. 1—31	7332.8

Average 236.5 tons per day.

February 1933

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
13	267.2	64.0	Febr. 1—28	6242.5

Average 222.9 tons per day.

September 1933

Date	Total mg/liter	Ignition loss mg/liter	Time	Tons
12	210.0	87.6	Sept. 1—30	2012.2

Average 67.1 tons per day.

(Tab. 36, cont.)

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
October 1933				
10	211.6	56.0	Oct. 1—31	1341.9
Average 43.3 tons per day.				
November 1933				
1	191.2	52.0	Nov. 1—30	1769.3
Average 59.0 tons per day.				
December 1933				
1	242.8	74.0	Dec. 1—14	725.8
15	263.6	74.0	» 15—31	646.8
Sum for December 1372.6				
Average 44.3 tons per day.				
January 1934				
1	242.0	62.0	Jan. 1—14	959.7
15	246.8	63.6	—	2765.7
Sum for January 3725.4				
Average 120.1 tons per day.				
February 1934				
1	289.2	75.6	Febr. 1—14	2031.4
15	266.0	66.4	» 15—28	2383.3
Sum for February 4414.7				
Average 157.7 tons per day.				

Date	Concentration: Total mg/liter	Concentration: Ignition loss mg/liter	Load: Time	Load: Tons
March 1934				
1	169.2	58.8	March 1—14	2754.2
15	241.6	67.2	» 15—31	5677.8
Sum for March 8432.0				
Average 272.0 tons per day.				
April 1934				
2	259.2	93.2	April 1—14	5117.2
15	180.0	51.6	» 15—31	3878.7
Sum for April 8995.9				
Average 299.9 tons per day.				
May 1934				
1	190.0	51.6	May 1—14	2510.0
16	210.0	58.8	» 15—31	2462.1
Sum for May 4972.1				
Average 160.4 tons per day.				
June 1934				
1	207.2	59.6	June 1—14	1632.7
15	216.8	59.2	» 15—30	1976.2
Sum for June 3608.9				
Average 120.3 tons per day.				

1. Maximum in contents of suspended material,
2. » » precipitation,
3. » » water-stage and discharge,
4. » » concentration of dissolved matter.

The total amount of material in solution transported by the river is very great; for the year July 1929—June 1930 58 thousands tons, which is 15 times as much as the transportation of suspended matter during the same time.[1] According to ERIKSSON transportation of large amounts of dissolved salts characterizes areas with lime in the ground, areas poor in precipitation and lakes, rivers with a very little slope and a low run-off percentage. All these qualities (except the latter) may be attributed to the Fyris river-basin. — In some other Swedish rivers (for instance in Västergötland and Skåne) the concentration of dissolved matter is, however, still greater than in the River Fyris.

Table 37.

The transportation of dissolved salts for different months (mean values).

January	9036.1 tons
February	5576.7 »
March	5367.8 »
April	8191.3 »
May	6433.3 »
June	3481.8 »
July	2954.9 »
August	3767.0 »
September	3420.5 »
October	3377.2 »
November	4647.3 »
December	5579.4 »
Year	61833.3 tons

The annual course is shown in Table 37. It is less marked, than that of the sedimentary load, but has the same trend. The maximum occurs, however here in winter, in accordance with the high concentration during this period.

In some parts of the river-basin the concentration is greater than at Uppsala. Thus, an analysis of a sample, procured at the little rill W. from Uvlunge in an area rich in springs, showed a concentration of 295.6 mg per liter. On this occasion, July 11, 1933, the discharge was very little.

The composition of the dissolved salts (HOFMAN-BANG, ERIKSSON) shows a very great percentage of lime, as mentioned above. The organic matter also forms a great part. The ignition loss was determined according to the directions of OHLMÜLLER-SPITTA (1921) and may be considered as giving a good picture of the contents of organic matter (O. ASCHAN, 1931). The percentage of organic matter amounts to 25—50 percent but with irregular variations. The maxima in spring and autumn, pointed out by ERIKSSON for other rivers in Sweden, are at any rate very little marked.

[1] The contents of salts in the precipitation was (by evaporation of 1250 cc.) determined to 6.1 (March 21, 1934), 1.1 (June 4) and 2.0 (May 12) mg/litre. About 3 % of the salts may, therefore, as a rough approcimation, originate from the precipitation.

The degradation of the Fyris river-basin.

From the foregoing sections it is obvious that, the River Fyris each year carries away from the drainage-area North of Uppsala sedimentary matter to an amount of more than 5500 tons per year and disolved matter to about 62000 tons, or together 67.370 tons. This forms per square-km. 56.1 tons per year. Expressed in volume of loose material with a specific gravity of 1.5, *the degradation per year amounts to a layer uniformly distributed, 0.037 mm. thick.* A volume corresponding to a layer, 1 m. thick, would be eroded in 27200 years.

Is the degradation of the Fyris river-basin great or little in comparision with that of other river-basins?

It seems to agree well with the values obtained or estimated for other rivers of the same character. It is somewhat greater than for the Elbe at Tetschen and the Seine at Paris (0.017 resp. 0.020 mm. per year, according to e. g. ERIKSSON and a little less than for the Maas at Liège, the Danube at Wien, and the Mississippi (0.050, 0.056 and 0.045). But the degradation of mountain rivers is much greater, often 10—15 times. (Sea HANS HESS, 1909, COLLET, 1925). The greatest known value, 0.50 mm. per year, is obtained for the Rio Magdalena in Columbia.

As the land rises somewhat more than 0.5 cm. per year the River Fyris is thus in a rising development, (»aufsteigende Entwicklung» according to W. PENCK, 1924). The rising takes place 130 times as fast as the degradation.

The process of erosion within the Fyris river-basin. The most remarkable feature concerning the degradation is the dominating influence of the chemical denudation.[1] The transportation of sedimentary matter only amounts to 8.2 percent of the total sum. Even if the water of the Fyris gives the impression of being particularly rich in silt the erosion of the river-basin is not great. The muddy appearance of the water depends on the high degree of dispersity of the particles.

The slope of the river being very little, the velocity of the water perhaps never reaches the value necessary for erosion. Though the material, which constitutes the soil is easily transported, when in motion, it is, like all such material, difficult to erode. The *Ancylus*-clay (size of particles 2 μ) is, according to Fig. 18 eroded only when the velocity increases to about 1.7 meter per sec., which is seldom or never the case.

The sedimentary material transported consists instead of weathering-products, loosened by various processes from the neighbouring particles and carried away by rain-wash, mainly, to the river. By the experiment, described on p. 239—243, it was found that the flow of rain-water is almost always turbulent. The transportation is thereby easily facilitated,

[1] This phenomenon is usual in areas covered by ice during the last glaciation.

Table 38.

Contents of silt in river-water from different places in the Fyris river-basin.

Place	Date	Silt		Dissolved salts	
		Total mg./liter	Ignition loss mg./liter	Total mg./liter	Ignition loss mg./liter
Kuggebro . .	Aug. 1, 1929	8.7	1.3	200	79
	» 2, »	9.3	1.9		
	» 3, »	8.1	2.5	209	69
	» 5, »	11.6	3.2		
	» 6, »	7.6	2.2	208	71
	» 7, »	12.0	2.4		
	» 8, »	16.1	3.1	208	81
	» 9, »	7.8	2.2		
	» 10, »	14.2	2.4	200	64
	» 12, »	19.8	4.0		
	» 13, »	17.4	3.5	208	83
	» 14, »	12.1	2.0		
	» 15, »	12.2	2.3	200	75
	» 16, »	14.1	2.5		
E. of Skyttorp	Aug. 15, 1929	3.0	0.6		
	Okt. 21, »	6.0	1.4		
	April 22, 1931	7.9	2.1		
	July 21, 1933	5.4	1.2		
	Aug. 6, »	3.4	0.9		
Åkerby . . .	Aug. 15, 1929	10.5	3.1		
	Oct. 21, »	45.2	10.0		
	April 22, 1931	80.5	12.1		
	July 21, 1933	12.5	4.6		
	Aug. 6, »	9.0	1.4		
Björklinge . .	Aug. 15, 1929	4.5	1.1		
	Oct. 21, 1929	18.1	6.1		
	April 22, 1931	50.8	12.9		
	July 22, 1933	10.0	4.1		
	Aug. 6, »	4.0	1.0		

and, the material being very fine, seems to be devoid of any upper limit. (This has been assumed in several theories for the explanation of the rounded hill-tops in humid regions).

An investigation into the signification of the rain-wash — or soil-erosion — is most suitably carried out in accordance with the plot-method.

See p. 225. As this method was excluded for several reasons, the writer made some simple determinations of the contents of suspended material in running water in ditches and furrows in the fields of the Uppsala-plain. The concentration of the silt in the samples varied considerably, but in all cases greater than in the Fyris-water. These determinations could, however, not be carried out systematically and, therefore, form no evident proof. The analyses are for these reasons not published here.

From the conclusions, occasioned by the variations in the silt-contents, p. 411, it is, however, evident that except during the cold and melting periods, the rain-wash is the most important factor in the degradation of the Fyris river-basin. The erosion-processes during the melting period is as a wash-phenomenon of the same character. — The great importance of the rain-wash in the degradation is no peculiarity for the Fyris, or even for rivers in plains generally. The washing-phenomenon, indicated by the strange appearance of the maximum in silt-contents, is found in all rivers investigated as to their transportation of sedimentary material. It is very marked even in mountain-rivers like the Rhen and the Rhône, where the slope and velocity are great. Hitherto, there is no river-basin investigated concerning its erosion, in which the river-erosion dominates over the other desintegrating processes, to such an extent that it is evident in the course of the silt-transportation. But, naturally, the intensity of the other processes would diminish, if their products were not carried away so rapidly by the running water.

Some analyses were made concerning the silt-contents at other profiles of the Fyris and its tributaries. Table 38 gives the results. During part of August 1929 samples were procured from the Sävja River at Kuggebro, 1 km. east of its mouth in the Fyris. The series was, however, interrupted as the water at the middle of the month was made dirty by dredging south of Fundbo. The silt-content is, as a rule, greater in the River Sävja for the short period, and the variations do not agree with those in the Fyris. For five days selected samples have been taken in the Vattholma River east of Skyttorp, where the river comes from a series of lakes, in a little rill near Ugglestad, east of Åkerby, from the plain, running through arable land, and in the Björklinge River at Björklinge, coming from marshes (though some of these are drained). The variations in the silt-content are greatest at the rill near Åkerby and least at Skyttorp, where the material is settled in the lakes to a great extent. The Björklinge River has intermediate values between these two, but the ignition loss is rather great here. — The Table indicates that the supply of the suspended material is greatest from the clayey planins.

Summary.

The investigation bears upon a determination of the rate of the mechanical and chemical denudation within the Fyris river-basin north of Uppsala in Central Sweden. The introduction deals with the morphological activity of rivers in general and the different methods (the sampling and the plot methods) for the determination of the rate of degradation.

In order to state the reason for the method of investigation as well as for the interpretation of the results there is given an account of the dynamics of streams (Ch. I) and some reflections upon the influence of the stream on solid material at the bottom and in suspension (Ch. II). — A short account of the falling of the water calls attention to the tendency of the water to spread out in drops, whereby the erosion is reduced. — The critical velocity for the transition from streamline to turbulent flow (or inversely) has an especially great interest as to the erosion and is the object for some experiments. It is shown that the increase in viscosity by adding silt to the water has almost no signification, compared to that of the temperature. The critical value of REYNOLDS' number for flow in thin water-sheets above sand, like the run-off of rain-water, is determined. The result is, that the $R_{crit.}$ is very low and that, therefore, the rain-wash is caused by water in turbulent motion (p. 233—243). As to the characteristics of turbulence treated at some length here, the pulsations, and their importance in erosion are especially noticed; the variations in the contents of silt in the case of erosion (p. 251—255) as well as without erosion (p. 388) have been examined, partly by means of the FALCK meter.

Chapter II gives an account of the theories of the influence of the hydrodynamic upthrust and the Austausch-process. The results in meteorology about turbulence are applied to streaming of water in a river. The equilibrium conditions, in regard to the distribution of silt have been examined. An experiment has been carried out in order to determine the Austausch-coefficient at different points of a cross-profile, and shows a very complicated distribution.

Chapter III discusses some problems of erosion, transportation and deposition. From old and new investigations a new curve is drawn, showing the relation between grain-size and erosion velocity. In a section about

erosion of solid rocks an attempt is made to show that besides evorsion and direct wearing by silt-laden water another, hitherto unobserved mode of erosion may exist, namely by cavitation-erosion. The agreement in appearance between the »Sichelwanne», described by LJUNGNER and the forms, caused by cavitation-erosion is pointed out. This mode of erosion may, in all probability, mainly have some affect below great ice-sheets with great hydrostatic pressure and in water-falls, where the velocity of the water is great. — The problem of transportation of different materials over a bed, consisting of a finer size of particles has been examined. The conclusion is, that only for a bed, consisting of special groups of material transportation of some material without erosion may exist. The stratigraphical significance of this conclusion is pointed out (p. 323—327). As to the transportation of bedload the problem of stability is applied to the motion of the bottom-layer. It is seen that the possibility of the occurrence of a bottom-layer with laminary motion is greatest in the case of erosion. The attempts to find a method for determining the amount of transportation of the bed-load brought about an examination of the mode of transportation along the bottom. The origin of the dune mode of traction is by laboratory-studies shown to be connected with the occurrence of pulsations. As to the wave-length it will be seen that there is a certain accordance with the results of research in the stability-problem, though these are not valid for streaming near a boundary. The presence of stream ripples in an unchanged form signifies equilibrium without erosion or deposition. The transportation of the sand as a uniform layer generally signifies erosion. — A short section deals with the capacity of a stream; it is suggested that a river with access to material of all grain-dimensions and the velocity necessary to erode them has no maximum-load of material transported. However, a stream which transports rolling matter without access to anything else can only transport a certain amount of this matter.

Chapter IV deals with the degradation of the Fyris river-basin. A summary of previous investigations in connection with the geographical, geological, climatological and hydrological conditions is given. An aspecially aggrevating circumstance for the present investigation was offered by the damming up of the Fyris-water by the Mälar lake; the rating-curve for the Uppsala Nedre gauge station is not reliable for low water-levels. The error caused by this circumstance, in the total sum of the material transported from the area concerned, however, only amounts to a few per cent. The method of investigation has demanded especially great care, as the material has a very fine grain-size, and partly consists of colloids. Different methods of procuring the samples are critically discussed. A practical method of analysis is worked out, based upon adsorption by asbestos.

For five years (July 1929—June 1934) analyses of water-samples have been carried out. It is seen that the River Fyris, on an average, each year carries away from the drainage-area north of Uppsala sedimentary matter to an amount of more than 5500 tons per year and dissolved matter to about 62000 tons, or together 57370 tons. Per sq.-km. this forms 56.1 tons per year. The variations in the contents of silt are put in relation to several, mainly climatological, factors. The erosion is mainly interfluvial, and caused by rain-wash. The spring flood at the melting of the cover of snow transports the greatest load of sedimentary matter but also the autumn rains cause transportation of large masses. The two other periods, the cold and the warm, have no great transportation. The mechanical and the chemical composition of the material have been examined.

List of references.

ACKERET, J. (1930): Experimentelle u. theoretische Untersuchungen über Kavitation. Techn. Mechanik u. Thermodynamik. Bd I. Berlin 1930.

—— (1931): Kavitation (Hohlraumbildung). In Handbuch der Experimentalphysik, herausgegeben v. *Wien* u. *Harms*. Bd 4, I Teil. p. 463—486. Leipzig 1931.

—— (1932): Kavitation u. Kavitationskorrosion. In Hydromechanische Probleme des Schiffsantriebs. Veröffentlichung der Vorträge u. Erörterungen d. Konferenz über hydromech. Probleme d. Schiffsantriebs 18 u. 19 Mai 1932 in Hamburg, herausgeg. v. *Kempf* u. *Foerster*. P. 227—240. Hamburg 1932.

AHLMANN, HANS W:SON (1914 a): Beitrag zur Kenntnis der Transportmechanik des Geschiebes und der Laufentwicklung des reifen Flusses. Sveriges Geol. Undersökning, Ser. C, n:o 262 (= Årsbok 8, nr 3). Stockholm 1914.

—— (1914 b): Ragundasjön. I. Morfologi. Sveriges Geologiska Undersökning. Serie Ca nr 12. Stockholm 1914.

ALLEN, J. (1934): Streamline and Turbulent Flow in Open Channels Phil. Mag. Ser. 7. Vol. 17. P. 1081—1112. London 1934.

ANDERSEN, S. A. (1931): Om Aase og Terrasser inden for Susaa's Vandområde og deres Vidnesbyrd om Isafsmeltningens Forløb. (With an English Summary). Danmarks Geologiske Undersøgelse. II Række. Nr. 54. København 1931.

ASCHAN, OSSIAN (1932): Om vattenhumus och dess medverkan vid sjömalmsbildningen. Kungl. Vetenskaps-Akademien, Arkiv för Kemi, Mineralogi och Geologi, Band 10 A. n:r 15. Stockholm 1932.

BAËFF, BONÉ (1891): Les eaux de l'Arve. Thèse Genève 1891.

BASCHIN, OTTO (1899): Die Entstehung wellenähnlicher Oberflächenformen. Ein Beitrag zur Kymatologie. Zeitschrift der Ges. f. Erdk. Berlin. Bd XXXIV, p. 408—424. Berlin 1899.

Bayerische Landestelle für Gewässerkunde (1929): Ermittlung der Schwemmstofführung in natürlichen Gewässern. Die Bautechnik 1929, Berlin 1929.

BENNDORF, H. (1930): Über die Bewegung fester Körper in einer Flüssigkeit mit Reibung. Physikal. Zeitschrift, Bd. 31, p. 593—610. Leipzig 1930.

BENNET, H. H. (1928): The geographical relation of soil erosion to land productivity. The Geographical Review, Vol. 18, p. 579—605. New York 1928.

—— (1933): The quantitative study of erosion technique und some preliminary results. The Geographical Review, Vol. 23, p. 423—432, New York 1933.

—— (1934): Dynamic action of rains in relation to erosion in the humid region. Transactions of the American Geophys. union, Fifteenth annual meeting 1934, Washington and Berkeley. Published by The Nat. Res. Council of the Nat. Ac. of Sc., p. 474—488. Washington 1934.

BEYERHAUS, E. (1916): Die wirbelige Fliessbewegung und das Voreilen treibender Schiffe. Zentralblatt der Bauverwaltung Jahrg. 36, p. 310—312. Berlin 1916.

BLASIUS, H. (1910): Über die Abhängigkeit der Formen der Riffeln und Geschiebebänke vom Gefälle. Zeitschrift f. Bauwesen. 1910, p. 466. With Atlas. Berlin 1910.

BOISSIER, RAOUL (1916): Le charriage des alluvions en suspension dans l'eau de l'Arve. Archives des Sc. physiques et naturelles, 4 période, t. XLI, p. 331—33. Genève 1916.

BORN, ARTUR (1928): Erhebungen über Sinkstoff- und Geschiebeführung in Flussläufen mit besonderer Berücksichtigung des Weichselstromes in seinem Unterlaufe. II. Baltische hydrolog. u. hydrometr. Konferenz Talinn June 17—21 1928. Talinn 1928.

BOUSSINESQ, J. (1877): Essai sur la théorie des eaux courantes. Memoires presentis par divers savants a l'Academie des sciences de l'Institut national de France. Tome XXIII. No. 1. Paris 1877.

BRAUER, RICHARD (1907): Die Grundzüge der praktischen Hydrographie. Bibliothek der gesamten Technik, 53. Band. Hannover 1907.

BRENNER, THORD (1931): Mineraljordarternas fysiska egenskaper (Deutsches Referat). Fennia 54. Helsingfors 1931.

BRUNHES, BERNHARD and BRUNHES, JEAN (1904): Les analogies des tourbillons atmosphériques et des tourbillons des cours d'eau et la question de la déviation des revières vers la droite. Annales de Geographie, XIII, p. 1—20. 1904.

BRUNHES, JEAN (1902): Le travail des eaux courantes. La tactique des tourbillons. Mém. Soc. Fribourgeoise des Sc. Nat. II Fasc. 4. Geologie et géographie. Fribourg 1902.

—— (1904): Nouvelles observations sur le role et l'action des tourbillons. Le Globe, Tome XLIII, p. 95—134, Genève 1904.

BUCKLEY, ARTHUR BURTON (1923): The Influence of Silt on the Velocity of Water Flowing in Open Channels. Min. of Proceedings of the Inst. of Civil Engineers, Vol. 216. P. 188—211 + discussion and correspondence 212—298. London 1923.

Bulletin mensuel de l'Observatoire météorologique de l'Université d'Upsala, Vol. LVII—LXVI par F. ÅKERBLOM (Vol. LXVI par F. ÅKERBLOM et H. KÖHLER). Uppsala 1925—1935.

BUTCHER, WALTER H. (1919): On Ripples and Related Sedimentary Surface Forms and their Paleogeographic Interpretation. American Journal of Science, Ser. 4. Vol. 47, p. 149—210, 241—269, New Haven 1919.

BÜDEL, A. (1933): Individuelle Bewegungen kleiner Luftmassen. Beiträge zur Physik der freien Atmosphäre, Bd XX, p. 214—219. Leipzig 1933.

BÖSS, PAUL (1927): Berechnung der Wasserspiegellage. Forschungsarbeiten auf dem Gebiete des Ingenieurwesens Heft 284. Berlin 1927.

CHALLINOR, JOHN (1930): The curve of stream erosion. The Geological Magazine, Vol. 67. London 1930.

CHAMBERLAIN and SALISBURY (1906): Geology, Processes and their results. 2:nd ed. London 1906.

CHATLEY, HERBERT (1921): Silt. Min. of proceedings of the Inst. of Civil Engineers. Vol. 212, p. 400—413. London 1921.

COLLET, LEON-W. (1916): Le charriage des alluvions dans certains cours d'eau de la Suisse. Annalen der Schweizerischen Landes-Hydrographie. Vol. II, Bern 1916.

Collet, Leon W. (1925): Les lacs. Paris 1925.
Cook, Stanley S. (1928): Erosion by Water-Hammer. Proc. Royal Soc. London. Ser. A. Vol. 119. P. 481—488. London 1928.
Cornish, Vaughan (1914): Waves of sand and snow and the eddies which make them. London 1914.
—— (1926): On rhytmic motion in rivers. A study in scenery. The Geographical teacher, Vol. 13. London 1925—1926.
—— (1934): Ocean waves and kindred geophysical phenomena. With photographs by the Author and Additional Notes by *Harold Jeffreys*. Cambridge 1934.
de Haller, P. (1933): Unters. über die durch Kavitation hervorgerufenen Korrosionen. Schweizerische Bauzeitung Bd 101. Zürich 1933.
de Martonne, Emm. (1913): Le climat facteur du relief. Scientia, Vol. XIII, Year VII., p. 339—355. Bologna 1913.
Demtchenko, Basile (1927): Forces pertubatrices agissant sur un corps qui se ment dans un liquide près d'une paroi. Comptes Rendus Acad. Sc. Paris. 185 p. 1186—1189, Paris 1927.
Devik, Olaf (1932): Trübungsmesser für Wasseruntersuchungen. Det Kongelige Norske Videnskabers Selskabs Forhandlinger Bd V. Nr 3. Trondhjem 1932.
Duley, F. L. and M. F. Miller (1923): Erosion and Surface Runoff Under different Soil Conditions. University of Missouri, College of Agriculture, Agricultural Experiment Station, Research Bulletin 63. Columbia 1923.
Ehrenberger, R. (1931): Direkte Geschiebemessungen an der Donau bei Wien und deren bisherige Ergebnisse. Die Wasserwirtsschaft, Jahrgang 1931, Wien 1931.
Erk, S. (1932): Zähigkeitsmessungen. In Handbuch d. Experimentalphysik, herausgegeben von *Wien* und *Harms*, Bd 4. 4 Teil. Leipzig 1932.
Exner, F. (1919): Zur Theorie der Flussmäander. Ak. d. Wiss. Sitz-Ber. Abt. II a. B. 128. II. Halbband. Wien 1919.
—— (1920): Zur Physik der Dünen. Ak. d. Wiss. Sitz-ber. Abt II a, Bd 129, p. 929—952. Wien 1920.
—— (1928): Dünenstudien auf der Kurischen Nehrung. Mit einem Anhang: Über Flussmäander, Wogenwolken und Zyklonen, die durch Reibungswalzen entstehen. Ak. d. Wiss. Sitz.-ber. Mathemat.-Naturwiss. Klasse, Abt. II a. Bd 137. Wien 1928.
Fage, A. and H. C. H. Townend (1932): An Examination of Turbulent Flow with an Ultramicroscope. Proc. Roy. Soc. Ser. A. 135, p. 656—677. Löndon 1931.
Falck, Olaf (1926): Einrichtungen zur Feststellung des Wirkungsgrades eiserner Zimmeröfen. Messungen kleiner Geschwindigkeiten strömender Medien. Diss. Techn. Hochschule Aachen 1926. Printed München 1927.
Faxén, Hilding (1921): Einwirkung der Gefässwände auf den Widerstand gegen die Bewegung einer kleiner Kugel in einer zähen Flüssigkeit. Diss. Upsala Univ. 1921.
Finger, Josef (1878): Über den Einfluss der Erdrotation auf die parallell zur sphäroidalen Erdoberfläche in beliebigen Bahnen vor sich gehenden Bewegungen insbesondere auf die Strömungen der Flüsse und Winde. Ak. d. Wiss. Sitz.-ber. Abth. II. Bd 76. Wien 1878.
Fischer, Josef (1913): Grösste Geschwindigkeiten in fliessenden Gewässern. Zeitschrift f. Gewasserkunde Bd XI, p. 71—74. Dresden 1913.
Forchheimer, Philipp (1930): Hydraulik. 3:e Auflage. Leipzig und Berlin 1930.

FOREL, F. A. (1901): Handbuch der Seenkunde. Stuttgart 1901.
FORSLING, C. L. (1931): A study of the influence of herbaceous plant cover on surface run off and soil erosion in relation to grazing on the Wasatch plateau in Utah. U. S. Dep. of Agriculture, Technical Bulletin No. 220. Washington 1931.
FORTIER, SAMUEL und HARRY F. BLANEY (1928): Silt in the Colorado River and its relation to irrigation. U. S. Dep. of Agriculture, Technical Bulletin No. 67. Washington 1928.
FORTIER, SAMUEL and FRED C. SCOBEY (1926): Permissible canal velocities. Trans. Am. Soc. Civ. Eng. New York, Vol. 89, p. 940—984. New York 1926.
FREEMAN, JOHN R. (1929): Hydraulic laboratory practice. Published by the American Society of Mechanical Engineers. Edited by John R. Freeman. New York 1929.
FÖTTINGER, H. (1926): Untersuchungen über Kavitation und Korrosion bei Turbinen, Turbopumpen und Propellern. Hydraulische Probleme p. 14—64. Berlin 1926.
GALLAY, RENÉ: Beitrag zur Kenntnis der Tonkoagulation. Kolloidchemische Beihefte, Band XXI. P. 431—489. Dresden und Leipzig 1925.
GESSNER, H. (1931): Die Schlämmanalyse. (Kolloidforschung in Einzeldarstellungen. Band 10). Leipzig 1931.
GIBSON, A. H. (1909): On the Depression of the Filement of Maximum Velocity in a Stream flowing through an Open Channel. Proc. Roy. Soc., Ser. A. Vol. 82, p. 149—159, London 1909.
GILBERT, KARL GROVE (1875): Report upon the geology of portions of Newada, Utah, California, and Arizona examined in the years 1871 and 1872. Geology of portions of New Mexico and Arizona, explored and surveyed in 1873.
Both in *Report* upon geogr. and geal. explorations and surveys west of the one hundredth meridian, in charge of *Geo M. Wheeler*. Engineer Department, U. S. Army Washington 1875.
—— (1914): The transportation of débris by running water. U. S. Geol. Survey, Professional paper 86. Washington 1914.
GLOCK, WALDO S. (1931): The development of drainage systems and the dynamic cycle. The Ohio Journal of Schience, Vol. XXXI, nr 5, p. 409—334, Columbus 1931.
GORKA, HELLMUT (1927): Neue Experimentaluntersuchungen über die Frostwirkung auf Erdboden. Kolloidchemische Beihefte, Bd XXV. P. 127—175. Dresden und Leipzig 1927.
GRANLUND, ERIK (1931): Kungshamnsmossens utvecklingshistoria. Sveriges Geol. Unders., Ser. C., nr 368 (= Årsbok 25, nr 1). Stockholm 1931.
GRIPENBERG, STINA (1934): A study of the sediments of the North Baltic and adjoining seas. Fennia, Bd 60, No. 3. Helsingfors 1934.
GRUNSKY, C. E. (1930): Silt transportation by Sacramento and Colorado Rivers and by the Imperial Canal. Trans. Am. Soc. of Civil Engineers, Vol. 94, p. 1104—1151. New York 1930.
HAHMANN, PETER (1912): Die Bildung von Sanddünen bei gleichmässiger Strömung. Diss. Leipzig 1912.
HAMBERG, H. E. (1905): Klimatet. Uppland, Skildring av land och folk. Utg. genom *Axel Erdmann* och *Karl Hildebrand*, Bd I, p. 65—78, Upsala 1905.
v. HANN, JULIUS (1932): Handbuch d. Klimatologie. Vierte Auflage von *Karl Knoch*, Bd I: Allgemeine Klimalehre. Stuttgart 1932.

HAURWITZ, BERNHARD (1931): Zur Theorie der Wellenbewegungen in Luft und Wasser. Veröff. Geophys. Inst. Univ. Leipzig, 2:e Serie, Bd V, Heft 1, p. 1—106. Leipzig 1931.

HAVELOCK, T. H. (1929): The Vertical Force on a Cylinder Submerged in a Uniform Stream. Proc. Roy. Soc. Ser. A. Vol. 122, p. 387—393, London 1929.

—— (1931): The Wave Resistance of a Spheroid. Proc. Roy. Soc. Ser. A, Vol. 131, p. 275—285, London 1931.

HESS, HANS (1909): Der Abtrag in den Schweizer Alpen. Petermanns Mitt. 1909, p. 360—362. Gotha 1909.

HETTNER, ALFRED (1928): Die Oberflächenformen des Festlandes. 2:e Auflage. Leipzig und Berlin 1928.

HJULSTRÖM, FILIP (1932): Das Transportvermögen der Flüsse und die Bestimmung des Erosionsbetrages. Geografiska Annaler 1932, p. 244—258. Stockholm 1932.

HOFMANN, ALBERT (1917): Über eine merkwürdige Oszillation des Rheinspiegels. Naturwiss. Wochenschr. N. F. Bd XVI. Göttingen 1917.

HOFMAN-BANG, O. (1903): Studien über Schwedische Fluss- und Quellwässer. Bull of Geol. Inst. Univ. Uppsala, Vol. VI, p. 101—159. Also as Diss. Uppsala 1903.

HOPF, LUDWIG (1910): Hydrodynamische Untersuchungen: Turbulenz bei einem Flusse. Über Schiffswellen. Diss. München 1909, printed Leipzig 1910.

HORTON, ROBERT E., H. R. LEACH and R. VAN VLIET (1934): Laminar sheet flow. Trans. of the American Geophysical Union, Fifteenth annual meeting April 26, 27, 28, 1934, Washington and Berkely, June 20, 21, 1934, Part II. P. 393—404. Washington 1934.

HOWARD, C. S. (1929): Suspended matter in Colorado River in 1925—1928. U. S. Geol. Survey, Water Supply Paper 636-B. Washington 1929.

HUMPHREYS, A. A. and H. L. ABBOT (1861): Report Upon the Physics and Hydraulics of the Mississippi River. Philadelphia 1861.

Hydrografiska Byrån. Årsbok och Årsberättelse. 1—6. Stockholm 1911—1917.

HÖGBOM, A. G. (1892): Studier öfver de glaciala aflagringarna i Upland. Geol. Föreningens Förhandlingar, Bd 14, p. 285—305, Stockholm 1892.

—— (1905): Land och vatten (= p. 3—64 i *Uppland*, skildring av land och folk. Utgiven av K. Hum. Vetenskapssamf. i Uppsala gm *Erdmann* och *Hildebrand*, vol. I) Uppsala 1905.

HÖRNER, N. G. (1927): Brattforsheden. (With an English summary.) Sveriges Geologiska Undersökning, Ser. C, nr 342, (= Årsbok 20, nr 3) Stockholm 1927. Also as dissertation from the University of Upsala 1927.

JAKUSHOFF, PAUL (1931): Bedeutung der Vegetation für die Geschiebeführung in Flüssen. Die Wasserwirtschaft Bd 24, Wien 1931.

—— (1932 a): Photoelektrische Methode zur Untersuchung der Schwebestoffführung in Wasserläufen. Wasserkraft und Wasserwirtschaft, Jahrgang 27, p. 152—155. München 1932.

—— (1932 b): Die Schwebestoffbewegung in Flüssen in Theorie und Praxis. Mitteilungen aus dem Institut für Wasserbau der Technischen Hochschule Berlin, Nr. 10. Sonderdruck aus der Zeitschrift Die Wasserwirtschaft, 25 Jahrg. Wien 1932.

JANDER, G. und J. ZAKOWSKI (1929): Membranfilter, Cella- und Ultrafeinfilter. Kolloidforschung in Einzeldarstellungen, Band 9, Leipzig 1929.

JEFFREYS, HAROLD (1925): The Flow of Water in an Inclined Channel of Rectangular Section. Philosophical Magazine, Series 6, Vol. 49, p. 793—807. London 1925.
—— (1929 a): On the Transverse Circulation in Streams. Proc. Cambridge Phil. Soc. Vol. XXV, p. 20—25. Cambridge 1929.
—— (1929 b): On the Transport of Sediments by Streams. Proc. Cambridge Phil. Soc. Vol. XXV, p. 272—276. Cambridge 1929.
—— (1934): See *Vaughan Cornish* 1934.
JOUKOWSKY, E. (1928): Le régime annuel du Rhône, de l'Arve, de l'Elbe et de la Meuse. Archives des Sc. Phys. et Nat., 5me Per. — Vol. 10., p. 347—362. Genève 1928.
JOUKOWSKY, N. F. och TSCHENTZOFF, N. G. (1925): Über Strömung des Wassers in offenen Kanalen und Strömung von Gasen in Rohren. Ber. der Zentralen Aero-Hydrodynam. Inst. in Moskau, Heft 1. Moskau 1925.
The writer has employed a summary by *A. B. Scherschevsky* in Z. f. angew. Math. u. Mech. Bd 7, p. 317—319. Berlin 1927.
JUNG, ERHARD (1931): Neue Fxperimentaluntersuchungen über die aggregierende Wirkung des Frostes auf den Erdboden. Kolloidchemische Beihefte Bd XXXII, p. 320—373. Dresden und Leipzig 1931.
v. KÁRMÁN (1930): Mechanische Ähnlichkeit und Turbulenz. Nachrichten von der Gesellschaft der Wissenschaften zu Göttingen 1930.
KAUFMANN, HENNING (1929): Rhytmische Phänomene der Erdoberfläche. Braunschweig 1929.
KAUFMANN, WALTHER (1931): Angewandte Hydromekanik I. Berlin 1931.
KIMBERLEY and HOMMAN (1906): The practical advantages of the Gooch crucible in the determination of the total and volatile suspended matter in sewage. The Journ. of Inf. Dis. Suppl. Nr 2. Chicago 1906.
KRAMER, HANS (1932): Modellgeschiebe und Schleppkraft. Mitt. Preuss. Versuchsanstalt für Wasserbau und Schiffbau, Berlin Heft 9. Berlin 1932. Also as dissertation.
KRAPF, PHILIPP (1919): Die Schwemmstofführung des Rheins und anderer Gewässer. Österreichische Wochenschrift für d. öff. Baudienst, Jahrg. 25, Heft 48—50. Wien 1919.
KREY, H. (1927): Die Quer-Geschwindigkeitskurve bei turbulenter Strömung. Z. f. angew. Math. u. Mech. Bd 7, p. 107—113. Berlin 1927.
KRÜMMEL, OTTO (1907): Handbuch d. Ozeanographie. Stuttgart 1907, 1911.
KURZMANN, SIGFRIED (1919): Beobachtungen über Geschiebebewegung. München 1919.
KÖHLER, HILDING (1929): Über den Austausch zwischen Unterlage und Luft. Erste Mitteilung. Gerlands Beiträge zur Geophysik. Bd 24, p. 94—116, Leipzig 1929.
—— (1932): Ein kurzes Studium des Austausches auf Grund des Potenzgesetzes. Beiträge zur Physik der freien Atmosphäre, Bd 19 (Bjerknes-Festschrift), p. 91—104. Leipzig 1932.
—— (1933): Meteorologische Turbulenzuntersuchungen. I. K. Svenska Vetenskapsakademiens Handlingar. 3:e serie. Bd 13, n:o 1. Stockholm 1933.
LAMB, HORACE (1932): Hydrodynamics. Sixth ed. Cambridge 1932.
LEIGHLY, JOHN B. (1932): Toward a theory of the morphological significance of turbulence in the flow of water in streams. Univ. of California Publ. in Geography, Vol. 6, No 1, p. 1—22. Berkeley 1932.
—— (1934): Turbulence and the transportation of rock débris by streams. The Geographical Review, Vol. XXIV, No 3, p. 453—464. New York 1934.

LENARD, P. (1904): Über Regen. Met. Zeitschrift. Bd 21, p. 249—262. Braunschweig 1904.

LEPPIK, EGON (1930): Untersuchungsmethoden der Sinkstoffe und des Geschiebes und deren Vereinheitlichung. III. Hydrologische Konferenz der Baltischen Staaten, Warszawa, Mai 1930. Herausgegeben vom Ministerium für öffentliche Arbeiten. Warszawa 1930.

LINDQUIST ERIC (1927): Om inverkan av vattnets strömart och ytspänningen vid flodbyggnadstekniska modellförsök. Teknisk Tidskrift Bd 57. Avd. Väg- och vattenbyggnadskonst p. 97—100. Stockholm 1927.

LJUNGNER, ERIK (1930): Spaltentektonik und Morphologie der schwedischen Skagerrak-Küste. Teil III: Lieferung I. Bull. Geol. Inst. of the Univ. Upsala, Vol. XXI. Upsala 1930.

LOWDERMILK, W. C. (1929): Further studies of factors affecting surficial run-off and erosion. Proc. of the Int. Congress of Forestry Exp. Stations Stockholm 1929. Rédigés par *Sven Petrini*. Stockholm 1930.

LUGEON, JEAN (1920): Contribution à l'étude des phenomènes d'ecoulement des cours d'eau. Résultats d'observations dans la gorge de la Jogue. Bull. Soc. Vandoise des Sc. Nat. Vol. 53, No 199, p. 215—257. Lausanne 1920.

LUGEON, MAURICE (1915): Le striage du lit fluvial. Annales de Géographie. Vol. 23—24. P. 385—393. Paris 1915.

LÜDERS, K. (1933): Unmittelbare Sandwanderungsmessungen auf dem Meeresboden. Veröff. d. Inst. f. Meereskunde Berlin. N. F. A. Heft 24. Berlin 1933.

LÜTSCHG, OTTO (1926): Über Niederschlag und Abfluss im Hochgebirge. Zürich 1926.

MATTSON, SANTE (1932): The laws of soil colloidal behavior: IX. Amphoteric reactions and isoelectric weathering. Soil Science, Vol. XXXIV, p. 209—240, Baltimore 1932.

MAYER, ROBERT (1928): Über Erosion. Mitt. d. Geograph. Gesellschaft in Wien. Bd 71, p. 299—330. Wien 1928.

MIYAGI, OTOGORO (1929): Measurements of Stream Veolocity by Air Bubbles. The Technology Reports of the Tôhoku Imperial University, Sendai, Japan. Vol. VIII, No 4, p. 117—130. Sendai 1929.

MURPHY, EDWARD CHARLES (1904): Accuracy of stream measurements. 2nd edition. U. S. Geol. Survey, Water-Supply and Irrigation Paper No 95. Washington 1904.

MÜHLHOFER, LUDWIG (1933): Untersuschungen über die Schwebstoff- und Geschiebeführung des Inn nächst Kirchbiehl (Tirol). Die Wasserwirtschaft Jahrgang 1933. Wien 1933.

NELSON, HELGE (1910): Om randdeltan och randåsar i mellersta och södra Sverige (With an English Summary). Sveriges Geologiska Undersökning Ser. C. N:o 220 (= Årsbok 3 (1909): N:o 3.) Stockholm 1910.

NEMÉNYI, PAUL (1933): Wasserbauliche Strömungslehre. Leipzig 1933.

NIKURADSE, J. (1926): Untersuchungen über die Geschwindigkeitsverteilung in turbulenten Strömungen. Forsch. Arb. Ing. Wes. Heft 281, Berlin 1926.

—— (1929): Untersuchungen über die Strömungen des Wassers in konvergenten und divergenten Kanälen. Forschungsarbeiten auf dem Gebiete des Ingenieurwesens, Heft 289. Berlin 1929.

—— (1931): Widerstandsgesetz und Geschwindigkeitsverteilung von turbulenten Wasserströmungen in glatten und rauhen Rohren. Verhandlungen des 3. internationalen Kongresses für technische Mekanik Stockholm Aug. 24—29, 1930, Stockholm 1931.

NIKURADSE, J. (1932): Gesetzmässigkeiten der turbulenten Strömung in glatten Rohren. Forschungsheftsheft 356. Berlin 1932.
—— (1933): Experimentelle Untersuchungen zur Turbulenzentstehung. Zeitschrift f. angewandte Mathematik und Mechanik, Bd 13, Berlin 1933.
O'BRIEN, MORROUGH P. (1933): Review of the theory of turbulent flow and its relation to sediment-transportation. Trans. Am. Geophys. Union April 27—29, 1933, p. 487—491. Published by Nat. Res. Council. Washington 1933.
O'BRIEN, MORROUGH P. and BRUCE D. RINDLAUB (1934): The transportation of bed-load by streams. Trans. Am. Geophys. Union, April 26—28 1934. Published by the Nat. Res. Council, Washington 1934.
ODÉN, SVEN (1916): Allgemeine Einleitung zur Chemie und physikalischen Chemie der Tone. Bull. of the Geological Institution of the University of Upsala. Vol. XV. p. 173—194. Upsala 1916.
—— (1919 a): Die Koagulation der Tone und die Schutzwirkung der Humussäure. Journal für Landwirtschaft, Bd 67. Berlin 1919.
—— (1919 b): Über die Vorbehandlung der Bodenproben zur mechanischen Analyse. Bull. Geol. Inst. Univ. Upsala, Bd XVI, p. 125—134. Upsala 1919.
ODÉN, SVEN und REUTERSKIÖLD, A. (1919): Zur Kenntnis des Ancylustons. Bull. Geol. Inst. Univ. Upsala, Bd XVI, p. 135—158. Upsala 1919.
OEHLER, P. (1930): Der Wasserstrahl und seine Auflösung in Tropfen. Techn. Mech. u. Thermodynamik. Berlin 1930.
OHLMÜLLER, W. und O. SPITTA (1921): Die Untersuchung und Beurteilung des Wassers und des Abwassers. 4:e Auflage. Berlin 1921.
OSEEN, C. W. (1931): Das Turbulenzproblem. Proceedings of the 3nd international congress for applied mechanics Stockholm 24—29 august. 1930, Vol. 1, p. 3—18. Stockholm 1931.
OSTWALD, WOLFGANG und F. PIEKENBROCK (1924): Beiträge zur kolloidchemischen Kennzeichnung technischer Tone und Kaoline I. Kolloidchemische Beihefte, Bd XIX, p. 138—170. Dresden und Leipzig 1924.
OSTWALD, WOLFGANG (1934): Über anomale Turbulenz bei Sohlen. Kolloid-Zeitschrift, Bd 68, p. 211—226. Berlin und Leipzig 1934.
OWENS, JOHN S. (1908): Experiments on the transporting power of sea currents. Geographical Journal *31* p. 415—425. London 1908.
—— (1911): Experiments on the settlement of solids in water. The Geographical Journal, Vol. 37, p. 59—79. London 1911.
PARDÉ, MAURICE (1933): Fleuves et Rivières. (Collection Colin, nr 155) Paris 1933.
PENCK, ALBRECHT (1894): Morphologie der Erdoberfläche. I, II. Stuttgart 1894.
—— (1934): Theorie der Bewegung der Strandlinie. Sitz-Berichte d. Preuss. Ak. d. Wiss. Phys.-Math. Kl., 1934, XIX. Berlin 1934.
PENCK, W. (1924): Die morphologische Analyse. Stuttgart 1924.
PIERCE, RAYMOND C. (1916): The measurement of silt-laden streams. U. S. Geol. Survey, Water-Supply Paper 400 C. Washington 1916.
POEBING, OSKAR (1922): Zur Bestimmung strömender Flüssigkeitsmengen im offenen Gerinne. Ein neues Verfahren. Berlin 1922.
PRANDTL, L. (1931): Abriss der Strömungslehre. Braunschweig 1931.
—— (1932): Meteorologische Anwendung der Strömungslehre. Beiträge zur Physik der freien Atmosphäre Bd 19. Bjerknes-Festschrift. Leipzig 1932.
—— (1933): Neue Ergebnisse der Turbulenzforschung. Zeitschrift d. Ver. Deutscher Ingenieure, Bd 77, p. 105—114. Berlin 1933.

Rehbock, Th. (1917): Betrachtungen über Abfluss, Stau und Walzenbildung bei fliessenden Gewässern und ihre Verwertung für die Ausbildung des Überfalles bei der Untertunnelung der Sihl durch die linksufrige Seebahn in der Stadt Zürich. Berlin 1917.
—— (1930): Bettbildung, Abfluss und Geschiebebewegung bei Wasserläufen. Zeitschrift der Deutschen Geolog. Ges. Bd 81, 1929. Berlin 1930.
Reynolds, Osborne (1894): Experiments showing the boiling of water in an open tube at ordinary temperatures. Papers on mechanical and physical subjects, Vol. II. Cambridge 1901.
Riabouchinsky, D. (1922): Recherche d'Hydrodynamique. Sur les équations générales du mouvement de corps solides dans un liquide incompressible. Thèses, Paris 1922.
—— (1931): Théorie cavitationelle de la résistance des fluides. Verhandlungen des 3. int. Kongr. für techn. Mechanik. Stockholm 1930. Teil I, p. 148—158. Stockholm 1931.
Rich, John L. (1933): Rock resistance and interfluvial degradation as dominant factors in geomorphology. Bull. Geol. Soc. America, Vol. 44, Pt 1, p. 97. New York 1933.
Richardson, Lewis F. (1920): The Supply of Energy from and to Atmospheric Eddies. Proc. Roy. Soc. London, Ser. A, Vol. XCVII, p. 354—373, London 1920.
Richardson, E. G. (1934): The transport of Silt by a Stream. Phil. Mag. Ser. 7, vol. XVII, p. 769—783, London 1934.
Rohr, Fritz (1934): Wasser- und Sinkstoff-Bewegungen in Fluss- und Seehäfen. München 1934.
Rubey, William W. (1933 a): Settling velocities of gravel, sand, and silt particles. American Journal of Science. 5th Ser., Vol. XXV, p. 325—338, New Haven, Conn. 1933.
—— (1933 b): Equilibrium-conditions in debris-laden streams. Transactions of the American Geophysical Union. 14th annual meeting Washington 1933. Published by the National Research Council of The Nat. Ac. of Sc. Washington 1933.
Ruden, P. (1933): Turbulente Ausbreitungsvorgänge im Freistrahl. Die Naturwissenschaften Vol. 21, Berlin 1933.
Rümelin, Th. (1913): Wie bewegt sich fliessendes Wasser? Dresden 1913.
Salomon, Wilhelm (1926): Die *Rehbock*schen Wasserwalzen und ihre Bedeutung für die Erosion und Akkumulation. Geologische Rundschau. Bd. XVII, Berlin 1926.
Sandegren, R. (1929): Interstadial varvig lera i Gefletrakten. Geologiska Föreningens Förhandlingar, Bd 51. Stockholm 1929.
Schaffernak, F. (1922): Neue Grundlagen für die Berechnung der Geschiebeführung in Flussläufen. Leipzig und Wien 1922.
Schlichting, H. (1933): Zur Entstehung der Turbulenz bei der Plattenströmung. Nachrichten d. Ges. d. Wissenschaften zu Göttingen. Math.-physikal. Kl. 1933, p. 181—208. Berlin. 1933.
—— (1934): Neue Untersuchungen über die Turbulenzentstehung. Die Naturwissenschaften Vol. 22, Heft 22—24. Berlin 1934,
Schmidt, Wilhelm (1917): Der Massenaustausch bei der ungeordneten Strömung in freier Luft und seine Folgen. Ak. d. Wiss., Sitz.-Ber. Mathem. naturw. Reihe, II a, Bd 126, p. 757—804. Wien 1917.
—— (1925): Der Massenaustausch in freier Luft und verwandte Erscheinungen. (Probleme der Kosmischen Physik, Bd VII). Hamburg 1925.

SCHOKLITSCH, ARMIN (1914): Über Schleppkraft und Geschiebebewegung. Leipzig und Berlin 1914.
—— (1930): Der Wasserbau I—II. Wien 1930.
—— (1935): Stauraumverlandung und Kolkabwehr. Wien 1935.
SCHÜRMANN, EUGEN (1916): Die chemisch-geologische Tätigkeit des Neckars. Diss. Tübingen 1916.
Sediment Investigations on the Missisippi River and its tributaries 1930—1931. War department, Corps of Engineers, U. S. Army. Paper U of the U. S. Waterways Experiment Station, Wicksburg, Mississippi, 1931.
SERNANDER, RUTGER (1920): En supralitoral havsstrandsäng från den äldre bronsåldern bevarad i det inre Uppland. Sv. Bot. Tidskrift, Bd 14, p. 330—340. Stockholm 1920.
Statens Meteorologisk-Hydrografiska Anstalt. Årsbok 1—16. Stockholm 1920—1935.
STINY, JOSEF (1926): Der »Schweb» der Mur (Steiermark). Zeitschrift f. Geomorphologie Bd I, p. 49—53, Leipzig 1926.
STOLPE, M. (1869): Några ord till upplysning om bladet »Upsala». Sveriges Geol. Unders. Ser. Aa, nr 31. Stockholm 1869.
STRAUB, L. G. (1932): Hydraulic and sedimentary characteristics of rivers. Trans. Am. Geophys. Union April 28 and 29, 1932, p. 375—382. Published by Nat. Res. Council. Washington 1932.
SUTTON, O. G. (1934): Wind Structure and Evaporation in a Turbulent Atmosphere. London Royal Soc., Proceedings, Ser. A, Vol. 146. London 1934.
SVEDBERG, THE (1928): Colloid Chemistry. Second Ed. in collab. with ARNE TISELIUS. New York 1928.
TAMM, OLOF (1920): Markstudier i det nordsvenska barrskogsområdet. Medd. fr. Statens Skogsförsöksanstalt, H. 17, N:r 3. Stockholm 1920.
TAYLOR, G. I. (1931): Effect of Variation in Density on the Stability of Superposed Streams of Fluid. Proc. Roy. Soc. London, Ser. A. Vol. 132, p. 499—523. London 1931.
THOMSON, SIR WILLIAM (1871): Hydrokinetic Solutions and Observations. The Philosophical Magazine, 4. Ser. Vol. XLII. London 1871.
THRUPP, EDGAR CHARLES (1908): Flowing Water Problems. Min. of proceedings of the Inst. of Civil Engineers. Vol. 171, p. 346—359. London 1908.
TOWNEND, H. C. H. (1934): Statistical Measurements of Turbulence in the Flow of Air through a Pipe. Proc. Roy. Soc., Ser. A. 145. London 1934.
TWENHOFEL, WILLIAM H. (1932): Treatise on Sedimentation. 2nd Ed. Baltimore 1932.
UETRECHT, ERICH (1906): Die Ablation der Rhone in ihrem Walliser Einzugsgebiete im Jahre 1904/05. Diss. Bern 1906.
ULLIK, F. (1880): Bericht über die Bestimmung der während eines Jahres im Profile von Fetschen sich ergebenden Quantitätsschwankungen der Bestandtheile des Elbewassers und der Mengen der von letzterem angeführten löslichen und undlöslichen Stoffe. Abh. d. kgl. böhm. Ges. d. Wissenschaften, VI. Folge, 10 Bd, Mathem.-naturw. Classe. Nro 6. Prag 1880.
WADELL, HAKON (1934 a): The coefficient of resistance as a function of *Reynolds'* number for solids of various shapes. Journal of the Franklin Inst. Vo. 217, p. 459—490. Philadelphia 1934.
—— (1934 b): Some New Sedimentation Formulas. Physics, Vol. 5, p. 381—391, Lancaster Pa. and New York, 1934.

WALLÉN, AXEL (1927): Eau tombée, débit et évaporation dans la Suède méridionale. Geografiska Annaler 1927, p. 181—208. Stockholm 1927.
—— (1930): Climate of Sweden. (Statens Meteorologisk-Hydrografiska Anstalt N:r 279). Stockholm 1930.
WEINIG, FRITZ (1931): Kavitation. In Handbuch d. Physikalischen und Technischen Mechanik, herausgegeb. v. *Auerbach* u. *Hort*. Bd V, p. 921—940. Leipzig 1931.
WELIKANOFF, M. (1932): Eine Untersuchung über erodierende Stromgeschwindigkeiten. Wasserkraft und Wasserwirtschaft. Jahrg. 1932, H. 17. München 1932.
WIEGERT, THURE (1893): Recherches sur le climat d'Upsal. Bull. Mens. de l'Obs. Mét. de l'Univ. d'Upsal par. *H. Hildebrand Hildebrandsson*. Upsala 1893.
WIMAN, ERIK (1930): Studies of some Archaean rocks in the neighbourhood of Upsala, Sweden, and of their geological position. Bull. Geol. Inst. Univ. Upsala, Vol. XXIII, Upsala 1930—32. Also as Dissertation Upsala 1930.
ÅKERBLOM, Filip (1908): Recherches sur les courants les plus bas de l'atmosphère au-dessus de Paris. Nova Acta Regiae Societatis Scient. Upsaliensis, Ser. IV, Vol. 2. N. 2. Upsala 1908.
Österreichisches Nationalkomitee (1930): Vorschläge für die Bestimmung der Feststoffführung der Gewässer. Gesamtbericht der II. Weltkraftkonferenz Berlin 1930. Bd XVIII. Berlin 1930.

Addenda:

DE GEER, STEN (1911): Klarälfvens serpentinlopp och flodplan. Sveriges Geol. Unders., Ser. C, N:r 236 (= Årsbok 4 N:o 8) Stockholm 1911.
EHRENBERGER, R. (1930): Wasserbewegung in steilen Rinnen. Z. d. Österr. Ing.-u. Architekten-Vereines, Bd 78, Wien 1926.
ERIKSSON, J. V. (1929): Den kemiska denudationen i Sverige. Medd. fr. Statens Met.-Hydr. Anstalt, Bd 5, N:o 3, Stockholm 1929.
EXNER, F. (1931): Zur Dynamik der Bewegungsformen. Gerlands Beiträge zur Geophysik, Supplementband I. Leipzig 1931.
FORBES, J. D. (1857): Contribution to a discussion about the delta of the Irrawaddy. Roy. Soc. of Edinburgh, Proc. Vol. III, p. 475. Edinburgh 1857.
GOLDSTEIN, S. (1931): On the Stability of Superposed Streams. Roy. Soc. Proc. Vol. CXXXII, Ser. A, p. 524—547, London 1931.
HAYASHI, KEIICHI (1926): Sieben- und mehrstellige Tafeln . . . Berlin 1926.
OSEEN, C. W. (1912): Über einen hydrodynamischen Satz von Herrn *M. Smoluchowski*. Arkiv f. Mat. Astr. o. Fysik, Bd 7. Stockholm 1912.
SCHOKLITSCH, ARMIN (1920): Über die Bewegungsweise d. Wassers in offenen Gerinnen. Ak. d. Wiss., Sitz.-Ber., math.-naturw. Kl. Abt II a, Bd 129, Wien 1920.
—— (1926): Energievernichter. Wasserkraft u. Wasserwirtschaft, Jahrg. 1926, p. 108. München 1926.
SCHRÖTER, H. (1933): Korrosion bei Kavitation. Z. d. Vereins Deutsch. Ing., Bd 77, p. 865—869. Berlin 1933.
—— (1934): Metallographische Unters. z. Frage d. Kavitationszerstörung. Ibid, Bd 78, p. 1161—1162. Berlin 1934.
TOLLMIEN, W. (1931): Turbulente Strömungen. Handb. d. Exp.-Physik, IV: I. Leipzig 1931.

APPENDIX

(TABLES)

Remarks concerning the Tables.

Temperature and precipitation are shown only for Uppsala, as being the best station within the river-basin. A star (∗) before the number of millimeter in precipitation indicates that the form of precipitation is other than rain, mainly snow. The mean temperature is — from the Bulletin de l'Observatoire de l'université d'Upsala — calculated from 8 to 8 o'clock, in order to correspond to the temperature conditions during the time which has passed since the foregoing sample was taken. All the climatological statements are valid for the time 8—8 and are dated when the sample was procured, which was influenced by these conditions.

The readings of the Uppsala gauge are to be obtained from the borough engineer at Uppsala.

In the column »Method» the letter A indicates the asbestos method as described on p. 394—397, B filtration through a Gooch-crucible and E indicates that no analysis was made and that the value given is estimated.

Remarks concerning Plates VI—VIII.

Plate VI is described on p. 343.

Plate VII is an abstract from the topographical and geological maps, very schematic. It only intends to give a picture of some general conditions, which have some bearing upon the degradation of the river-basin, and to give the situation of places, mentioned in the text.

Plate VIII is an abstract from the Tables. See the remarks corcerning these. The stems indicate the precipitation; white stems rain and black other forms, mainly snow.

July 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	0.1	+20.5	+10.4	13.4		81	6.5	4.9	1.9	A	3.9
2	1.5	+18.9	+12.3	15.0		78	4.9	6.0	2.8	»	2.9
3	1.5	+21.7	+ 7.7	15.0		77	4.3	19.1	4.0	»	8.2
4	0.1	+21.2	+12.4	15.6	2.1	76	5.1	11.1	0.5	»	7.0
5	1.5	+16.9	+11.6	14.5	0.4	74	4.3	23.5	4.4	»	10.1
6	1.5	+22.6	+12.5	16.6		74	4.3	8.0	3.7	»	3.4
7	1.5	+18.6	+ 6.3	12.8	6.5	70	3.2	9.2		E	2.9
8	1.5	+18.5	+10.3	13.7	9.5	63	1.0	10.3	2.6	A	1.3
9	0.1	+12.3	+ 9.7	10.5	28.5	70	1.2	27.4	5.1	»	3.3
10	1.0	+16.2	+ 9.4	11.5	3.5	81	5.5	24.0	7.1	»	14.5
	2.0							36.1	8.6	»	
11	1.0	+20.0	+11.4	15.0	6.1	84	9.2	37.8	8.0	»	38.3
	2.0							33.0	5.1	»	
12	1.0	+21.6	+14.6	18.1		85	9.0	22.8	5.2	»	22.6
	2.0							23.8	6.3	»	
13	1.0	+23.5	+11.2	18.4		84	8.4	19.1	4.5	»	17.6
	2.0							18,0	4.1	»	
14	1.0	+19.3	+ 9.1	14.3		80	6.3	22.4		E	15.5
15	1.0	+24.1	+13.5	17.3		80	7.3	25.6	4.1	A	20.6
	2.0							30.2	6.8	»	
16	1.0	+22.8	+ 8.9	15.5	0.4	78	7.8	12.3	3.9	»	10.6
	2.0							16.7	3.8	»	
17	0.0	+19.3	+ 9.3	14.5	1.0	75	5.8	10.1	2.3	»	7.2
	1.0							13,0	4.6	»	
18	1.0	+20.0	+ 6.8	13.0		75	5.8	20.7	4.4	»	13.2
	3.0							12.2	3.8	»	
19	1.0	+19.6	+ 8.2	14.4		74	6.3	12.6	4.6	»	8.7
	3.0							10.8	3.2	»	
20	2.0	+27.5	+15.1	20.6		74	6.3	11.6	4.3	»	6.6
	3.0							9.9	3.4	»	
21	1.1	+27.3	+15.1	21.1		72	5.2	16.9		E	9.7
22	1.0	+27.7	+17.2	22.3		73	8.1	20.2	5.6	A	18.0
	3.0							29.3	4.0	»	
23	1.0	+25.6	+15.3	20.4	3.9	73	8.1	18.1	3.6	»	16.1
	2.0							15.4	3.3	»	

July 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
24	1.0	+21.7	+11.6	15.9	0.8	72	4.4	9.8	5.5	A	4.7
	2.0							13.5	3.3	»	
	3.0							26.1	3.7	»	
25	1.0	+16.7	+10.3	13.2	6.2	72	7.8	10.6	5.9	»	9.1
	2.0							8.1	3.1	»	
	3.0							9.7	3.8	»	
26	1.0	+15.2	+ 7.7	11.3	8.9	72	9.4	6.5	5.8	»	6.7
	2.0							12.0	6.2	»	
	3.0							10.8	4.6	»	
27	1.0	+19.2	+10.8	14.6	1.5	70	8.9	14.4	7.3	»	14.1
	2.0							10.3	2.9	»	
	3.0							10.9	2.8	»	
28	1.0	+19.4	+10.9	14.3	1.2	68	7.6	12.8		E	10.7
29	1.5	+19.9	+ 8.9	14.8		67	7.2	14.7	3.8	A	10.6
	3.0							10.3	3.7	»	
30	0.0	+23.1	+11.1	15.8		66	8.0	6.9	2.3	»	
	1.5							9.0	2,0	»	7.2
	3.0							11.9	3.6	»	
31	1.5	+20.7	+ 9.9	14.8	2.3	65	7.6	24.6	4.3	»	18.7
			Sum for July		82.8						344.0

August 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	0.0	+21.1	+12.0	+16.1		65	7.7	9.7	2.3	A	
	1.5							18.7	3.2	»	14.4
	3.0							12.6	3.0	»	
2	0.0	+19.7	+13.8	+15.6	2.6	66	8.2	6.5	2.5	»	
	1.5							10.4	4.1	»	8.5
	3.0							12.3	4.2	»	
3	0.0	+18.8	+11.9	+15.2	5.7	67	8.9	5.6	2.0	»	
	1.5							15.3	4.5	»	13.6
	3.0							11.2	3.4	»	
4	0.0	+17.1	+10.9	+13.1	0.9	66	8.0	9.2		E	9.1
5	0.0	+19.0	+13.6	+15.6		66	9.9	12.8	1.7	A	
	1.5							14.2	4.3	»	14.1
	3.0							14.2	4.4	»	
6	0.0	+20.3	+12.9	+16.1		65	8.2	5.7	2.4	»	
	1.5							16.3	4.7	»	13.4
	3.0							16.4	2.9	»	
7	0.0	+18.6	+ 7.2	+13.8		63	8.3	5.5	3.8	»	5.7
8	1.0	+21.1	+ 9.8	+15.2		62	8.3	7.2	3.6	»	6.6
9	0.0	+22.4	+11.3	+16.0		60	6.6	8.1	4.8	»	6.6
10	0.0	+18.8	+10.7	+14.0	3.7	60	6.6	8.6	2.4	»	7.0
11	0.0	+19.8	+11.8	+15.5		58	6.7	6.8		E	5.6
12	0.0	+20.1	+15.4	+17.3		61	8.0	4.9	3.3	A	
	1.5							10.4	2.8	»	8.3
13	0.0	+21.1	+ 9.3	+15.2	0.2	58	7.2	7.2	1.7	»	
	1.5							18.6	4.1	»	13.4
	3.0							13.4	5.0	»	
14	0.0	+19.1	+ 8.1	+12.5	7.4	58	7.2	8.8	3.7	»	
	1.5							8.6	3.8	»	6.2
	3.0							6.4	3.3	»	
15	0.0	+18.1	+11.6	+14.6	8.4	59	7.7	4.4	2.8	»	
	1.5							11.4	4.4	»	8.8
	3.0							11.7	6.1	»	
16	0.0	+16.7	+ 9.2	+12.8		58	7.6	3.4	1.7	»	
	1.5							7.2	3.4	»	5.5
	3.0							11.6	3.9	»	
17	0.0	+18.4	+ 9.8	+14.2		57	7.7	5.3	2.8	»	
	1.5							9.8	3.3	»	7.5
	3.0							7.5	2.2	»	

August 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
18	0.0	+20.6	+13.6	+16.5	14.8	59	8.6	6.7		E	7.1
19	0.0	+20.0	+11.9	+15.2	0.1	58	8.7	8.1		»	8.7
20	0.0	+18.2	+ 8.4	+12.6	8.7	57	4.1	9.6	3.9	A	
	1.5							15.2	3.0	»	6.2
	3.0							14.6	6.2	»	
21	0.0	+16.6	+ 3.4	+ 9.7	0.2	55	7.6	6.7	2.8	»	
	1.5							12.2	4.3	»	9.3
	3.0							12.3	4.4	»	
22	0.0	+20.9	+ 7.6	+13.7		54	7.7	6.7	3.1	»	
	1.5							11.2	3.8	»	8.6
	3.0							8.7	4.5	»	
23	0.0	+16.9	+ 7.4	+12.0	6.6	53	7.6	9.5	5.4	»	
	1.5							13.1	5.6	»	10.0
	3.0							11.1	3.7	»	
24	0.0	+18.3	+11.9	+14.5	2.9	55	8.5	5.3	—	»	
	1.5							3.1	—	»	2.6
	3.0							8.0	4.7	»	
25	0.0	+19.1	+11.1	+15.2	1.7	55	8.5	5.4		E	5.6
26	0.0	+17.7	+ 8.1	+12.5	0.6	55	7.7	5.5	4.3	A	
	1.5							8.5	3.5	»	6.5
	3.0							15.0	4.2	»	
27	0.0	+18.0	+ 4.8	+11.6		52	6.7	10.7	2.4	»	
	1.5							11.6	2.8	»	7.8
	3.0							9.9	2.8	»	
28	0.0	+18.2	+ 3.6	+11.4		52	6.7	17.8	6.2	»	
	1.5							11.0	3.5	»	7.4
	3.0							12.9	3.2	»	
29	0.0	+17.9	+ 8.8	+12.6		51	8.0	8.8	3.3	»	
	1.5							10.1	1.7	»	8.1
	3.0							6.4	3.0	»	
30	0.0	+20.1	+12.2	+15.3	1.2	52	7.4	13.6	3.4	»	12.4
	1.0							10.7	2.7	»	
31	0.0	+20.2	+10.9	+15.2		51	6.8	6.8	3.4	»	5.7
	1.0							7.7	2.8	»	
		Sum for August			65.7						260.3

September 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	0.0	+18.9	+ 4.0	+11.8		47	5.2	6.0		E	3.8
2	0.0	+18.7	+11.7	+14.5	5.3	49	7.3	5.3	2.2	A	
	1.5							10.5	4.7	»	7.7
	3.0							24.5	5.3	»	
3	0.0	+19.3	+ 9.5	+15.3		49	5.6	10.8	3.6	»	
	1.5							20.0	2.8	»	11.2
	3.0							17.1	4.5	»	
4	0.0	+19.5	+ 8.3	+13.3	0.1	48	7.7	3.6	—	»	
	1.5							8.6	4.7	»	6.6
	3.0							7.8	4.3	»	
5	1.5	+18.3	+10.9	+13.8	1.0	47	5.1	7.4	4.2	»	3.8
	3.0							8.4	4.3	»	
6	0.0	+16.4	+10.2	+13.9	8.9	46	3.5	6.7	3.1	»	
	1.5							8.1	3.8	»	2.8
	3.0							10.1	3.1	»	
7	0.0	+13.4	+ 8.2	+ 9.7	2.3	45	7.3	12.0	2.4	»	
	1.5							12.2	2.7	»	8.9
8	0.0	+15.4	+ 3.0	+ 9.1		41	1.4	9.2		E	1.6
9	0.0	+11.3	+ 5.1	+ 7.7	2.3	45	4.8	6.3	2.1	A	
	1.5							8.2	3.0	»	3.9
	3.0							8.0	2.7	»	
10	0.0	+ 9.8	+ 6.0	+ 8.2	1.7	45	3.0	5.5	3.4	»	
	1.5							14.9	4.1	»	4.5
	3.0							14.8	3.7	»	
11	0.0	+12.4	+ 3.6	+ 8.2	0.6	44	2.4	6.9	1.4	»	
	1.5							7.4	3.2	»	1.8
	3.0							9.8	2.9	»	
12	0.0	+17.2	+ 5.7	+10.8		46	3.5	3.5	2.6	»	
	1.5							6.6	4.5	»	2.3
	3.0							18.5	3.3	»	
13	0.0	+19.8	+10.1	+14.2		48	4.6	5.4	4,0	»	
	1.5							9.0	2.2	»	4.1
	3.0							21.8	3.4	»	
14	0.0	+16.0	+ 8.8	+11.8		48	4.6	4.1	3.2	»	
	1.5							5.8	3.0	»	2.7
	3.0							8.8	3.8	»	

September 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
15	0.0	+21.7	+12.0	+15.2		47	4.3	4.1		E	2.2
16	0.0	+17.6	+ 9.2	+13.5		50	5.0	4.1	2.7	A	2.5
	3.0							8.0	3.5	»	
17	0.0	+15.4	+ 4.3	+ 9.7		50	5.4	5.1	2.8	»	
	1.5							9.5	5.0	»	5.1
	3.0							9.3	3.6	»	
18	0.0	+18.7	+ 4.6	+11.2		48	5.3	6.6	2.3	»	
	1.5							6.9	3.2	»	3.7
19	0.0	+14.3	+ 9.0	+11.0		50	7.2	4.0	—	»	
	1.5							9.4	3.7	»	6.8
	3.0							9.4	4.4	»	
20	0.0	+16.8	+12.1	+14.0	1.8	49	6.6	6.8	2.8	»	
	1.5							10.2	4.5	»	6.7
21	0.0	+13.9	+11.0	+12.4	9.5	50	6.1	2.5	0.8	»	
	1.5							8.0	3.5	»	4.9
	3.0							24.3	4.1	»	
22	0.0	+11.3	+ 1.2	+ 6.3	3.8	49	5.1	3.9		E	2.5
23	0.0	+13.3	+ 0.5	+ 5.8		49	4.7	5.2	3.3	A	
	1.5							6.4	3.1	»	3.0
	3.0							4.4	1.8	»	
24	0.0	+12.9	− 1.5	+ 5.2		49	5.1	4.3	—	»	2.7
25	0.0	+14.7	+ 7.0	+10.1		50	6.1	3.3	—	»	
	1.5							4.1	0.9	»	2.5
26	0.0	+13.9	+ 7.4	+11.4		50	5.6	3.7	1.2	»	
	1.5							19.4	3.6	»	10.9
27	0.0	+16.9	+ 8.4	+11.1		50	5.0	3.8	1.2	»	
	1.5							12.3	2.3	»	6.2
	3.0							4.0	1.6	»	
28	0.0	+14.6	+ 3.7	+10.2		49	5.6	4.0	1.3	»	
	1.5							7.3	1.7	»	4.1
	3.0							4.9	1.2	»	
29	0.0	+12.5	+ 9.9	+11.2		51	6.6	2.2		E	1.8
30	0.0	+19.3	+10.6	+14.7	0.3	50	4.7	3.2	1.2	A	
	1.5							8.2	1.6	»	3.9
	3.0							4.4	0.9	»	
		Sum for September			37.6						135.2

October 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	0.0	+14.3	+3.9		+ 9.0		50	6.1	4.1	0.8	A	
	1.5								1.9	1.1	»	1.2
	3.0								7.5	3.0	»	
2	0.0	+10.5	+2.1		+ 6.7	4.9	50	6.1	6.0	—	»	
	1.5								9.8	1.8	»	6.0
	3.0								8.1	1.8	»	
3	0.0	+ 9.7	+6.1		+ 8.2	6.9	54	8.4	5.1	1.5	»	
	1.5								6.0	1.1	»	5.0
	3.0								8.0	1.4	»	
4	0.0	+12.7	+6.4		+ 8.6	3.9	55	8.1	2.3	0.4	»	
	1.5								4.7	1.8	»	3.8
	3.0								4.3	1.7	»	
5	0.0	+13.0	+6.7		+ 9.2	0.1	54	8.7	4.7	1.1	»	
	1.5								3.8	0.9	»	3.3
	3.0								6.5	—	»	
6	0.0	+12.3	−0.8	4	+ 5.8		52	7.1	5.2		E	4.5
7	0.0	+11.0	+1.0		+ 8.4	1.1	54	10.3	5.7	4.0	A	
	1.5								5.2	1.3	»	5.4
8	0.0	+13.4	+8 4		+10.4	1.1	57	9.9	6.3	0.6	»	
	1.5								7.0	1.9	»	6.9
	3.0								6.3	0.8	»	
9	0.0	+13.3	+7.7		+10.1	5.3	54	8 3	3.0	0.6	»	
	1.5								3.6	1.2	»	3.0
	3.0								4.2	1.2	»	
10	0.0	+12.4	+8.2		+10.9	8.7	54	8.3	4.4	1.1	»	
	1.5								7.6	1.2	»	6.3
	3.0								7.5	2.4	»	
11	0.0	+ 8.6	+4.0		+ 6.7	2.1	60	9.1	22.8	2.5	»	
	1.5								26.3	3.3	»	23.9
	3.0								24.5	3.2	»	
12	0.0	+11.1	+3.2		+ 7.3	5.5	60	9 0	20.0	2.9	»	
	1.5								20.0	3.1	»	18.0
	3.0								18.6	2.9	»	
13	1.0	+ 9.8	+1.7		+ 6.2		61	7.1	19.3	3.1	»	15.1

October 1929 (cont.).

Date	Depth in m.	Temperature max.	min.	number of hours ≤0°	mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
14	0.0	+12.3	+1.1		+6.2		62	8.2	11.5	3.5	A	
	1.5								10.4	2.5	»	8.5
	3.0								20.2	2.2	»	
15	0.0	+11.6	+3.6		+8.8	7.2	65	4.9	7.1	2.6	»	
	1.5								9.9	1.3	»	4.9
	3.0								11.5	3.5	»	
16	0.0	+8.9	+0.7		+5.1		65	9.3	13.0	1.6	»	
	1.5								11.6	1.3	»	10.8
	3.0								11.4	2.8	»	
17	0.0	+6.8	−1.2	10	+1.9		64	8.9	3.6	—	»	
	1.5								10.4	4.8	»	9.3
	3.0								11.9	3.4	»	
18	0.0	+4.5	+0.9		+3.0	5.2	64	8.3	8.8	—	»	
	1.5								7.6	2.1	»	6.3
	3.0								10.1	4.3	»	
19	0.0	+4.5	+2.9		+3.7	2.8	65	9.3	7.5	2.2	»	
	1.5								8.6	2.3	»	8.0
	3.0								7.9	—	»	
20	0.0	+8.1	+2.9		+4.8	11.3	70	11.9	21.3		E	31.2
21	0.0	+3.5	+1.2		+2.2	0.5	76	8.7	35.1	11.5	A	
	1.5								39.9	5.5	»	34.7
	3.0								38.3	3.9	»	
22	0.0	+5.5	+1.0		+3.1		80	12.0	16.7	3.7	»	
	1.5								16.9	3.9	»	20.3
	3.0								17.2	2.3	»	
23	0.0	+10.0	+6.4		+8.3		82	11.7	12.4	1.3	»	
	1.5								9.9	1.7	»	11.6
	3.0								14.0	4.0	»	
24	0.0	+9.5	+6.8		+8.2		85	13.0	12.8	3.4	»	
	1.5								12.5	2.8	»	16.3
	3.0								11.6	3.4	»	
25	0.0	+10.7	+7.8		+9.4		83	12.4	7.7	1.1	»	
	1.5								9.1	1.4	»	11.3
	3.0								10.3	2.2	»	
26	0.0	+12.9	+9.0		+10.1	2.3	79	10.1	11.7	2.1	»	
	1.5								9.0	—	»	9.1
27	0.0	+10.0	+7.6		+8.6	2.5	80	8.9	10.0		E	10.9

October 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
28	0.0	+9.5	+4.1		+7.3	0.7	80	7.9	8.3		E	8.1
29	0.0	+5.7	+2.5		+4.7	0.4	80	7.9	6.7	—	A	
	1.5								6.4	1.8	»	5.1
	3.0								6.2	1.7	»	
30	0.0	+7.1	+3.6		+4.9	0.7	79	7.1	9.2	—	»	8.0
	3.0								6.8	1.9	»	
31	0.0	+5.8	+0.4		+3.0	0.3	78	3.7	7.9	2.2	»	
	1.5								4.2	2.9	»	1.6
	3.0								11.6	4.5	»	
Sum for October						73.5						318.4

November 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	0.0	+4.0	−4.2	12	−0.1		79	4.4	7.5	2.5	A	5.3	
	1.5								7.6	2.5	»		3.3
	3.0								8.3	3.0	»		
2	0.0	+2.9	−7.0	18	−3.3		79	6.1	7.1	2.3	»	5.8	5.3
3	0.0	+3.4	−3.2	13	−0.3		78	4.9	5.7		E		3.4
4	0.0	+3.9	+0.3		+2.4	1.9	80	5.0	3.9	2.1	A	5.0	
	1.5								4.8	—	»		2.4
	3.0								5.9	2.0	»		
5	0.0	+4.5	−0.5	7	+1.2		80	5.0	4.4	1.3	»	4.3	
	1.5								4.5	2.5	»		2.3
	3.0								4.8	1.4	»		
6	0.0	+8.7	+3.3		+6.7	3.8	82	6.2	5.2	2.1	»	4.0	
	1.5								5.6	1.9	»		3.5
	3.0								6.7	2.2	»		
7	0.0	+8.9	+1.7		+5.6	—	82	7.1	5.3	2.4	»	4.6	
	1.5								4.8	1.3	»		3.4
	3.0								8.4	1.5	»		
8	0.0	+6.4	+3.4		+4.9		82	6.2	5.1	1.4	»	5.0	
	1.5								4.5	2.4	»		2.8
	3.0								8.4	3.0	»		
9	0.0	+6.3	+4.1		+5.4	4.9	84	7.3	7.5	1.7	»		
	1.5								6.1	1.9	»		4.5
	3.0								7.7	1.9	»		
10	0.0	+6.6	+1.2		+3.3	—	84	7.3	8.7		E		7.8
11	0.0	+6.7	+2.7		+5.4		88	11.6	9.9		»		14.1
12	0.0	+7.0	+4.0		+5.4	2.0	97	18.0	11.2	2,0	A	8.8	
	1.5								15.5	2.0	»		27.9
	3.0								12.7	2.6	»		
13	0.0	+7.8	+4.2		+6.2	1.2	97	14.0	12.6	4.4	»	7.3	
	1.5								9.9	1.3	»		13.9
	3.0								9.6	2.2	»		
14	0.0	+5.2	−0.7	2	+2.7		85	7.9	9.9	1.1	»		
	1.5								10.3	2.0	»		8.1
	3.0								12.0	1.5	»		
15	0.0	+7.3	−0.3	2	+2.9	8.1	84	9.8	8.0	2.4	»		7.8

November 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipi-tation	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
16	0.0	+7.3	+3.7		+5.2	6.5	88	10.0	39.2	5.1	A	30.9	9.6
	1.5								42.1	3.9	»		42.1
	3.0								39.0	8.5	»		
17	0.0	+5.6	+1.1		+2.9	0.3	92	10.6	31.1		E		40.5
18	0.0	+1.8	−0.2	3	+0.9		93	11.3	23.0	2.4	A	19.2	
	1.5								23.4	2.9	»		26.4
	3.0								23.5	4.3	»		
19	0.0	+0.2	−3.8	23	−1.8		92	9.9	18.7	3.7	»	13.8	22.8
	3.0								19.0	2.1	»		
20	0.0	+0.1	−1.6	22	−0.8		92	9.9	12.5	1.7	»	9.4	
	1.5								12.1	2.1	»		12.0
	3.0								15.2	1.9	»		
21	0.0	+3.9	−1.6	13	+0.2		92	9.9	10.2		E		12.4
22	0.0	+6.0	+1.1		+4.4		93	10.5	7.9	—	A		
	1.5								8.9	2.2	»		9.3
	3.0								12.0	4.3	»		
23	0.0	+5.9	+3.5		+4.6	0.1	90	8.8	7.2	1.7	»	8.7	
	1.5								8.5	2.0	»		7.5
	3.0								8.7	2.1	»		
24	0.0	+4.5	+3.7		+4.1	0.8	90	8.8	7.8		E		8.4
25	0.0	+5.4	+4.9		+5.2	0.1	92	8.6	8.5	1.2	A		
	1.5								12.2	2.3	»		10.5
	3.0								8.9	5.1	»		
26	0.0	+6.0	+3.8		+5.0		93	9.8	6.9	1.0	»	6.2	
	1.5								8.8	1.6	»		8.6
	3.0								7.1	1.0	»		
27	0.0	+6.4	+5.3		+5.9	0.5	91	9.1	6.9		E		7.7
28	0.0	+6.3	+4.1		+4.7	0.3	90	7.4	6.9		»		6.3
29	0.0	+5.2	+3.7		+4.3	1.0	90	7.4	6.9	0.5	A	6.6	6.3
	3.0								8.8	1.2	»		
30	0.0	+4.7	+2.9		+3.4		89	6.6	9.6	0.3	»	5.0	7.8
Sum for November						32.3							348.7

December 1929.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	0.0	+4.3	+1.5		+2.8	0.8	88	7.0	8.6		E		7.4
2	0.0	+6.1	+1.5		+3.0		90	9.5	7.6		»		8.9
3	0.0	+6.9	+5.5		+6.0	0.3	90	7.4	6.6	2.3	A	6.8	
	1.5								8.4	3.0	»		6.2
	3.0								8.9	3.6	»		
4	0.0	+6.3	+1.9		+4.6	2.5	91	7.3	6.9		E		6.2
5	0.0	+5.1	+1.7		+2.7		92	8.7	7.2	—	A	6.1	
	1.5								8.6	1.0	»		7.5
	3.0								8.7	1.1	»		
6	0.0	+5.9	+5.0		+5.5	4.8	92	8.8	9.9	2.5	»	9.5	
	1.5								10.3	2.5	»		10.1
	3.0								9.6	1.9	»		
7	0.0	+6.8	+5.2		+6.1	3.5	96	10.2	14.3	5.0	»	13.0	
	1.5								15.8	2.4	»		16.1
	3.0								16.8	2.2	«		
8	0.0	+6.8	+5.3		+6.1	3.7	100	12.0	13.9		E		20.5
9	0.0	+7.4	+4.3		+5.6	1.9	103	13.9	13.5	2.1	A		
	1.5								14.6	2.9	»		20.3
	3.0								14.9	2.3	»		
10	0.0	+6.3	+2.4		+4.3	1.5	105	15.7	31.2		E		60.3
11	0.0	+5.0	+2.5		+4.0	8.5	108	14.6	48.8	—	A	43.0	
	1.5								56.1	4.6	»		81.9
12	0.0	+4.9	+0.8		+3.2	0.6	109	14.8	24.4	3.5	»	22.0	
	1.5								24.4	2.7	»		36.1
	3.0								26.7	2.8	»		
13	0.0	+5.1	+3.3		+4.5	2.4	109	12.7	27.4	2.3	»		
	1.5								16.8	2.4	»		21.3
	3.0								24.5	3.5	»		
14	0.0	+2.5	−0.2	3	+1.6	0.7	114	15.2	24.6		E		46.0
15	0.0	+7.2	+2.5		+4.2	7.8	118	16.4	21.8		»		44.0
16	0.0	+3.0	+0.7		+1.7		120	15.9	19.1	2.1	A	13.7	
	1.5								18.2	1.8	»		28.9
17	1.5	+2.1	−3.4	12	−0.2		114	11.8	19.2	2.9	»		22.7
18	1.5	−0.2	−6.2	24	−3.7		119	13.9	13.1	1.7	»	12.0	18.2
19	1.5	+1.4	−5.6	21	−1.2		120	14.4	11.4	3.7	»		16.4
20	1.5	+5.2	+1.4		+3.8		118	13.3	6.3	2.8	»		8.4

December 1929 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
21	1.5	+3.7	±0.0		+2.4	0.2	118	12.0	4.9	1.0	A		5.9
22	1.5	+2.7	−1.8	11	±0.0		116	12.2	6.6		E		8.1
23	1.5	+2.7	+0.9		+1.6	0.3	117	11.9	8.3	2.5	A		9.9
24	1.5	+0.9	−0.6	9	±0.0		118	12.3	7.9	2.0	»		9.7
25	1.5	−0.6	−6.2	24	−2.9	⁎1.5	118	11.4	7.4		E		8.4
26	1.5	+3.8	−5.7	14	−1.4	⁎6.2	122	13.0	6.9	2.4	A		9.0
27	1.5	+4.7	+3.2		+4.1	0.3	123	13.2	8.0		E		10.6
28	1.5	+2.9	−0.2	3	+1.7		123	13.1	9.2	2.5	A		12.1
29	1.5	+3.5	+1.8		+2.8	2.9	124	12.1	24.2		E		29.3
30	1.5	+4.7	+0.8		+3.1	8.9	129	14.6	40.1	3.3	A		58.5
31	1.5	+4.6	+2.6		+3.8	0.2	137	18.7	35.1	1.9	»		65.6
Sum for December						58.7							714.5

Remarks. Cover of snow at Uppsala Dec. 25. Till Dec. 17 the samples are procured from boat at Sandkällan, but from that date from the bridge at Fyrisbadet, North of Uppsala, fig. XX.

January 1930.

Date	Temperatur max.	Temperatur min.	Temperatur number of hours ≤ 0°	Temperatur mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/lit.	Ignition loss mg/lit.	Method	Load in tons/24 hours
1	+3.5	−0.6	7	+1.5		137	17.7	38.4	11.3	A	68.0
2	+1.6	−0.2	1	+0.8	✱0.9	136	17.8	24.9	7.6	»	44.3
3	+2.4	−0.5	3	+1.6	1.3	135	17.1	18.0	5.3	»	30.8
4	+5.5	+1.8		+3.6	2.7	135	16.2	12.0	1.8	»	19.4
5	+4.3	+0.7		+2.3	0.4	137	16.6	10.0	2.6	»	16.6
6	+4.1	+1.1		+2.7	0.5	136	17.4	14.6		E	25.4
7	+6.0	+2.6		+4.3	0.9	136	15.8	19.1	2.6	A	30.2
8	+8.3	+2.1		+6.3	0.2	137	17.5	11.6	2.2	»	20.3
9	+8.0	+2.1		+4.3		135	15.7	10.3	2.6	»	16.2
10	+3.4	+0.1		+2.3		137	16.1	9.8	3.4	»	15.8
11	+4.2	+0.6		+2.6		135	16.9	7.0	1.5	»	11.8
12	+3.9	+1.5		+3.1		134	16.8	6.5		E	10.9
13	+3.5	+0.4		+2.4	✱3.5	132	15.5	5.9	1.2	A	9.1
14	+1.6	−1.3	13	+0.1		130	13.9	5.9	1.3	»	8.2
15	+7.2	−1.2	3	+3.2	2.8	129	13.7	7.3	1.5	»	10.0
16	+8.3	+0.8		+6.1	1.5	129	13.7	13.1	2.1	»	17.9
17	+2.4	−3.3	16	−0.5		129	14.3	12.7	1.4	»	18.2
18	+1.4	−3.6	15	−0.7		130	14.8	9.2	4.9	»	13.6
19	+2.2	+1.0		+1.5	✱1.7	129	14.1	9.5		E	13.4
20	+5.4	+1.5		+3.9		129	14.2	9.9	2.8	A	14.1
21	+7.9	+2.8		+5.7		128	13.3	21.8	3.1	»	29.0
22	+4.1	−5.5	13	−0.5		126	12.7	5.8	3.0	»	7.4
23	+0.4	−5.4	19	−1.1		126	12.5	7.0	1.9	»	8.8
24	+1.2	−0.7	4	+0.6	✱0.8	126	12.5	4.4	1.2	»	5.5
25	+2.1	−0.6	2	+0.8	0.3	123	12.3	3.4	1.4	»	4.2
26	+2.4	+0.7		+1.4	✱0.1	122	12.2	5.7		E	7.0
27	+1.5	−0.3	4	+0.6		122	12.3	8.0	0.8	A	9.8
28	+3.6	−4.6	14	−1.0		120	12.0	1.5	0.5	»	1.8
29	+0.1	−3.6	22	−1.0	✱3.0	118	11.1	0.9	0.5	»	1.0
30	−0.1	−3.8	24	−2.4		118	11.2	4.0	1.7	»	4.5
31	−3.0	−4.2	24	−3.6	✱0.3	116	10.8	7.2	3.0	»	7.8
Sum for January					20,9						501.0

Remarks. Cover of snow at Uppsala January 29—31.

February 1930.

Date	Temperatur max.	min.	number of hours ≤ 0°	mean	Precipitation in mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silt mg/lit.	Ignition loss mg/lit.	Method	Load in tons/24 hours
1	−3.6	− 6.2	24	−4.5		112	12.1	5.0	2.1	A	6.1
2	−5.1	− 6.0	24	−5.5	✳1.5	108	10.1	5.0		E	5.1
3	−3.8	− 5.3	24	−4.6	✳0.5	110	11.9	4.9	2.2	A	5.8
4	−3.4	− 4.7	24	−4.1		107	9.6	7.1	2.3	»	6.8
5	−3.3	− 5.1	24	−4.2	✳2.0	106	9.1	8.4	2.7	»	7.6
6	−3.0	− 4.7	24	−3.7	✳5.8	105	8.3	5.6		E	4.6
7	−3.8	−15.3	24	−8.6	✳0.5	104	7.5	3.7	2.7	A	2.8
8	−5.5	−14.1	24	−9.1		104	8.2	10.5	5.7	»	8.6
9	−3.3	−13.8	24	−9.0	✳0.8	102	7.7	8.3		E	6.4
10	+1.5	− 8.0	5	−0.4	✳1.0	104	9.4	6.2	3.8	A	5.8
11	+2.9	− 0.5	4	+1.3		101	8.5	8.1	2.3	»	6.9
12	+3.9	− 0.5	1	+1.7		101	8.9	12.0	3.1	»	10.7
13	+4.6	− 1.9	5	+1.6		100	10.0	7.7	2.6	»	7.7
14	+3.5	− 1.8	16	+0.2		97	8.4	7.0		E	5.9
15	+3.5	+ 0.4		+2.4		97	9.7	7.0		»	6.8
16	+2.2	− 1.4	11	−0.6	✳4.5	95	8.8	7.0		»	6.2
17	−1.8	−10.4	24	−6.3		95	8.8	6.2	0.7	A	5.5
18	+0.3	− 9.2	23	−2.3		93	8.1	9.0		E	7.3
19	+5.5	− 4.9	14	−0.6		91	7.7	9.0		»	7.9
20	+4.2	− 7.4	17	−2.6		90	7.6	11.8		A	9.0
21	+3.7	− 8.2	19	−3.6		89	7.7	10.0		E	7.7
22	+2.7	− 6.3	18	−2.3		87	6.9	8.0		»	5.5
23	−1.0	− 7.1	24	−3.0		87	7.5	6.0		»	4.5
24	+3.6	− 6.3	17	−2.7		86	7.2	4.0		»	2.9
25	−2.5	− 5.9	24	−3.5	✳0.1	84	6.7	3.0	1.7	A	2.0
26	−0.8	− 2.6	24	−1.4		82	6.4	5.0		E	3.2
27	+0.3	− 2.9	21	−2.6		81	5.7	7.0		»	4.0
28	+2.2	− 4.2	16	−1.7		79	5.5	7.9		A	4.3
			Sum för February		16.7						167.6

Remarks. Cover of snow at Uppsala February 1—28 and of ice on the Fyris from February 2.

March 1930.

Date	Temperatur				Precipitation in mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silt mg/lit.	Ignition loss mg/lit.	Method	Load in tons/24 hours
	max.	min.	number of hours $\leq 0°$	mean							
1	± 0.0	− 3.3	23	−1.6		79	5.6	9.0		E	5.0
2	+ 8.4	+ 0.4		+2.6		77	5.8	11.0		»	6.4
3	+13.8	− 0.9	5	+5.4		78	7.3	13.4	2.0	A	9.8
4	+ 4.4	− 3.4	14	+0.2		76	6.8	8.8	1.3	»	5.8
5	+ 6.2	− 1.1	12	+1.4	✳ 0.1	75	6.5	10.7	2.7	»	7.0
6	+ 3.4	− 5.5	18	+1.5	✳ 0.1	74	8.5	11.5	2.6	»	9.8
7	+ 6.1	− 2.5	9	+1.5		74	8.5	7.3	1.6	»	6.2
8	+ 5.8	+ 1.6		+4.0		72	7.6	6.7	2.9	»	5.1
9	+12.1	+ 1.4		+6.4		71	7.3	16.0		E	11.7
10	+ 5.9	+ 1.7		+4.2	6.0	73	9.2	26.1	6.5	A	24.0
11	+ 7.1	− 5.8	12	+0.6	0.1	73	9.7	34.7	5.3	»	33.7
12	+ 4.2	− 3.1	16	−0.5		73	10.2	23.0	2.4	»	23.5
13	− 0.5	− 6.1	24	−3.3		71	8.2	17.7	6.2	»	14.5
14	− 0.4	− 9.3	24	−5.2		70	8.3	17.0	4.4	»	14.1
15	+ 0.5	− 8.7	20	−4.5		69	7.6	14.2	4.0	»	10.8
16	+ 3.2	−11.8	17	−4.1		68	8.7	12		E	10.4
17	+ 4.2	− 7.9	17	−3.0		68	9.2	10.3	3.2	A	9.5
18	+ 4.4	−10.4	16	−3.2		66	8.1	6.6	2.4	»	5.3
19	+ 1.7	− 3.1	14	−0.1	✳ 1.8	67	10.3	6.6	2.5	»	6.8
20	+ 4.4	− 3.0	7	+1.3	✳ 0.1	66	9.3	9.0	3.0	»	8.4
21	+ 6.4	− 1.3	11	+1.9	✳11.5	65	5.6	12.2	2.6	»	6.8
22	+ 3.6	± 0.0	1	+1.5	✳ 0.2	66	9.4	10.9	2.4	»	10.2
23	+ 4.9	− 1.0	7	+3.5	✳ 0.6	64	7.3	9.5		E	6.9
24	+ 6.7	− 1.1	8	+1.9		65	8.8	8.6	3.2	A	7.6
25	+ 6.1	− 4.8	12	+0.5		63	7.7	9.7		E	7.5
26	+ 7.2	− 4.2	12	+1.1		64	8.7	11.0	1.3	A	9.6
27	+ 7.2	− 1.8	9	+1.8	✳ 0.1	62	8.7	10.1	2.6	»	8.8
28	+ 3.8	− 1.8	11	+0.5		63	9.9	11.5	2.2	»	11.4
29	+ 6.3	+ 0.3		+2.7		62	10.0	11.0	3.5	»	11.0
30	+ 5.5	− 0.1	2	+1.9		64	11.3	11.0		E	12.4
31	+ 6.1	+ 1.5		+2.9	0.2	64	9.7	10.9	2.7	A	10.6
			Sum for March		20.8						330.6

Remarks. Cover of snow at Uppsala March 1 and 21—24. Breaking up of the ice on the Fyris Febr. 10, freezing over Febr. 13 and breaking up again Febr. 22.

April 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/lit.	Ignition loss mg/lit.	Method	Load in tons/24 hours
1	+10.7	−1.3	6	+6.6		63	9.9	8.8	3.0	A	8.7
2	−10.8	−6.1	11	+2.0		62	9.3	10.6	3.6	»	9.9
3	+ 8.0	−4.0	11	+1.5		62	9.9	9.4	3.5	»	9.3
4	+ 8.1	+0.2		+3.4		61	9.8	11.2	3.3	»	11.0
5	+ 8.9	+3.0		+5.2	0.1	61	10.6	9.9	3.5	»	10.5
6	+ 8.9	+3.5		+5.3	0.6	59	9.8	11		E	10.8
7	+ 7.4	+3.1		+4.7		62	11.0	12.2	3.4	A	13.4
8	+11.2	−1.9	8	+3.7		60	9.4	11.8	2.5	»	11.1
9	+12.9	−0.1	2	+5.7		60	9.9	10.2	3.2	»	10.1
10	+12.6	+0.7		+6.9		60	9.9	8.4	2.0	»	8.3
11	+16.1	+1.6		+8.5		60	9.9	21.7	2.8	»	21.5
12	+13.1	+2.3		+7.9	0.1	60	9.9	9.0	2.2	»	8.9
13	+11.8	+1.3		+5.9		60	10.9	8.0		E	8.7
14	+14.2	+2.6		+7.4		61	12.9	7.0	2.6	A	9.0
15	+10.2	+6.4		+7.7	1.1	61	11.5	10.2	2.8	»	11.7
16	+13.8	+2.5		+7.8		58	9.1	7.0	2.4	»	6.4
17	+14.5	+2.7		+6.7		54	6.9	6.9	2.3	»	4.8
18	+ 4.1	+1.0		+2.2	0.7	51	5.1	6.9		E	3.5
19	+ 2.3	−1.8	19	−0.7	⋇0.6	51	4.0	6.8	3.0	A	2.7
20	+ 1.3	−3.5	15	−0.7	⋇6.5	54	5.6	5.6		E	3.1
21	+ 1.8	−1.8	17	−0.3	⋇1.1	57	7.6	4.4	1.9	A	3.3
22	+ 5.9	+2.2		+4.0	0.7	58	9.2	4.6	2.9	»	4.2
23	+ 4.7	+1.5		+3.5	8.5	67	12.2	55.0	11.3	»	67.1
24	+ 9.2	−0.6	2	+4.8		68	13.0	27.2	8.2	»	35.4
25	+15.6	−1.4	4	+7.7		67	11.9	24.4	2.6	»	29.0
26	+14.4	−0.2	4	+6.9		66	11.3	14.8	2.4	»	28.0
27	+10.1	−2.9	8	+3.4		65	10.2	9.5		E	9.7
28	+14.4	+3.7		+8.7		66	10.7	4.1	2.1	A	4.4
29	+14.6	±0.0	1	+7.1	1.0	64	9.0	10.7	6.4	»	9.6
30	+12.3	+2.3		+7.3		64	9.7	4.1	2.0	»	4.0
			Sum for April		21,0						378.1

Remarks. Cover of snow at Uppsala April 20 and 21.

May 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+17.3	+ 0.7		+ 9.6		63	9.9	5.6	2.6	A	5.5
2	+20.5	+ 5.5		+12.7		61	7.6	5.2	3.1	»	4.0
3	+15.0	+ 1.8		+ 6.7	1.5	60	7.6	5.6	4.1	»	4.3
4	+17.4	+ 1.3		+ 9.8		58	7.6	5.2		E	4.0
5	+10.5	− 0.3	1	+ 5.6		59	8.1	4.8	3.2	A	3.9
6	+12.8	+ 1.5		+ 6.5		59	9.2	4.2	2.2	»	3.9
7	+13.1	− 2.1	5	+ 6.0		58	8.7	4.1	2.0	»	3.6
8	+12.5	+ 4.2		+ 7.5		56	7.6	9.0	3.1	»	6.8
9	+11.2	+ 5.4		+ 6.9	13.7	58	9.3	7.7	3.8	»	7.3
10	+14.9	+ 4.8		+ 8.6	0.4	58	8.7	5.3	2.5	»	4.6
11	+12.1	+ 2.9		+ 8.2		58	8.7	5.1		E	4.4
12	+16.4	+ 3.8		+10.5		57	7.7	4.9	2.4	A	3.8
13	+18.1	+ 1.4		+10.7		57	8.1	7.3	2.3	»	5.9
14	+16.3	+ 7.7		+11.4		53	6.0	5.2	3.7	»	3.1
15	+13.1	+ 0.5		+ 7.4		50	4.3	14.4	4.3	»	6.2
16	+12.8	− 2.8	6	+ 6.5		53	6.0	7.5	4.3	»	4.5
17	+18.5	+ 3.6		+11.6		53	7.4	9.2	3.1	»	6.8
18	+17.7	+ 6.3		+11.9	0.3	51	6.4	12.0		E	7.7
19	+18.8	+ 6.8		+13.5		52	8.0	14.9	2.5	A	11.9
20	+22.3	+10.1		+15.4		52	7.4	9.8	3.3	»	7.3
21	+16.8	+ 5.1		+11.1	1.3	52	7.4	11.6	6.7	»	8.6
22	+19.6	+ 9.3		+13.0		48	4.7	10.3	4.1	»	4.8
23	+20.0	+ 6.8		+13.0		48	4.4	9.9	3.3	»	4.4
24	+24.7	+ 9.9		+17.9		48	4.7	13.4	3.5	»	6.3
25	+25.8	+10.9		+18.1		48	3.8	12.3		E	4.7
26	+24.4	+12.4		+18.2		48	6.6	11.1	4.0	A	7.3
27	+20.4	+11.9		+15.1	0.3	51	7.4	17.2	4.4	»	12.7
28	+22.2	+10.3		+15.8		48	5.3	16.7	3.7	»	8.9
29	+17.4	+ 8.5		+13.4		50	4.9	21.5	6.7	»	10.5
30	+12.2	+ 8.7		+10.0	5.9	49	6.5	15.5		E	10.1
31	+12.5	+ 1.8		+ 8.2	0.6	47	6.4	9.5	3.2	A	6.1
				Sum for May	24.0						193.9

June 1930.

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	1.5	+20.5	+ 7.2		+13.5		46	6.0	7.0		E	4.2
2	1.5	+ 9.7	+ 4.2		+ 6.2	5.7	42	3.3	4.5	1.8	A	1.5
3	1.5	+10.6	— 1.9	6	+ 5.2		42	3.3	14.2	5.2	»	4.7
4	1.5	+14.6	— 1.7	5	+ 7.1		42	3.3	14.0	2.7	»	4.6
5	1.5	+21.0	+ 7.1		+13.5		44	4.9	10.6	2.1	»	5.2
6	1.5	+22.1	+10.1		+13.7		43	5.0	9.6	5.3	»	4.8
7	1.5	+21.5	+12.9		+16.4		44	5.9	19.5	4.5	»	11.5
8	1.5	+24.8	+ 8.8		+16.6	2.8	42	3.8	19.5		E	7.4
9	1.5	+18.2	+ 7.9		+11.6	8.2	41	3.4	15.0		»	5.1
10	1.5	+17.2	+ 9.4		+13.3		41	4.1	10.3	3.0	A	4.2
11	1.5	+21.6	+13.9		+16.9		44	6.4	11.9	3.2	»	7.6
12	1.5	+20.2	+11.2		+15.6	0.1	42	5.7	15.7	5.4	»	8.9
13	0.0	+22.3	+10.7		+17.1		41	4.8	13.3	3.4	»	
	1.0								15.4	—	»	8.1
	3.0								22.5	5.3	»	
14	0.0	+22.5	+10.1		+14.0	15.5	38	3.3	12.7	5.3	»	
	1.0								13.5	3.5	»	4.9
	3.0								16.4	3.2	»	
15	0.0	+19.0	+ 4.7		+13.2		38	3.1	11.3		E	4.3
16	0.0	+19.9	+ 4.2		+13.7		38	3.3	9.8	2.8	A	
	1.0								12.6	4.6	»	4.6
	3.0								18.5	4.2	»	
17	0.0	+24.3	+ 7.5		+16.4	3.2	38	3.1	11.3		E	4.3
18	0.0	+24.6	+ 8.5		+17.6		37	3.1	12.8	5.7	A	
	1.0								20.1	4.8	»	6.9
	3.0								26.1	6.5	»	
19	0.0	+27.0	+14.0		+20.4		36	2.7	11.6	6.2	»	
	1.0								19.9	4.7	»	5.9
	3.0								22.9	7.7	»	
20	0.0	+29.0	+13.1		+21.5		36	3.0	10.6	5.2	»	
	1.0								16.0	5.4	»	5.3
	3.0								25.6	7.9	»	
21	0.0	+31.2	+12.4		+22.3		36	3.2	9.1		E	3.6
22	0.0	+31.0	+16.5		+23.0		36	3.2	7.6		»	3.0
23	0.0	+27.1	+12.5		+18.1	3.5	34	2.6	6.0	2.6	A	
	1.0								10.7	3.7	»	3.1
	3.0								10.4	2.7	»	

June 1930 (cont.).

Date	Depth in m.	Temperature max.	Temperature min.	Temperature number of hours ≥ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
24	0.0	+28.7	+14.7		+22.0		34	3.0	7.5		E	2.8
25	0.0	+26.4	+16.7		+21.2	0.3	34	4.0	9.1	3.9	A	
	1.0								14.5	5.3	»	6.4
	3.0								15.1	4.4	»	
26	0.0	+23.6	+11.3		+16.5	1.1	36	3.3	11.1	5.1	»	
	1.0								13.7	4.3	»	5.0
	3.0								17.4	4.6	»	
27	0.0	+21.1	+ 7.5		+14.3	4.5	33	2.9	7.2	3.2	»	
	1.0								12.2	2.9	»	3.9
	3.0								16.7	3.9	»	
28	0.0	+24.4	+ 8.7		+16.8		32	3.4	9.3	4.2	»	
	1.0								13.1	5.2	»	4.9
	3.0								14.9	3.4	»	
29	0.0	+22.9	+11.6		+16.5	5.7	31	2.3	9.4		E	2.7
30	0.0	+17.4	+10.5		+12.7	17.2	28	1.5	10.0	5.2	A	1.5
					Sum for June	67.8						150.9

July 1930.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+23.3	+ 9.6	+17.3		28	1.6	13.3	2.4	A	2.1
2	+28.5	+13.3	+21.7		29	1.7	9.6	3.3	»	1.6
3	+29.6	+12.4	+22.2		29	1.8	12.4	4.3	»	2.2
4	+24.2	+ 8.4	+18.0		29	1.9	17.2	3.8	»	3.3
5	+27.1	+12.2	+20.4		29	1.9	6.5	3.2	»	1.2
6	+26.9	+11.5	+20.1		28	1.8	6.5		E	1.2
7	+27.1	+11.1	+20.2		28	1.8	25.7	13.6	A	4.6
8	+22.8	+12.5	+16.7	10.5	28	1.8	9.3	2.5	»	1.7
9	+19.6	+11.5	+14.4	18.0	27	1.1	10.1	2.7	»	1.1
10	+21.3	+13.0	+16.4	0.1	27	1.3	12.4	5.1	»	1.6
11	+25.7	+15.6	+20.9		29	1.5	9.5	2.7	»	1.4
12	+22.4	+12.6	+16.7	6.5	32	1.7	16.5	4.4	»	2.8
13	+24.3	+13.3	+15.8	34.3	33	1.9	13.8		E	2.6
14	+20.5	+10.8	+15.2	2.7	33	1.6	11.2	2.2	A	1.8
15	+19.7	+ 8.5	+13.8	3.0	38	2.2	7.2	2.7	»	1.6
16	+20.2	+ 8.1	+14.6	7.1	38	2.3	11.0	3.2	»	2.5
17	+21.1	+ 9.6	+16.3		42	4.2	12.6	3.0	»	5.3
18	+22.9	+ 9.7	+16.6	1.0	41	3.6	10.4	2.0	»	3.7
19	+22.8	+ 9.8	+16.9	0.6	40	4.2	10.7	2.0	»	4.5
20	+22.5	+17.3	+19.1	2.4	38	2.3	9.8		E	2.3
21	+21.3	+12.7	+17.0		39	2.8	9.0	2.0	A	2.5
22	+22.4	+17.0	+19.2	4.8	40	2.1	12.5	2.8	»	2.6
23	+22.0	+ 7.9	+16.2		41	2.3	9.6	3.4	»	2.2
24	+25.6	+12.1	+18.7		43	2.4	7.4	4.0	»	1.8
25	+27.4	+10.0	+19.3		44	4.0	6.7	3.0	»	2.7
26	+25.1	+10.6	+18.6		40	2.0	10.1	5.2	»	2.0
27	+26.3	+14.1	+20.0		44	4.0	8.6		E	3.4
28	+23.5	+14.0	+19.1		45	5.0	7.1	1.8	A	3.6
29	+21.5	+14.0	+17.2	0.9	46	5.6	8.5	2.1	»	4.8
30	+23.2	+ 9.6	+15.9	0.6	46	5.6	8.5	2.1	»	4.8
31	+22.4	+12.6	+17.3	0.1	45	4.6	8.4	4.6	»	3.9
			Sum for July	20.9						83.4

August 1930.

Date	Temperature			Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	mean								
1	+19.5	+11.2	+15.4	0.1	45	4.4	7.2	3.0	A	4.4	3.2
2	+21.4	+10.4	+15.3	0.2	44	2.8	8.6	2.6	»		2.4
3	+23.0	+10.1	+17.6		46	4.5	8.8		E		4.0
4	+24.2	+10.8	+18.2		45	4.0	9.0	3.4	A	5.8	3.6
5	+23.6	+14.1	+18.2	3.6	46	4.2	28.3	5.0	»		11.9
6	+20.4	+12.1	+16.6	3.4	47	4.4	28.0	4.4	»	23.8	12.3
7	+23.1	+12.5	+17.1		47	4.4	163.7	25.0	»		72.0
8	+18.1	+14.7	+15.8	22.9	55	7.6	237.7	19.6	»	174.3	180.7
9	+19.5	+13.6	+15.3	43.5	74	8.6	52.6	8.2	»		45.2
10	+18.6	+10.6	+14.0	8.5	87	19.0	45.4	6.3	»		86.3
11	+19.1	+ 8.0	+13.7	0.4	89	18.7	30.1	5.4	»	24.2	56.3
12	+21.1	+ 8.8	+14.9		89	18.7	26.4	3.8	»		49.4
13	+20.9	+ 7.5	+14.3		88	19.4	19.6	2.7	»	16.8	38.0
14	+19.3	+10.5	+14.4	2.0	88	19.0	13.0	2.8	»		24.7
15	+20.9	+10.2	+15.4		87	18.6	27.1	12.7	»	14.5	50.4
16	+19.5	+12.6	+15.6	4.5	84	17.6	14.2	5.0	»		25.0
17	+19.0	+ 9.1	+14.0	0.2	83	15.1	13.7		E		20.7
18	+18.5	+13.5	+16.2	7.0	83	14.5	13.2	4.8	A	8.2	19.1
19	+18.1	+14.4	+16.0	0.1	82	13.5	14.3	4.0	»		19.3
20	+21.8	+11.5	+16.5	✳0.1	82	14.4	15.9	4.0	»	12.1	22.9
21	+23.4	+13.7	+17.8	1.2	81	11.4	14.0	4.0	»		16.0
22	+18.0	+15.8	+16.6	5.8	79	10.7	13.9	4.8	»	8.9	14.9
23	+21.2	+11.7	+16.2	0.7	79	11.1	11.3	3.1	»		12.5
24	+18.9	+10.0	+14.3		79	11.7	11.2		E		13.1
25	+19.3	+11.0	+15.2		76	10.8	11.0	2.5	A	8.3	11.9
26	+21.1	+10.8	+14.9	0.5	74	8.2	7.3	2.4	»		6.0
27	+21.2	+ 8.9	+15.0		71	9.4	8.5	3.6	»	4.9	8.0
28	+21.7	+ 6.6	+13.5		70	10.2	11.4	3.1	»		11.6
29	+25.4	+10.3	+17.0		69	9.9	5.3	2.5	»	6.4	5.2
30	+26.5	+11.6	+17.8		68	9.2	8.2	2.6	»		7.5
31	+25.5	+13.1	+18.6		67	9.3	8.4		»		7.8
Sum for August				145.2							861,9

September 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤o°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+22.4	+10.2		+15.7	40.6	68	9.1	8.6	3.5	A	7.8
2	+17.2	+ 5.7		+11.0		72	10.8	33.4	4.8	»	36.1
3	+17.7	+ 8.2		+11.7	3.7	75	12.2	14 4	4.3	»	17.6
4	+15.6	+ 4.6		+ 9.3		72	10.8	10.0	2.7	»	10.8
5	+13.0	+ 4.4		+ 8.3	1.5	70	10.2	8.4	2.7	»	8.4
6	+13.2	+ 0.3		+ 6.3	1.4	70	10.4	5.6	2.2	»	5.8
7	+14.1	+ 6.6		+ 9.1	0.8	68	10.3	5.8		E	6.0
8	+13.6	+ 1.4		+ 7.5		67	9.8	6.0	2.0	A	5.9
9	+13.1	+ 4.9		+ 8.5	0.2	64	9.1	4.3	1.9	»	3.9
10	+11.7	+ 7.0		+ 8.8	3.0	63	8.0	4.9	2.1	»	3.9
11	+10.2	+ 6.2		+ 8.2	0.7	62	8.4	6.1	2.0	»	5.1
12	+11.5	+ 6.9		+ 8.7	0.1	61	8.0	6.7	2.3	»	5.4
13	+12.3	+ 7.0		+ 9.5		60	10.6	5.9	1.9	»	6.3
14	+12.7	+ 9.0		+ 9.9	0.1	57	10.2	7.7		E	7.9
15	+11.0	+ 9.4		+10.2	6.5	58	10.8	7.7	2.1	A	8.3
16	+13.4	+11.5		+12.5	9.3	58	9.4	21.3	4.3	»	20.0
17	+14.7	+10.7		+12.2	19.5	59	8.2	18.1	4.7	»	14.8
18	+10.9	+ 2.4		+ 6.7	6.5	83	19.8	66.8	6.1	»	132.3
19	+ 9.8	— 2.3	8	+ 3.6		86	19.4	9.8	2.4	»	19.0
20	+ 9.6	— 0.6	2	+ 4.5		82	18.4	14.3	3.4	»	26.3
21	+10.9	+ 7.7		+ 9.4	11.8	82	16.9	18.8		E	31.8
22	+13.3	+ 9.1		+11.1	0.6	86	17.7	23.5	5.0	A	41.6
23	+10.6	+ 5.8		+ 8.2	0.1	86	18.2	18.7	4.1	»	34.0
24	+12.4	+ 7.9		+10.1	0.3	87	19.0	14.5	3.0	»	27.6
25	+15.3	+11.6		+13.9		86	18.2	17.5	3.3	»	31.9
26	+15.5	+10.3		+13.3	1.2	85	18.0	8.2	2.8	B	14.8
27	+13.7	+ 5.6		+10.0	2.8	81	14.0	8.7	2.2		12.2
28	+13.1	— 0.6	4	+ 5.6		81	14.0	8.4		E	11.8
29	+15.0	+ 5.5		+ 8.8		82	14.4	8.1	2.7	B	11.7
30	+17.5	+ 8.1		+12.6	3.2	79	15.4	9.1	2.1	»	14.0
Sum for September					73.5						583.0

October 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+ 10.4	+ 0.6		+ 4.2	0.2	75	10.0	8.1	2.3	B	8.1
2	+ 7.5	— 3.2	9	+ 2.0		75	11.0	7.7	2.9	»	8.5
3	+ 10.6	+ 3.7		+ 7.7		74	10.6	6.7	2.7	»	7.1
4	+ 14.0	+ 1.7		+ 7.4		72	10.2	6.4	3.4	»	6.5
5	+ 9.3	+ 1.0		+ 4.6		69	11.0	5.5		E	6.1
6	+ 8.4	+ 6.3		+ 7.2	1.6	71	12.3	4.5	1.7	B	5.5
7	+ 6.2	+ 1.3		+ 4.1	1.8	66	8.0	5.8	1.6	»	4.6
8	+ 4.5	— 2.8	6	+ 1.0		68	8.4	5.4	2.1	»	4.5
9	+ 8.4	+ 3.0		+ 6.7	8.3	70	8.3	6.5	1.9	»	5.4
10	+ 9.3	+ 1.7		+ 4.8	7.3	75	2.5	23.8	3.1	»	6.0
11	+ 8.2	— 0.4	1	+ 3.2		80	9.0	18.5	4.3	»	16.7
12	+ 8.5	+ 0.9		+ 4.9		79	10.7	17.0		E	18.2
13	+ 10.3	+ 6.4		+ 7.5	0.8	81	13.6	15.5	3.4	B	21.1
14	+ 11.2	+ 5.1		+ 7.6	0.3	80	10.8	14.6	2.1	»	15.8
15	+ 11.8	+ 8.8		+ 10.5	0.3	80	10.8	8.5	2.3	»	9.2
16	+ 11.7	+ 10.4		+ 11.1	2.8	80	9.0	7.4	2.2	»	6.7
17	+ 15.5	+ 9.6		+ 12.0		82	10.6	10.3	2.8	»	10.9
18	+ 14.3	+ 7.1		+ 11.0		80	8.8	13.6	5.0	»	12.0
19	+ 13.3	+ 8.3		+ 11.3		81	8.8	11.0		E	9.7
20	+ 12.9	+ 3.2		+ 7.5	✳0.2	81	8.8	7.9	3.3	B	7.0
21	+ 10.9	+ 3.9		+ 8.2	✳0.2	80	9.6	7.2	4.1	»	6.9
22	+ 10.1	+ 8.3		+ 9.1	0.3	79	8.6	7.6	3.4	»	6.5
23	+ 9.6	+ 8.4		+ 9.3	4.8	81	8.2	9.2	5.0	»	7.5
24	+ 10.2	+ 8.2		+ 9.3	16.8	89	12.3	41.8	5.0	»	51.4
25	+ 10.4	+ 5.2		+ 7.8	0.6	95	14.0	38.7	6.1	»	54.2
26	+ 9.1	+ 4.6		+ 8.0	8.2	106	18.4	34.1		E	62.7
27	+ 8.2	+ 1.1		+ 4.3	✳0.1	105	16.9	29.5	4.5	B	49.9
28	+ 6.8	+ 3.5		+ 6.1	7.7	103	16.0	25.0	4.0	»	40.0
29	+ 7.3	+ 5.3		+ 6.2	✳0.4	109	18.4	21.3	2.4	»	39.2
30	+ 6.6	± 0.0	1	+ 3.9	0.4	110	19.2	20.6	5.1	»	39.6
31	+ 6.7	+ 2.5		+ 5.5	8.2	113	19.8	16.3	4.2	»	32.3
Sum for October					71.1						579.8

November 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+ 6.3	− 2.1	11	+ 1.2		116	19.4	14.2	3.1	B	27.7
2	+ 3.9	− 4.4	14	− 0.3		115	20.4	16.3		E	33.3
3	+ 7.5	− 1.8	2	+ 4.4	5.5	116	19.4	16.3	3.0	B	31.6
4	+ 9.5	+ 7.0		+ 8.1	5.7	123	24.0	64.7	8.3	A (3 times)	155.3
5	+ 9.1	+ 1.7		+ 6.1	0.4	129	26.2	21.3	2.4	A	55.8
6	+ 7.3	− 1.5	9	+ 1.5		129	25.2	24.3	4.5	»	61.2
7	+ 3.2	− 0.8	12	+ 0.4		127	25.8	17.9	4.7	B	46.2
8	+ 4.5	+ 0.7		+ 2.6		127	25.4	15.1	3.3	»	38.4
9	+ 5.6	± 0.0		+ 2.8	6.5	126	24.6	16.9		E	41.6
10	+ 8.5	+ 1.8		+ 5.1		127	25.4	18.7	6.6	B	47.5
11	+ 6.0	− 1.9	12	+ 1.2		127	23.3	15.2	2.8	»	35.4
12	+ 0.4	− 2.1	18	− 0.7		121	19.0	10.4	3.3	»	19.8
13	+ 8.3	± 0.0	1	+ 2.5	⁎2.1	123	19.4	10.3	2.5	»	20.0
14	+ 10.2	+ 4.1		+ 6.6	1.6	122	18.5	18.9	5.3	»	35.0
15	+ 5.0	+ 1.8		+ 3.5	1.6	120	16.6	9.7	3.0	»	16.1
16	+ 3.3	− 3.7	15	− 0.5		118	16.6	11.7		E	19.4
17	− 0.5	− 8.1	24	− 4.5		118	16.2	13.8	4.3	B	22.4
18	− 2.5	− 10.2	24	− 6.7		118	15.6	12.3	7.0	»	19.2
19	− 3.8	− 9.9	24	− 7.5		118	15.1	11.4	4.5	»	17.2
20	− 1.6	− 8.4	24	− 5.7		117	15.0	9.7	3.0	»	14.6
21	− 3.5	− 8.5	24	− 6.5		113	12.6	8.9	5.6	»	11.2
22	+ 3.7	− 5.8	6	+ 0.6	5.0	115	15.0	8.8	3.8	»	13.2
23	+ 4.3	+ 2.5		+ 3.2	3.9	112	12.4	32.6		E	40.4
24	+ 4.6	+ 0.7		+ 2.4	10.3	113	12.6	32.6	4.6	B	41.1
25	+ 1.4	− 0.3	8	+ 0.5	⁎0.2	116	14.2	20.3	5.7	»	28.8
26	+ 0.2	− 0.5	23	− 0.2		116	14.2	15.5	3,6	»	22.0
27	+ 5.4	+ 0.1		+ 3.8	⁎4.0	116	15.4	13.7	4.4	»	21.1
28	+ 6.2	+ 4.3		+ 5.2	4.6	128	18.5	41.1	6.0	»	76.0
29	+ 5.7	+ 1.8		+ 4.1		127	18.9	28.3	3.7	»	53.5
30	+ 5.0	+ 2.5		+ 4.1	4.4	133	20.0	36.3		E	72.6
		Sum for November			55.8						1137.6

Remarks. The Fyris was frozen over Nov. 20 and broke up Nov. 24.

December 1930.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+4.2	− 0.6	9	+1.0		138	22.3	44.2	4.2	B	98.6
2	+1.1	− 3.0	16	−0.9		134	21.1	21.3	2.9	»	44.9
3	+5.0	+ 1.3		+3.2	0.4	135	20.1	15.5	4.3	»	31.2
4	+5.4	+ 3.7		+4.6		135	21.0	12.0	2.3	»	25.2
5	+6.4	+ 2.6		+3.4	0.2	133	19.8	15.2	3.5	»	30.1
6	+5.9	+ 3.5		+4.9	0.4	131	18.2	6.4	3.4	»	11.6
7	+3.9	− 1.2	8	+1.2		130	18.6	8.8		E	16.4
8	+3.5	+ 1.4		+2.3	✳0.3	127	19.7	8.8	2.7	B	17.3
9	+3.1	+ 1.8		+2.2	0.8	126	17.2	11.3	4.3	»	19.4
10	+3.3	+ 2.1		+2.6	✳1.9	125	16.6	9.3	3.5	»	15.4
11	+3.5	+ 1.4		+2.5	✳0.2	124	16.0	29.2	5.4	»	46.7
12	+4.1	+ 0.9		+2.7	✳9.3	130	19.0	26.7	6.6	»	50.7
13	+3.7	+ 1.6		+2.3	1.3	133	20.2	26.2	3.7	»	52.9
14	+1.3	− 1.5	12	±0.0	✳1.0	134	21.0	18.1		E	38.0
15	−0.4	− 1.9	24	−1.2	✳0.2	132	19.8	10.0	2.6	B	19.8
16	−0.9	− 2.5	24	−1.6	✳4.8	129	18.6	10.2	2.3	»	19.0
17	−1.7	− 4.9	24	−3.0	✳1.7	127	17.2	10.3	2.6	»	17.7
18	−4.0	− 6.1	24	−5.1	✳0.4	128	16.2	8.3	3.1	»	13.4
19	−5.6	−11.8	24	−7.8		130	17.0	9.1	2.8	»	15.5
20	+1.7	− 5.2	10	−0.4	✳0.2	130	17.4	10.2	2.3	»	17.7
21	+3.9	+ 1.3		+2.4	✳0.1	127	17.2	9.5		E	16.3
22	+2.9	+ 0.3		+1.5	0.7	126	13.2	8.7	2.8	B	11.5
23	+0.6	− 4.4	17	−0.8	✳1.2	126	14.0	9.8	2.9	»	13.7
24	−0.8	− 7.2	24	−4.5	✳0.1	127	15.2	9.9	3.3	»	15.0
25	+0.1	− 3.3	23	−1.1	✳3.8	126	16.0	9.1		E	14.6
26	−1.5	− 4.6	24	−3.7	✳2.9	124	15.8	8.3	3.1	B	13.1
27	−1.8	− 4.0	24	−2.9		123	15.0	8.9	1.4	»	13.4
28	−4.6	− 7.1	24	−4.8		121	14.8	9.2		E	13.6
29	+1.7	− 2.7	11	−0.1	✳2.0	120	14.5	9.5	2.1	B	13.8
30	+2.8	+ 1.5		+2.1	0.8	121	16.5	9.7	2.8	»	16.0
31	+2.5	+ 0.7		+1.5	✳1.9	120	14.0	11.7	2.6	»	16.4
Sum for December					36.8						758.9

Remarks. Cover of snow at Uppsala Dec. 14—20 and 22—29.

January 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+2.4	−1.9	12	+0.5	0.2	122	17.2	11.0	2.0	A		18.9
2	+0.4	−1,6	20	−0.8	* 4.4	121	16.0	7.2	3.1	»		11.5
3	+0.5	−2.2	18	−0.8	* 1.2	120	14.3	2.3	1.0	»		3.3
4	−0.8	−2.9	24	−1.9		118	14.0	2.2		E		3.1
5	−2.7	−4.1	24	−3.4	* 1.3	116	12.8	2.0	0.5	A		2.6
6	−2.2	−4.6	24	−3.2	*18.5	115	12.0	3.0		E		3.6
7	−1.8	−6.4	24	−3.9	* 6.0	117	12.8	3.9	1.8	A		5.0
8	−3.4	−13.2	24	−7.4	* 0.5	115	12.0	5.5	2.4	»		6 6
9	−6.3	−9.7	24	−7.3		114	12.7	4.4	1.9	»		5.6
10	−2.0	−7.7	24	−5.7	* 1.6	113	12.8	4.3	1.4	»		5.5
11	−1.2	−4.2	24	−3.3	* 1.5	115	14.6	4.3		E		6.3
12	+0.2	−2.8	23	−0.9		116	15.0	6.3	1.3	A	4.8	9.5
13	−1.8	−5.9	24	−4.1	* 0.4	114	13.5	5.7		E		7.7
14	−4.7	−6.4	24	−5.5	* 0.5	115	14.8	5.1	1.2	A	3.9	7.5
15	−4.1	−10.4	24	−7.2	* 6.9	116	15.2	5.0		E		7.6
16	−1.5	−11.3	24	−4.9	* 0.6	117	16.2	4.9	1.1	A		7.9
17	−3.7	−11.2	24	−9.5	* 2.7	118	17.1	5.3		E		9.1
18	−1.4	−13.0	24	−7.4	* 2.2	118	16.7	5.7		»		9.5
19	−7.1	−12.4	24	−9.0		116	16.1	6.0	1.9	A	4.1	9.7
20	−7.8	−13.8	24	−11.2	* 0.6	112	14.7	6.3		E		9.3
21	−7.7	−19.4	24	−13.5	* 0.1	111	14.9	6.6	1.0	A	5.7	9.8
22	−8.7	−19.9	24	−12.6		109	16.0	6.5		E		10.7
23	−1.6	−9.8	24	−3.6		107	15.2	6.4	1.4	A		9.7
24	+1.3	−1.6	10	+0.2	* 0.2	105	14.4	6.5	1.4	»		9.4
25	+2.2	+0.5		+1.5	* 2.0	106	15.0	10.0		E		15.0
26	+2.3	±0.0		+1.0	* 2.5	111	17.2	13.4	1.8	A	10.6	23.0
27	+1.1	+0.1		+0.4	* 3.7	113	17.6	11.1		E		19.5
28	+0.8	−0.2	7	+0.2	* 2.4	117	19.4	8.8	1.5	A	7.2	17.1
29	+0.3	−4.1	21	−0.9	* 2.1	115	18.8	9.6		E		18.0
30	−4.1	−9.3	24	−7.2	* 0.1	116	18.9	10.5	1.9	A	8.4	19.8
31	−4.6	−8.5	24	−6.7	* 1.2	115	18.6	10.2		E		19.0
			Sum for January		63.4							320.8

Remarks. Cover of snow at Uppsala January 1—31. Cover of ice on the Fyris from Jan. 8.

February 1931.

Date	Temperature				Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	number of hours ≤ 0°	mean								
1	− 5.6	−10.9	24	− 7.2	✱0.2	112	17.2	9.9		E		17.0
2	− 2.7	−11.3	24	− 5.0	✱2.0	114	18.6	9.5	1.7	A	7.9	17.7
3	− 2.3	− 8.8	24	− 5.8	✱0.2	111	17.6	9.0		E		15.8
4	− 5.4	−11.1	24	− 8.1	✱0.5	108	16.0	8.5		»		13.6
5	− 4.2	− 7.5	24	− 6.3		106	15.5	8.0	1.9	A	6.1	12.4
6	− 4.9	− 9.8	24	− 7.3	✱0.4	105	14.8	8.1	2.0	»	6.2	12.0
7	− 9.5	−14.8	24	−11.2	✱0.1	104	14.2	8.0		E		11.4
8	−10.8	−18.0	24	−13.5	✱0.1	103	14.8	7.9		»		11.7
9	− 2.6	−14.0	24	− 5.8		104	15.9	7.7	1.5	A	6.2	12.2
10	+ 0.3	− 2.5	23	− 1.3		100	14.8	9.6		E		14.2
11	+ 1.6	+ 0.4		+ 0.9	5.0	98	13.2	11.5	1.9	A	9.4	15.2
12	+ 2.5	+ 0.4		+ 1.6		97	13.4	10.7		E		14.3
13	+ 2.5	− 1.5	9	+ 0.6	✱0.5	96	13.0	9.8	1.3	A	8.7	12.7
14	− 1.8	− 3.6	24	− 2.5	✱2.2	96	13.0	9.5	1.9	»		12.4
15	− 2.8	− 7.6	24	− 5.4	✱1.4	94	12.8	9.0		E		11.5
16	− 1.1	− 3.9	24	− 2.7	✱0.1	94	12.2	8.4	1.4	A		10.2
17	− 2.7	− 9.2	24	− 5.4	✱1.9	92	11.8	8.7		E		10.3
18	− 4.3	− 9.4	24	− 6.6	✱0.2	90	12.0	9.0	2.0	A	6.9	10.8
19	− 4.5	− 8.6	24	− 6.1		89	11.5	8.7		E		10.0
20	− 1.7	− 5.3	24	− 2.8		87	10.8	8.3	1.5	A	6.4	9.0
21	+ 1.0	− 1.8	13	− 0.4	✱0.2	87	10.8	7.9		E		8.5
22	+ 1.5	− 0.3	4	+ 0.5	✱1.4	85	10.0	7.6		»		7,6
23	+ 1.3	− 2.8	12	− 0.2	✱3.0	85	9.6	7.3	0.9	A	6.8	7.0
24	− 1.1	− 6.8	24	− 3.7		83	9.6	7.2		E		6.5
25	− 3.2	− 5.8	24	− 4.4	✱0.2	83	11.9	7.0	1.9	A	5.2	8.3
26	+ 0.6	− 2.9	20	− 1.3	✱9.0	83	10.6	6.1		E		6.5
27	+ 0.5	− 9.2	22	− 3.2	✱0.1	82	9.8	5.2	1.5	A	3.3	5.1
28	− 5.0	−11.9	24	− 8.5	✱0.9	82	10.2	5.3		E		5.4
	Sum for February				30.2							309.3

Remarks. Cover of snow at Uppsala and of ice on the Fyris February 1—28.

March 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	− 4.3	− 8.7	24	− 6.2	⁎ 0.9	79	9.0	5.4		E		4.9
2	− 8.0	−15.5	24	−12.0		81	10.2	5.5	2.6	A	4.0	5.6
3	− 5.2	−16.0	24	−11.5		77	9.2	6.1		E		5.6
4	− 4.5	−19.6	24	−10.8		78	10.4	6.8	2.0	A	4.5	7.1
5	− 5.8	−20.4	24	−12.7		75	8.8	7.7		E		6.8
6	− 3.3	−10.4	24	− 7.2	⁎ 1.2	74	8.3	8.6	1.8	A	7.2	7.1
7	− 4.4	− 7.0	24	− 5.6	⁎ 1.9	74	8.9	5.1	1.3	»		4.5
8	− 3.4	− 6.1	24	− 5.1	⁎ 0.9	73	9.1	5.5		E		5.0
9	− 5.1	−20.8	24	−12.4		73	9.1	6.0	2.4	A	3.4	5.5
10	− 2.0	−16.7	24	− 6.2		71	8.7	6.7		E		5.8
11	− 1.4	− 7.4	24	− 4.8	⁎ 3.5	70	8.2	7.4		»		6.1
12	− 4.7	− 8.2	24	− 6.0	⁎10.2	70	8.6	8.1		»		7.0
13	− 1.7	−17.0	24	− 9.4		72	10.0	8.8	1.0	A	7.4	8.8
14	− 5.3	−13.5	24	− 9.5	⁎ 0.1	71	10.2	8.2		E		8.4
15	− 1.5	−18.8	24	− 9.4		72	9.6	7.7		»		7.4
16	− 3.3	−13.3	24	− 7.8	⁎ 0.1	71	9.1	7.1	2.1	A	5.0	6.5
17	− 3.4	−17.9	24	−10.4		71	9.1	7.5		E		6.8
18	− 0.1	−10.0	24	− 6.0		69	8.5	7.9	1.5	A	6.8	6.7
19	+ 1.4	− 8.1	21	− 4.3		69	8.5	8.5		E		7.2
20	+ 4.9	− 8.4	16	− 2.3		68	9.0	9.0	3.0	A	5.3	8.1
21	+ 5.9	− 3.1	10	+ 1.0		68	9.3	9.0		E		8.4
22	+ 8.8	− 3.4	8	+ 2.3		66	8.2	9.0		»		7.4
23	+10.7	− 1.5	5	+ 4.0		70	10.5	9.0	2.0	A	5.9	9.5
24	+ 7.4	− 5.2	9	+ 0.7		68	9.7	10.8		E		10.5
25	+ 6.3	− 6.4	13	− 0.7	⁎ 0.1	65	7.4	12.6		»		9.3
26	+ 3.7	− 2.5	15	− 0.3		69	10.0	14.5	2.6	A	12.3	14.5
27	+ 9.7	− 0.8	2	+ 4.7		68	10.3	14.1	1.9	»	11.6	14.5
28	+ 5.9	− 6.0	9	+ 1.2	⁎ 0.3	69	9.9	8.8	2.3	»	7.0	8.7
29	− 1.2	− 8.4	24	− 5.0	⁎ 2.7	69	9.9	8.2		E		8.1
30	− 0.5	−16.2	24	− 8.1		69	10.2	7.6	1.6	A	10.8	7.8
31	− 0.2	−12.6	24	− 6.4		69	11.3	6.9	1.8	»		7.8
Sum for March					21.0							237.4

Remarks. Cover of snow at Uppsala and of ice on the Fyris March 1—31.

April 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contenis of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+ 4.3	−6.1	18	−2.3		68	9.4	7.0	1.8	A	4.9	6.6
2	+ 2.5	−7.9	15	−3.1		68	9.4	10.0	1.1	»	8.1	9.4
3	+ 2.5	−2.6	16	−0.5		68	9.4	10.6		E		10.0
4	+ 5.2	−2.3	13	+0.8		68	9.0	11.2		»		10.1
5	+ 2.4	−0.2	5	+0.8		66	9.8	11.8		»		11.6
6	+ 4.0	−0.6	5	+1.4	✱2.4	66	9.8	12.4	3.6	A		12.2
7	+ 2.9	−5.6	14	−1.3	✱0.2	66	8.2	15.9	4.7	»		13.0
8	+ 2.2	−7.4	17	−2.6		66	8.9	9.4		E	6.8	8.4
9	+ 2.6	−7.8	15	−2.5		65	8.4	10.4		»	7.9	8.7
10	+ 2.8	−4.8	18	−1.5		66	9.4	8.5	1.5	A	6.9	8.0
11	+ 2.5	−1.1	16	−0.2	✱0.1	66	9.4	8.9		E		8.4
12	+ 3.3	−6.3	15	−1.7		65	9.8	9.3		»		9.1
13	+ 7.9	−2.1	12	+1.3		70	10.0	9.6	0.4	A	6.6	9.6
14	+ 1.1	−2.7	15	−0.7	✱0.5	68	9.2	11.1		E	8.1	10.2
15	+ 3.5	−2.7	13	+0.3		69	9.6	11.3		»	8.3	10.8
16	+ 4.3	+0.7		+2.1		70	10.0	11.2		»	8.2	11.2
17	+ 5.5	−1.5	3	+2.5		77	13.0	21.0	2.5	A	17.9	27.3
18	+ 8.8	−2.4	12	+2.6		89	17.2	47.7	5.0	»		82.0
19	+ 6.2	−2.2	12	+1.3		99	19.8	45.9		E		90.9
20	+ 3.0	+0.3		+1.1	✱0.9	103	21.3	44.0	5.0	A		93.7
21	+ 3.0	+0.1		+1.7		107	22.2	77.2	11.3	»		171.4
22	+ 4.6	+0.2		+2.2	0.1	118	25.7	71.2	4.7	»	51.4	183.0
23	+ 3.3	+1.0		+1.8	✱6.5	135	31.1	47.1	4.5	»	24.6	146.5
24	+ 6.4	+1.4		+3.8	0.8	156	36.8	45.3	3.2	»	37.4	166.7
25	+14.0	−1.4	4	+6.5		170	40.8	129.9	5.1	»	121.9	530.0
26	+14.7	+2.2		+7.7	1.9	170	39.8	111.3	6.9	»		443.0
27	+12.2	+0.7		+5.5	0.1	176	41.8	58.4	3.4	»	31.6	244.1
28.	+ 7.1	+3.5		+5.3	4.1	178	40.7	30.0	3.0	»		122.1
29	+18.2	+5.9		+9.6	6.8	184	42.6	44.9	4.0	»		191.3
30	+11.3	+5.2		+8.1		187	43.5	39.5	4.5	»		171.8
			Sum for April		24.4							2821.1

Remarks. Cover of snow at Uppsala April 1—12, cover of ice on the Fyris April 1—11.

May 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+ 15.2	+ 2.9		+ 8.4		186	41.9	35.1	4.1	A		147.1
2	+ 12.8	+ 4.8		+ 7.7	8.0	184	40.7	23.1	4.9	»		94.0
3	+ 8.8	+ 5.0		+ 6.6	0.8	185	39.6	18.3		E		72.5
4	+ 9.1	+ 5.3		+ 7.0		184	38.9	13.6	8.8	A		52.9
5	+ 13.7	+ 6.0		+ 8.7	3.6	179	35.8	24.9		E	16.6	89.1
6	+ 15.9	+ 5.0		+ 9.8	2.2	180	45.3	22.9	7.8	A		103.7
7	+ 17.6	+ 3.9		+ 11.5		174	42.6	20.0		E	15.6	85.2
8	+ 18.0	+ 6.0		+ 11.9		172	41.4	10.3	1.1	A		42.6
9	+ 18.3	— 0.1	2	+ 8.9		166	42.4	10.1		E		41.8
10	+ 13.4	+ 3.3		+ 7.9		161	24.7	9.9		»		24.5
11	+ 10.1	— 0.7	2	+ 4.8		159	24.0	9.6	3.6	A		23.0
12	+ 14.1	+ 7.0		+ 9.2	0.6	156	21.8	9.2		E		20.1
13	+ 11.4	+ 5.7		+ 8.6	0.8	154	19.8	8.7	4.3	A		17.2
14	+ 18.8	+ 8.9		+ 13.3		154	19.3	9.6	3.2	»		18.5
15	+ 21.0	+ 10.9		+ 15.2	2.3	153	17.2	11.1		E	8.5	19.1
16	+ 15.4	+ 7.6		+ 11.6		152	16.7	10.1	2.0	A		16.9
17	+ 15.5	+ 8.5		+ 11.0	2.8	152	16.7	10.9		E		18.2
18	+ 16.9	+ 7.0		+ 12.0	2.2	152	17.0	11.8		»		20.1
19	+ 19.3	+ 11.0		+ 13.7	2.1	153	16.0	12.6		»		20.2
20	+ 17.1	+ 7.0		+ 12.1		153	15.2	11.2	2.8	A	9.6	17.0
21	+ 9.4	+ 2.4		+ 5.6		147	11.6	9.0		E		10.4
22	+ 9.9	+ 5.3		+ 7.4	0.1	148	13.7	6.8	2.1	A		9.3
23	+ 13.5	+ 7.5		+ 9.8	0.9	148	13.4	9.3	3.1	»		12.5
24	+ 11.9	+ 6.9		+ 9.5	1.1	150	14.0	6.0		E		8.4
25	+ 17.7	+ 7.6		+ 13.4		150	14.5	2.7	1.7	A		3.9
26	+ 23.7	+ 9.0		+ 16.7		150	15.0	5.7		E		8.6
27	+ 22.6	+ 8.7		+ 16.8		149	14.3	8.7	1.3	A		12.4
28	+ 23.0	+ 9.7		+ 16.8		148	14.3	9.2		E		13.2
29	+ 20.5	+ 9.7		+ 15.0		146	13.8	11.6	0.9	A		16.0
30	+ 14.1	+ 3.8		+ 7.4	10.1	145	13.5	11.3		»		15.3
31	+ 10.8	+ 5.3		+ 7.6		142	12.2	11.0		E		13.4
			Sum for May		39.2							1067.1

June 1931.

Date	Temperature			Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	mean								
1	+15.8	+ 7.3	+10.9	1.6	141	10.4	10.8	0.7	A		11.2
2	+19.7	+ 8.3	+12.8	0.5	140	13.4	13.3		E		13.8
3	+13.1	+ 7.0	+10.1	1.6	145	14.3	13.3	3.1	A		19.0
4	+11.3	+ 4.1	+ 7.1	1.1	141	12.2	10.3		E		12.6
5	+12.1	+ 2.2	+ 7.3		139	11.3	7.2	0.7	A		8.1
6	+ 8.8	+ 1.9	+ 5.6	0.6	136	10.0	7.4		E		7.4
7	+10.2	+ 3.6	+ 7.4		134	9.5	7.6		»		7.2
8	+11.5	+ 4.2	+ 7.5		135	13.0	7.7	2.2	A		10.0
9	+13.0	+ 0.9	+ 7.7	0.6	133	13.0	8.4		E		10.9
10	+16.8	+ 4.2	+13.6		132	12.4	9.1		»		11.3
11	+20.3	+10.8	+14.6		130	12.5	9.7		»	6.7	12.1
12	+16.0	+ 7.2	+11.3	0.2	126	10.2	8.2	6.1	A		8.4
13	+17.9	+ 8.0	+11.7	0.8	126	11.1	7.6		E		8.4
14	+18.4	+ 4.9	+12.1		123	9.6	7.0		»		6.7
15	+20.9	+ 5.9	+14.2		123	10.0	6.5	3.2	A		6.5
16	+22.5	+10.3	+15.7		121	9.2	6.6		E		6.1
17	+17.7	+12.9	+15.2	0.1	122	9.3	6.8	4.4	A		6.3
18	+21.7	+11.0	+16.5		120	10.5	5.8		E		6.1
19	+19.3	+ 8.9	+14.4	2.2	120	10.5	4.8	3.8	A		5.0
20	+19.4	+10.3	+15.0		119	11.3	8.2		E		9.3
21	+16.9	+ 7.5	+12.3	2.2	116	10.7	8.2		»		8.8
22	+18.4	+10.6	+13.5	0.9	115	11.4	8.2	3.1	A		9.3
23	+16.8	+ 8.5	+11.7	3.4	115	11.8	8.7		E	5.6	10.3
24	+18.7	+ 6.5	+13.7		110	9.2	8.2		»		7.5
25	+18.9	+ 7.3	+12.4	2.9	106	7.2	7.7		»		5.5
26	+18.4	+ 4.6	+12.7		104	8.0	7.2		»		5.8
27	+25.3	+10.9	+18.4		104	8.5	6.6	2.5	A	5.0	5.6
28	+24.2	+14.4	+18.2		104	8.5	7.2		E		6.1
29	+22.2	+10.2	+16.5		104	9.9	7.8		»		7.7
30	+20.2	+ 6.9	+13.2	1.1	101	8.7	8.3	2.0	A	5.8	7.2
Sum for June				18.2							260.2

July 1931.

Date	Temperature			Precipita-tion in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	mean								
1	+18.2	+10.2	+14.0		99	7.8	5.6	3.4	A		4.4
2	+19.6	+ 8.5	+14.1		96	6.3	5.6		E		3.5
3	+20.7	+10.2	+15.2		95	9.0	5.6	3.5	A		5.0
4	+21.0	+11.7	+16.2		92	7.4	6.2		E		4.6
5	+26.8	+13.1	+20.1		91	6.4	6.8		»		4.4
6	+28.5	+11.9	+21.4		89	6.1	7.5	2.6	A		4.6
7	+28.9	+14.6	+21.7	0.6	86	4.3	8.6		E		3.7
8	+20.7	+15.4	+17.7		84	4.7	9.7	7.1	A		4.6
9	+25.9	+14.0	+18.3	1.9	87	12.0	9.4		E		11.3
10	+17.0	+11.9	+13.3	11.0	90	4.6	9.1		»	6.1	4.2
11	+20.4	+13.6	+16.5	1.2	87	5.2	7.8	2.0	A		4.1
12	+21.5	+13.9	+16.3	9.1	85	4.5	8.7		E		3.9
13	+24.2	+12.6	+16.7		85	5.8	9.6	3.4	A		5.6
14	+23.4	+11.4	+16.9		84	6.8	9.9		E		6.7
15	+23.7	+13.6	+17.9		80	4.3	10.3	6.2	A		4.4
16	+20.0	+13.5	+16.3	0.9	80	4.5	9.7		E		4.4
17	+18.3	+13.7	+15.0	10.5	82	5.8	9.2	1.6	A		5.3
18	+19.4	+13.5	+16.0		83	6.7	11.4	1.9	»		7.6
19	+19.8	+10.4	+14.2	4.5	82	6.8	10.0		E		6.8
20	+18.1	+12.5	+14.4	0.8	80	4.8	8.7		»	5.7	4.2
21	+19.9	+ 8.4	+14.0	0.1	80	4.8	8.2	2.3	A		3.9
22	+19.1	+12.2	+14.8		78	6.2	8.8		E	3.2	5.5
23	+21.2	+10.0	+15.1	0.8	78	3.7	9.4	1.8	A		3.5
24	+21.8	+16.1	+18.4		79	6.6	8.3		E	5.3	5.5
25	+24.6	+14.2	+19.7		77	7.2	7.8		»		5.6
26	+26.5	+13.1	+20.7		74	6.3	7.3		»		4.6
27	+25.7	+16.5	+20.7		73	5.1	6.8	2.1	A		3.5
28	+24.2	+13.6	+18.4	2.0	73	5.6	8.1		E		4.5
29	+21.1	+12.2	+17.0		70	4.5	9.4	5.3	A	5.4	4.2
30	+19.3	+11.0	+15.9	1.8	70	4.5	7.4		E		3.3
31	+24.4	+11.5	+17.4		70	6.7	5.4	1.4	A	4.8	3.6
	Sum for July			45.2							151.0

August 1931.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+22.8	+11.6	+16.9		70	7.5	4.3	2.5	A		3.2
2	+24.6	+11.5	+17.7		69	8.0	6.7		E		5.4
3	+23.9	+ 9.4	+16.9		66	4.8	9.1	3.0	A	5.6	4.4
4	+26.5	+14.7	+20.4		66	4.8	7.1	3.1	»		3.4
5	+31.2	+14.9	+23.8		66	6.0	9.3		E	6.3	5.6
6	+29.6	+14.1	+21.4		64	6.5	6.5	2.8	A		4.2
7	+28.8	+14.2	+20.8		65	8.0	7.1		E	4.1	5.7
8	+25.2	+15.8	+18.7	0.4	62	5.8	9.8	3.1	A		5.7
9	+18.7	+ 8.5	+13.9	1.0	63	6.3	12.1		E		7.6
10	+17.0	+12.3	+13.7	10.2	65	7.8	12.1	5.6	A	4.1	9.4
11	+17.2	+ 5.5	+12.1	1.3	64	7.3	9.9		E		7.2
12	+18.8	+ 8.0	+12.4	1.2	62	6.8	7.6	2.6	A	3.6	5.2
13	+17.8	+ 6.3	+12.2	0.2	61	7.1	14.6	3.9	»		10.4
14	+18.4	+12.0	+14.4	17.5	64	7.2	9.6	4.4	»	3.9	6.9
15	+16.3	+ 9.3	+12.2	1.0	63	6.5	8.0		E		5.2
16	+19.3	+ 8.9	+13.8	0.2	61	5.0	6.4		»		3.2
17	+21.8	+ 6.9	+14.6		61	6.3	4.8	3.5	A		3.0
18	+20.0	+11.5	+15.1		61	6.0	8.7	2.5	»		5.2
19	+17.8	+12.9	+14.5	4.4	60	4.6	9.0		E	6.0	4.1
20	+18.3	+ 8.9	+13.4	9.5	61	5.0	9.0	2.0	A		4.5
21	+21.0	+12.9	+15.7	3.7	61	5.0	14.7		E	5.1	7.4
22	+19.8	+10.2	+14.2	0.9	61	7.8	20.4	3.6	A		15.9
23	+17.8	+11.3	+14.6	21.3	64	1.6	20.4		E		3.3
24	+11.6	+ 7.4	+ 9.9	23.5	68	5.8	10.0		»	7.0	5.8
25	+15.2	+ 8.5	+11.3	3.0	72	8.5	9.8	2.3	A		8.3
26	+16.0	+ 3.4	+10.2		70	7.4	11.2	3.4	»		8.3
27	+16.5	+ 9.2	+12.0		68	6.1	9.5		E		5.8
28	+16.6	+ 7.8	+12.0		67	4.7	7.8	4.2	A		3.7
29	+19.0	+ 5.1	+12.1		67	4.7	7.6	3.1	»		3.6
30	+21.4	+ 8.4	+14.2	1.9	64	3.5	6.8		E		2.4
31	+17.1	+ 3.2	+10.0		65	5.4	6.1	2.9	A	3.3	3.3
Sum for August				101.2							177.3

September 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tous/24 hours
1	+19.9	+7.6		+13.8		67	6.6	5.9	2.2	A		3.9
2	+13.3	+6.5		+ 9.7		66	6.2	6.4		E	3.4	4.0
3	+14.3	+8.0		+10.6	18.0	67	8.0	7.5	2.9	A		6.0
4	+13.5	+8.3		+10.7	10.0	69	7.0	9.3		E	6.3	6.5
5	+11.6	+4.1		+ 8.8		71	8.1	8.1	2.7	A		6.6
6	+12.7	+8.7		+10.7	1.5	67	5.5	9.9		E		5.4
7	+ 9.8	+5.8		+ 7.9	4.9	70	3.8	11.7		»	8.7	4.4
8	+14.3	+2.5		+ 7.8		70	6.2	11.5	3.1	A		7.1
9	+13.7	+2.6		+ 7.2	0.3	71	8.9	4.8	3.7	»	3.0	4.3
10	+10.8	±0.0		+ 4.7	1.8	72	8.0	5.4		E		4.3
11	+ 8.7	+2.0		+ 5.5	1.2	71	9.0	6.1	3.5	A		5.5
12	+13.6	+0.3		+ 6.6		71	9.0	9.2		E	6.2	8.3
13	+12.7	+6.1		+ 8.4	0.5	70	8.9	8.1		»		7.2
14	+12.0	+0.8		+ 5.9		68	8.0	7.0		»	4.0	5.6
15	+12.8	+1.2		+ 6.5		68	8.0	6.9		A		5.5
16	+11.0	+5.4		+ 9.5		68	8.0	6.1	3.2	»	3.2	4.9
17	+21.0	+4.8		+12.7		68	8.8	6.4		E		5.6
18	+17.1	+9.0		+12.4		67	8.6	6.8	2.5	A	3.7	5.8
19	+17.3	+7.7		+11.7	0.2	67	8.6	8.9	2.4	»		7.7
20	+13.6	+3.7		+ 7.9	3.5	65	7.7	8.1		E		6.2
21	+12.7	+2.4		+ 7.1	0.7	65	7.7	7.3		»	4.3	5.6
22	+ 8.7	+0.7		+ 4.0	0.1	63	6.4	9.0	2.7	A		5.8
23	+ 8.5	−2.9	11	+ 2.0	0.4	63	8.0	5.2	2.8	»	2.2	4.2
24	+12.1	+3.6		+ 7.6		63	8.0	5.1	1.9	»		4.1
25	+16,1	+5.6		+ 9.8		61	7.2	6.9		E	2.3	5.0
26	+ 9.9	+2.4		+ 6.0	0.3	59	6.7	8.6		A		5.8
27	+ 7.9	−0.9	3	+ 3.5	1.3	58	6.5	7.0		E		4.6
28	+ 6.0	+4.1		+ 5.2	0.8	58	7.4	5.4		»	2.4	4.0
29	+12.4	+6.4		+ 8.2		57	6.9	5.0	2.0	A		3.5
30	+11.6	+4.2		+ 7.5		57	6.9	4.8		E	1.8	3.3
Sum for September					45.5							160.7

October 1931.

Date	Temperature				Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	number of hours ≤ 0°	mean								
1	+10.8	+5.2		+7.8		57	8.0	6.9		E	3.9	5.5
2	+11.9	+8.4		+9.8		58	8.9	5.3	3.7	A		4.7
3	+14.8	+8.5		+11.8		58	9.4	5.3		E		5.0
4	+13.7	+4.1		+9.0		57	6.4	5.3		»		3.4
5	+10.2	+2.7		+6.3	1.2	58	10.3	5.3	2.2	A	3.1	5.5
6	+12.3	+6.6		+9.9	1.6	56	8.8	5.6		E		4.9
7	+14.6	+5.3		+9.3		54	8.2	5.8	1.7	A	3.0	4.8
8	+15.9	+9.4		+12.1	17.5	55	8.3	7.8	2.4	»		6.5
9	+11.7	+4.7		+8.2	0.5	56	8.0	5.9		E	2.9	4.7
10	+12.9	+7.3		+12.5		57	9.4	6.1	3.0	A		5.7
11	+15.6	+3.0		+9.4		55	8.3	5.7		E		4.7
12	+13.0	+6.2		+10.3		56	8.2	5.4		»	2.4	4.4
13	+12.7	+4.9		+8.1		56	9.3	6.1	3.0	A		5.7
14	+13.2	+4.8		+9.9	0.2	54	6.6	7.1	2.4	»		4.7
15	+7.1	−1.2	4	+3.2	2.0	54	7.0	6.4		E	2.8	4.5
16	+8.3	+2.8		+5.2		54	7.0	5.4	2.4	A		3.8
17	+12.5	+3.5		+7.4		55	7.6	5.0	2.1	»	3.0	3.8
18	+12.4	−0.1	2	+6.0		54	6.6	5.3		E		3.5
19	+5.5	−1.8	9	+1.5		56	8.1	5.5	1.3	A		4.5
20	+8.4	+2.3		+6.9	5.5	57	8.0	8.1	3.4	»		6.5
21	+1.7	+0.4		+1.0	* 17.5	58	6.5	7.9	4.7	»		5.1
22	+2.7	−3.7	11	−0.1		56	6.2	9.1	3.1	»		5.6
23	+1.9	−1.4	8	+0.4	* 6.0	56	5.8	7.0	4.3	»	4.0	4.1
24	+1.6	−9.3	14	−2.3		56	5.3	3.1	1.4	»		1.6
25	+0.6	−6.2	22	−2.7		56	5.3	4.4		E		2.3
26	+1.5	−10.2	19	−4.4		57	6.0	5.7	1.9	A	2.7	3.4
27	−1.2	−9.5	24	−5.4		59	8.0	4.6	1.3	»		3.7
28	+2.6	−1.9	2	+1.4		64	11.0	8.2		E	5.2	9.0
29	+3.9	−8.3	15	−2.2		60	9.0	6.5	1.9	A		5.9
30	−0.3	−5.3	24	−1.8	* 4.3	59	7.0	8.3	3.2	»		5.8
31	+0.8	−4.2	21	−1.8	1.3	57	6.0	7.9		E	4.9	4.7
Sum for October					47.6							148.0

Remarks. Cover of snow at Uppsala October 20—31, cover of ice on the Fyris from October 27.

November 1931.

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tous/24 hours
1	− 1.8	−10.6	24	− 5.4		56	6.0	8.6		E		5.2
2	+ 1.1	− 8.9	20	− 2.4		59	7.0	9.4	3.4	A		6.6
3	+ 5.1	+ 1.5		+ 3.9		60	7.4	10.5		E		7.8
4	+10.5	+ 4.8		+ 7.0		66	10.5	11.5	2.8	A		12.1
5	+12.6	+10.0		+11.5		68	11.5	11.8		E		13.6
6	+11.4	+ 3.5		+ 7.3	⁎0.1	66	11.2	12.0	6.2	A		13.4
7	+ 5.7	+ 3.6		+ 4.7	0.1	65	10.6	13.1		E		13.9
8	+ 6.9	+ 5.2		+ 5.8	⁎0.1	65	11.0	14.2		»		15.6
9	+ 7.6	+ 5.7		+ 6.6		65	10.6	15.3	5.4	A		16.2
10	+ 6.4	+ 5.4		+ 5.9	0.1	65	11.0	11.7		E	8.7	12.9
11	+ 8.0	+ 6.2		+ 7.1		64	9.0	9.5	4.1	A	4.3	8.6
12	+ 8.2	+ 5.4		+ 6.6		65	9.6	7.0		E	4.0	6.7
13	+ 8.5	+ 6.2		+ 7.3		63	8.4	8.2	3.3	A		6.9
14	+ 7.7	+ 6.0		+ 6.6	0.1	63	8.4	7.9		E	3.9	6.6
15	+ 6.5	+ 3.6		+ 4.8	0.8	61	7.0	7.6		»		5.3
16	+ 4.7	+ 2.3		+ 3.7	1.6	60	6.5	7.3	5.4	A		4.7
17	+ 3.9	+ 2.1		+ 3.0	2.0	60	7.5	5.9	2.2	»		4.4
18	+ 3.2	+ 1.8		+ 2.7	1.5	59	7.6	4.5		E	1.5	3.4
19	+ 3.7	+ 1.2		+ 2.3	0.5	61	8.2	5.8	3.2	A		4.8
20	+ 2.7	+ 0.8		+ 1.4	⁎0.2	63	10.6	8.8	3.4	»		9.3
21	+ 2.9	+ 1.3		+ 2.2	1.9	63	10.6	8.4		E	5.4	8.9
22	+ 2.9	+ 0.8		+ 2.3	0.1	63	10.6	7.8		»		8.3
23	+ 1.2	+ 0.4		+ 0.8	⁎1.8	63	10.2	7.1	2.0	A	4.2	7.2
24	+ 2.0	+ 0.1		+ 0.7	⁎0.5	63	10.6	8.1	3.9	»	4.0	8.6
25	+ 1.6	+ 0.3		+ 0.8	0.2	62	12.0	7.6		E	4.6	9.1
26	+ 2.8	+ 1.5		+ 2.3	0.8	61	11.6	8.3	3.1	A		9.6
27	+ 4.2	+ 0.6		+ 2.6	0.2	61	11.6	6.6	2.6	»	5.7	7.7
28	+ 0.9	− 0.2	7	+ 0.3		60	11.0	7.3		E		8.0
29	+ 0.5	− 0.7	16	− 0.2		58	8.8	8.0		»		7.0
30	± 0.0	− 5.8	24	− 3.2		57	9.0	8.6	4.1	A	4.4	7.7
	Sum for November				12.6							260.1

Remarks. Cover of snow at Uppsala Nov. 1 and 2, cover of ice on the Fyris to Nov. 4.

December 1931.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	−1.9	− 5.7	24	− 2.6		55	9.3	7.9	2.3	A		7.3
2	−1.8	− 2.5	24	− 2.1	⁎ 1.6	55	9.3	5.2	3.5	»		4.8
3	−0.5	− 3.5	24	− 1.8		57	10.5	7.2		E		7.6
4	+2.9	− 0.9	11	+ 0.9	0.2	60	16.6	9.2		»	6.2	15.3
5	+4.4	+ 1.4		+ 3.1	⁎17.2	57	11.8	9.7	2.9	A		11.4
6	+3.9	− 2.1	7	+ 1.5	3.2	59	13.7	7.9		E		10.8
7	+2.6	− 2.1	4	+ 0.7	⁎15.0	63	9.0	6.1	2.0	A		5.5
8	+0.4	− 8.4	17	− 2.1	⁎ 1.7	67	15.3	7.0	5.4	»		10.7
9	+0.7	− 7.5	12	− 1.2	⁎ 3.1	72	17.2	6.6		E		11.4
10	−0.7	−10.9	24	− 6.8	⁎ 0.1	73	18.2	6.2	3.5	A		11.3
11	−1.6	− 7.2	24	− 3.9	⁎ 3.2	80	21.0	3.2	1.5	»		6.7
12	+1.1	− 5.4	19	− 2.7	⁎ 0.5	80	19.5	7.0		E	4.0	13.7
13	+1.6	− 2.1	15	− 0.2		75	19.1	5.5		»		10.5
14	+0.1	− 6.3	21	− 2.3		78	13.5	8.9		»	5.1	12.0
15	+4.0	− 5.0	8	+ 0.6	⁎ 6.0	76	12.3	7.5	2.1	A		9.2
16	−0.2	− 7.0	24	− 4.9	⁎ 6.8	73	16.4	8.4	3.9	»		13.8
17	−3.7	− 6.3	24	− 4.6	⁎ 2.5	71	17.2	5.1		E		8.8
18	−4.6	− 9.8	24	− 7.4	⁎ 0.3	67	15.8	6.7	3.9	A		10.6
19	+0.7	− 6.5	21	− 2.8		71	16.4	6.9		E		11.3
20	+2.7	− 5.3	13	− 1.1		69	16.0	7.1		»		11.4
21	−1.9	− 7.1	24	− 4.5		73	18.2	7.4	3.0	A		13.5
22	−0.7	− 7.2	24	− 3.5		74	18.2	9.2		E		16.7
23	−4.7	−11.7	24	− 8.5	⁎ 0.2	76	19.4	10.9	4.0	A		21.1
24	+2.4	−11.2	8	− 1.2		72	17.8	10.2		E	7.2	18.2
25	+6.7	+ 0.6		+ 4.0		82	19.8	9.8		»		19.4
26	+4.5	− 2.0	11	+ 0.9	1.5	87	21.5	9.3	3.1	A		20.0
27	−1.4	− 4.8	24	− 3.1	⁎ 1.0	90	24.1	9.6		E		23.1
28	+0.2	− 7.7	24	− 4.4	⁎ 3.9	93	25.0	9.9	3.9	A		24.8
29	−1.1	− 5.8	24	− 3.7	⁎ 0.6	94	22.1	8.9		E		19.7
30	−5.3	−12.4	24	− 7.9	⁎16.5	94	22.1	7.9	1.9	A		17.5
31	−8.8	−15.9		−11.3	⁎ 3.3	93	21.7	7.0		E		15.2
Sum for December					88.7							413.3

Remarks. Cover of snow at Uppsala Dec. 2, 3, 7—24 and 26—31, cover of ice on the Fyris from Dec. 10.

January 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignitions loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours	Remarks
1	− 10.9	− 20.2	24	− 15.3	* 0.3	94	21,7	6.0	—	A		13.0	
2	− 0.3	− 12.2	24	− 6.2	* 3.3	94	21.0	6.0	2.3	»		12.6	
3	+ 1.3	− 9.9	18	− 4.3		92	19.7	7.1		E		14.0	
4	− 4.6	− 11.9	24	− 7.9		95	21.0	8.2	5.9	A		17.2	
5	− 3.7	− 17.1	24	− 12.5	* 1.0	91	19.3	21.0	6.8	»	15.0	40.5	
6	+ 1.8	− 6.8	16	− 1.4	* 3.9	90	19.4	22.8		E		44.2	
7	+ 3.1	+ 0.2		+ 2.3	* 13.0	101	19.2	24.6	8.4	A		47.2	
8	+ 1.5	− 0.8	2	+ 0.6	* 4.0	111	24.9	22.5	5.1	»	13.8	56.0	
9	+ 0.1	− 6.7	22	− 2,6	* 0.5	114	21.3	18.4	4.1	»		39.2	
10	− 5.0	− 13.2	24	− 9.4		110	23.8	24.0		E		57.1	
11	+ 0.5	− 11.4	17	− 2.4		113	24.6	29.5	15.4	A		72.6	
12	+ 1.7	− 0.1	2	+ 1.0	* 0.5	110	25.4	26.4		E	21.4	67.1	
13	+ 1.7	+ 1.0		+ 1.4	3.7	110	25.4	24.2		»	19.2	61.5	
14	+ 3.3	+ 1.5		+ 2.3	1.2	116	25.7	14.8		»	9.8	38.0	
15	+ 4.2	+ 0.5		+ 2.5		138	42.4	20.3	3.3	A		86.1	
16	+ 3.1	− 0.4	5	+ 1.5	* 2.7	142	42.6	27.8	8.2	»		118.4	
17	+ 6.4	+ 2.7		+ 4.3	0.9	156	46.6	27.1		E		126.3	
18	+ 6.1	+ 4.1		+ 5.0		202	71.6	26.5	11.7	A		189.7	
19	+ 8.4	+ 4.6		+ 6.9		189	62.7	64.1	9.1	»		401.9	
20	+ 8.7	+ 7.5		+ 8.2		221	82.4	62.0	9.0	»		149.2	8 o'clock
						224	84.5	72.7	7.2	»		434.9	15 »
												584.1	
21	+ 7.5	+ 4.0		+ 5.3		203	69.0	55.8	1.3	»		112.4	8 »
						202	69.4	71.5	10.8	»		351.3	15 »
												463.7	
22	+ 6.8	+ 1.3		+ 4.6		197	65.0	31.4	7.4	»		59.6	8 »
						196	64.0	32.0	14.2	»		145.0	15 »
												204.6	
23	+ 4.2	+ 1.3		+ 3.1		189	58.8	21,1	5.7	»		36.2	8 »
						189	58.8	14.1	3.0	»		58.7	15 »
												94.9	
24	+ 3.1	− 1.1	7	+ 0.8		182	54.7	11.7		E		64.0	
25	+ 4.8	+ 1.3		+ 3.9		181	54.0	9.3	7.0	A		14.7	8 »
						180	53.7	5.3	0.6	»		20.2	15 »
												34.9	
26	+ 3.1	− 1.0	8	+ 0.9		174	51.2	6.6	3.0	»		33.8	

Januari 1932 (cont.).

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignitions loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours	Remarks
27	+4.1	−0.6	1	+3.1		166	47.8	11.8	7.3	A		56.4	
28	+7.7	+3.0		+5.5	0.1	160	44.3	7.6	2.0	»		33.7	
29	+7.5	+1.8		+4.8		157	42.5	8.0		E		34.0	
30	+5.3	+1.6		+3.5		148	28.8	8.4	2.8	A		24.2	
31	+4.4	−5.3	12	−0.2	⋇0.2	137	27.1	7.2		E		19.5	
Sum for January					35.0							3 150.4	

Remarks. Cover of snow at Uppsala Jan. 1—17, cover of ice on the Fyris to Jan. 19.

February 1932.

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+4.5	− 4.9	8	+1.0	4.0	128	18.5	5.9	1.9	A		10.9
2	+2.5	− 5.3	14	−1.3	⋇0.1	134	25.7	5.5		E		14.1
3	−0.5	− 7.8	24	−3.6	⋇0.9	138	27.7	5.2	2.9	A		14.4
4	+5.5	− 5.1	7	+1.5	⋇0.9	130	23.1	5.0		E	5.3	11.6
5	+4.5	− 8.1	13	−0.9		123	20.7	4.8	2.0	A		9.9
6	−2.8	− 8.3	24	−4.7		120	20.7	5.2		E	4.4	10.8
7	+5.0	− 2.8	3	+2.6		119	20.8	5.6		»		11.6
8	+4.9	− 2.3	12	+0.8	⋇0.9	114	18.4	5.9	1.3	A		10.9
9	−2.2	−12.4	24	−7.1		110	16.6	6.2		E		10.3
10	−6.7	−11.5	24	−8.6	⋇0.2	113	18.0	6.6	4.2	A		11.9
11	−5.8	−12.8	24	−7.7	⋇0.1	109	16.2	4.9		E		7.9
12	−1.0	−11.4	24	−5.0	⋇3.5	108	15.8	3.3	0.7	A		5.2
13	−0.1	−10.9	24	−3.3	⋇0.8	100	12.3	3.7		E		4.6
14	−1.9	− 6.8	24	−3.7	⋇0.5	102	13.6	4.1		»		5.6
15	−1.0	− 6.4	24	−3.4	⋇0.1	103	14.6	4.5	0.6	A		6.6
16	+2.1	− 5.2	19	−1.5	⋇1.2	98	12.7	4.5		E		5.7
17	+1.4	− 4.8	20	−2.8		96	12.3	4.4	1.8	A		5.4
18	+4.5	− 3.6	13	±0.0		94	12.2	4.5		E		5.5
19	+4.7	− 2.5	18	−1.1		92	11.5	4.6	2.2	A		5.3
20	+5.3	− 5.1	14	−0.2		90	9.6	5.2		E		5.0
21	−3.0	− 7.3	24	−5.3	⋇0.1	87	9.2	5.8		»		5.3

February 1932 (cont.)

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Principitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
22	+5.2	−2.5	3	+2.7	⋇0.6	85	7.8	6.5	4.7	A		5.1
23	+1.4	−7.5	19	−3.5	⋇0.4	83	8.1	6.7		E		5.4
24	−3.4	−11.0	24	−7.3	⋇0.1	83	8.7	6.9	4.1	A		6.0
25	−4.7	−10.2	24	−7.3	⋇0.1	83	10.3	7.4		E		7.6
26	+2.8	−6.9	18	−2.1	⋇0.8	82	9.8	8.0	4.1	A		7.8
27	+4.5	−8.4	15	−2.2		81	9.5	6.4		E		6.1
28	+2.3	−11.0	19	−4.6		80	11.4	4.9		»		5.6
29	+2.4	−6.4	18	−2.4		79	10.7	3.4	1.4	A		3.6
Sum for February					11.3							225.7

Remarks. Cover of snow at Uppsala Febr. 3 and 8—29, cover of ice on the Fyris February 10—14.

March 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Principitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+ 4.8	− 9.0	15	− 2.2		76	9.7	7.2		E		7.0
2	+ 5.4	− 4.8	15	− 1.1		75	9.9	10.9	1.5	A		10.8
3	− 2.3	− 4.1	24	− 3.0		74	10.0	10.4		E		10.4
4	+ 2.6	− 5.0	20	− 2.4	⋇0.1	72	9.3	9.9	2.5	A		9.2
5	+ 0.1	− 6.7	24	− 3.9	⋇0.1	71	10.0	8.1		E		8.1
6	− 0.8	− 3.6	24	− 2.4		67	8.1	6.4		»		5.2
7	− 2.0	− 3.6	24	− 3.0		69	10.8	4.7	4.6	A		5.1
8	− 2.6	− 5.6	24	− 4.1	⋇1.0	67	10.1	4.6		E		4.6
9	− 3.8	− 7.9	24	− 5.6	⋇1.9	66	9.7	4.5	1.0	A		4.4
10	− 7.0	−10.6	24	− 8.7	⋇0.5	65	9.3	6.2		E		5.8
11	− 8.9	−13.1	24	−10.8	⋇4.0	63	8.1	7.8	5.7	A		6.3
12	− 7.0	−21.0	24	−13.3	⋇0.1	61	7.9	7.5		E		5.9
13	− 3.6	−10.4	24	− 6.6	⋇1.8	60	7.5	7.2		»		5.4
14	+ 0.5	− 5.1	20	− 1.3		62	8.9	6.8	4.9	A		6.1
15	+ 2.1	− 8.0	18	− 3.0	⋇1.6	60	7.5	6.3		E		4.7
16	+ 3.9	− 4.2	15	− 0.3		59	7.8	5.8	2.7	A		4.5
17	+ 4.3	− 7.8	16	− 2.1	⋇0.1	57	6.8	6.6		E		4.5

March 1932 (cont.).

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
18	+ 3.0	− 6.5	19	− 2.7		56	7.2	7.5	3.1	A	5.3	5.4
19	+ 1.0	−14.7	20	− 6.5		55	5.6	7.0		E		3.9
20	+ 4.8	− 9.3	16	− 2.6		53	5.9	6.5		»		3.8
21	+ 1.1	−11.6	22	− 5.2		54	7.1	6.1	2.4	A		4.3
22	+ 1.0	− 7.7	21	− 4.2		54	7.1	11.7		E	6.2	8.3
23	+ 5.9	− 5.1	12	± 0.0		52	6.7	17.2	7.7	A		11.5
24	+ 5.2	− 5.1	14	− 0.2		51	7.3	13.1		E	8.1	9.6
25	+ 5.0	− 1.3	14	+ 0.6		50	6.4	14.6		»		9.3
26	+ 5.5	− 3.3	12	+ 0.4		50	7.1	16.1	3.8	A		11.4
27	+ 6.7	+ 1.1		+ 3.3		48	5.7	14.6		E		8.3
28	+ 9.4	− 1.9	7	+ 3.7		48	6.5	13.1		»		8.5
29	+ 8.8	− 2.7	11	+ 2.4		50	8.6	11.5	5.3	A		9.9
30	+ 4.8	− 0.2	7	+ 1.8		49	8.9	8.1	0.4	»		7.2
31	+10.6	+ 1.8		+ 4.7	3.1	51	10.6	18.2	6.0	»		19.3
Sum for March					18.3							228.7

Remarks. Cover of snow at Uppsala March 3, 4 and 7—25, cover of ice on the Fyris March 1—31.

April 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
1	+ 4.9	+ 1.8		+3.6		55	13.1	47.9	—	A	18.3	8 o'clock
						56	13.7	50.4	5.4	»	48.9	15 »
											67.2	
2	+ 7.7	−2.2	8	+2.1	0.1	56	12.8	41.8	6.4	»	15.6	8 »
						58	14.0	25.7	5.8	»	25.5	15 »
											41.1	
3	+ 7.6	+2.0		+3.9	3.9	59	14.4	26.0		E	37.4	
4	+ 4.8	+1.2		+3.2	0.4	65	15.5	26.2	8.1	B	11.9	8 »
						65	15.5	46.5	8.0	A	51.0	15 »
											62.9	

April 1932 (cont.).

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
5	+ 6.6	+0.4		+2.8	⋇ 2.2	64	16.0	31.8	—	A	14.9	8 o'clock
						64	16.0	23.1	4.4	»	26.2	15 »
											41,1	
6	+1. 0	+0.3		+0.5	⋇ 10.5	64	14.7	26.7	6.6	»	11.5	8 »
						66	15.6	22.8	6.3	»	25.2	15 »
											36 7	
7	+ 1.8	−2.6	7	+0.5	⋇ 0.3	68	16.2	33.8	8.5	»	16.1	8 »
						69	16.7	27.2	5.2	»	32.2	15 »
											48.3	
8	+ 1.8	−1.8	16	−0.3	⋇ 1.0	70	17.1	30.8	10.3	»	15.4	8 »
						70	17.1	34.4	7.6	»	41.6	15 »
											57.0	
9	+ 0.9	−2.7	15	−0.6	⋇ 0.2	69	14.8	36.9		E	54.6	
10	+ 6.2	−3.5	10	+ 1.1		69	16.7	39.5		»	66.0	
11	+ 5.0	+ 1.0		+ 3.2	⋇ 8.8	77	18.4	42.1	9.3	A	77.5	
12	+ 8.4	+ 2.0		+4.6	2.0	91	21.1	72.5	8.8	»	44.7	8 »
						90	22.8	57.8	10.4	»	93.3	15 »
											138.0	
13	+ 9.2	+0.5		+4.4		87	19.7	49.3	8.4	»	28.4	8 »
						88	20.0	17.4	4.7	»	24.6	15 »
											53.0	
14	+ 12.1	− 1.1	4	+4.7	0.2	88	20.0	19.5	4.6	»	11.4	8 »
						88	20.0	29.8	7.8	»	42.2	15 »
											53.6	
15	+ 12.8	±0.0	1	+ 5.1		86	18.7	24.4	6.3	»	13.3	8 »
						86	18.7	17.0	3.8	»	22.5	15 »
											35.8	
16	+ 10.1	−3.2	9	+ 3.2		84	17.9	16.9	3.9	»	8.8	8 »
						84	17.9	18.2	4.9	»	23.1	15 »
											31 9	
17	+ 8.9	−5.4	9	+ 2.2		83	16.9	18.3		E	30.9	
18	+ 12.3	+0.9		+ 5.3	⋇ 0.3	83	16.5	18.4	3.5	A	30.4	
19	+ 8.4	−2.7	7	+ 3.0		80	12.9	21.0		E	27.1	
20	+ 7.0	−5.4	10	+ 1.4		80	15.0	23.6	7.1	A	35.4	
21	+ 10.0	+0.4		+ 4.4		80	14.2	13.2		E	18.7	
22	+ 9.8	+ 3.1		+ 6.2	0.3	79	13.7	18.3	5.6	B	25.1	
23	+ 12.5	+ 3.7		+ 7.3	3.3	79	13.7	19.8	7.3	»	27.1	

April 1932 (cons.).

Date	Temperature				Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
	max.	min.	number of hours ≤ 0°	mean								
24	+ 7.9	−1.0	7	+3.3	6.8	82	14.3	20.4		E	29.2	
25	+13.9	−1.0	5	+5.5		87	12.8	20.9	4.0	B	26.8	
26	+12.4	+1.1		+5.5	1.2	86	14.6	15.5		E	22.6	
27	+10.2	−0.7	1	+4.8	✱ 0.3	86	15.4	15.0		»	23.1	
28	+ 8.2	+1.1		+3.9	10.6	86	12.7	15.1		»	19.2	
29	+ 7.2	+2.1		+4.1	4.5	94	16.0	39.6	10.5	B	63.4	
30	+ 6.9	−2.0	9	+2.5		97	17.7	33.3	10.4	»	58.9	
			Sum for April		56.9						1 340.0	

Remarks. Cover of snow at Uppsala April 5, 6 and 10, cover of ice on the Fyris to April 2.

May 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+14.2	− 1.1	3	+ 6.7		96	16.7	27.3		E	45.6
2	+16.4	+ 1.3		+ 8.9		94	15.5	21.4	6.9	B	33.2
3	+11.1	+ 0.8		+ 6.4		89	14.9	21.3		E	31.7
4	+12.6	+ 3.2		+ 7.2		89	15.8	21.3	8.7	B	33.7
5	+ 5.8	+ 0.8		+10.3	0.8	85	13.7	16.9		E	23.2
6	+ 5.1	+ 2.5		+ 3.5		86	13.6	12.4	6.4	B	16.9
7	+ 4.8	+ 1.3		+ 2.5	⋇6.8	89	14.9	15.3		E	22.8
8	+ 8.4	− 0.6	4	+ 3.5		84	12.8	18.2		»	23.3
9	+12.6	+ 2.5		+ 6.8		85	13.3	21.1	9.9	B	28.1
10	+12.1	+ 0.9		+ 5.8	⋇2.6	80	9.6	22.6		E	21.7
11	+ 6.6	+ 1.2		+ 2.9	3.8	82	11.0	24.4	15.8	A	26.8
12	+16.1	− 0.9	4	+ 7.3		81	11.4	19.4		E	22.1
13	+12.8	− 0.8	3	+ 6.9	0.1	80	11.5	14.3	8.3	B	16.4
14	+15.4	+ 6.7		+10.4	2.1	80	12.1	12.6	5.0	»	15.2
15	+14.4	+ 7.9		+10.7	1.2	79	11.6	12.3		E	14.3
16	+17.9	+ 2.8		+10.4		76	10.3	12.0		»	12.4
17	+20.2	+ 2.9		+13.2		75	10.8	11.7	6.1	B	12.6
18	+23.0	+ 7.4		+16.1		74	11.7	21.0	7.2	»	24.6
19	+24.5	+ 9.7		+17.7		74	10.4	19.3		E	20.1
20	+17.2	+11.6		+13.1	14.1	75	10.4	17.6	6.2	B	18.3
21	+20.0	+11.4		+14.6		76	12.4	26.2		E	32.5
22	+19.7	+ 8.6		+11.9	8.2	73	12.1	34.8	9.1	B	42.1
23	+ 8.9	+ 4.4		+ 5.9	22.0	79	12.9	20.7	3.4	»	26.7
24	+12.1	+ 8.1		+ 9.6	2.5	92	17.0	69.2	6.3	A	117.6
25	+10.6	+ 3.1		+ 6.4		90	17.0	26.5	4.8	»	45.1
26	+ 9.3	+ 5.2		+ 6.6		89	15.3	25.3	3.3	»	38.7
27	+12.3	+ 8.0		+ 9.5	5.1	90	15.4	14.4	0.5	B	22.2
28	+16.6	+ 2.0		+10.8		90	15.8	13.3	4.9	»	21.0
29	+19.1	+ 6.5		+13.1		89	15.4	19.4		E	29.9
30	+22.0	+ 9.4		+16.0		89	13.8	25.6	15.8	B	35.3
31	+21.5	+ 3.8		+13.5		86	14.6	14.8	5.6	»	21.6
			Sum for May		69.3						895.7

June 1932.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
1	+23.4	+ 4.9	+14.5		84	11.5	12.7	3.1	B	14.6	
2	+17.4	+ 2.5	+11.2		83	12.4	11.7	3.1	»	14.5	
3	+16.3	+ 5.8	+11.8	0.3	82	7.7	10.2	2.4	»	7.9	
4	+14.0	+ 1.3	+ 8.1		81	9.0	8.3	3.0	»	7.5	
5	+12.2	+ 1.4	+ 6.8	⋇0.4	78	6.3	7.2		E	4.5	
6	+13.0	+ 0.5	+ 7.5	0.3	78	9.1	6.1	1.8	B	5.6	
7	+15.6	+ 1.3	+10.1		77	7.0	9.4	1.9	»	6.6	
8	+17.1	+ 9.1	+11.9	3.7	77	8.5	10.2	3.1	»	2.9	8 o'clock
					77	8.5	8.9	3.3	»	1.3	16 »
					76	7.9	10.0	4.8	»	4.0	20 »
										8.2	
9	+11.5	+ 4.5	+ 8.2	10.0	74	5.5	8.3	2.8	»	1.5	8 »
					75	6.2	8.7	6.5	»	0.9	16 »
					75	6.2	10.6	3.8	»	3.3	20 »
										5.7	
10	+15.0	+ 4.4	+ 9.7	0.8	75	6.2	6.7	2.8	»	1.4	8 »
					75	6.2	14.7	3.1	»	1.5	16 »
					75	6.2	9.1	2.8	»	2.8	20 »
										5.7	
11	+18.3	+ 5.1	+12.2		75	6.6	10.8		E	7.1	
12	+22.1	+10.5	+16.5		78	10.2	12.5		»	12.8	
13	+20.1	+11.5	+15.7	0.7	77	10.8	14.1	2.7	B	15.2	
14	+15.0	+ 4.6	+ 9.8	2.6	73	8.0	13.1	3.7	»	10.5	
15	+19.6	+ 5.5	+13.3		70	6.1	11.4	4.9	»	7.0	
16	+17.0	+ 6.0	+11.7		65	2.8	11.3		E	3.2	
17	+15.2	+ 5.8	+ 9.9	3.1	65	5.0	11.2	2.1	B	5.6	
18	+10.2	+ 7.3	+ 8.9	0.5	65	7.2	12.5	3.2	»	9.0	
19	+14.9	+ 8.2	+11.3	12.8	66	4.1	12.5		E	5.1	
20	+14.1	+ 9.5	+11.1	9.7	69	10.2	12.5	2.5	B	12.8	
21	+12.0	+ 6.5	+ 9.1	0.2	65	5.5	15.6	3.1	»	8.6	
22	+13.8	+ 3.0	+ 8.4		66	6.4	10.4	3.2	»	6.7	
23	+21.7	+ 4.8	+14.3		65	7.0	11.7	3.5	»	8.2	
24	+22.2	+ 6.1	+15.2		64	7.5	10.5		E	7.9	
25	+21.6	+11.6	+16.2	0.9	64	7.5	9.3	2.5	B	7.0	
26	+21.9	+11.5	+16.1	0.2	65	8.2	10.7		E	8.8	
27	+18.3	+ 8.8	+13.7	1.7	64	8.1	12.1	2.7	B	9.8	

June 1932 (cont.).

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
28	+20.8	+13.5	+16.9		63	7.6	16.6	3.4	B	12.6	
29	+24.3	+15.0	+19.0		62	8.4	13.5	4.2	»	11.3	
30	+23.4	+ 7.6	+14.5	1.9	61	7.2	15.7	4.4	»	11.3	
	Sum for June			65.1						261.2	

July 1932.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
1	+22.5	+11.5	+16.6	15.3	62	8.3	13.8	3.2	B	11.5	
2	+23.1	+ 8.8	+16.7		60	8.4	13.3	3.3	»	11.2	
3	+24.9	+13.3	+19.3	5.5	59	8.0	10.0		E	8.0	
4	+27.2	+15.0	+20.5		58	6.5	7.5	3.8	B	4.9	
5	+26.3	+12.6	+19.3		57	7.0	11.3	4.7	»	7.9	
6	+28.1	+14.1	+21.3		58	8.0	10.3	3.9	»	8.2	
7	+28.4	+11.8	+20.8		56	8.0	11.7	3.6	»	9.4	
8	+27.2	+12.8	+20.2		56	8.2	10.7	—	»	8.8	
9	+26.1	+13.8	+19.6		55	8.0	7.5	2.6	»	6.0	
10	+24.6	+15.1	+19.5		55	9.3	5.9		E	5.5	
11	+27.4	+10.6	+19.2		52	6.7	4.3	2.1	B	2.9	
12	+28.7	+15.2	+22.1		51	7.9	5.5	4.8	»	4.3	
13	+26.8	+12.4	+19.3		49	7.2	7.0	1.9	»	5.0	
14	+23.1	+ 8.3	+16.7		47	5.9	4.7	2.1	»	2.8	
15	+24.6	+11.2	+17.9		47	5.6	12.2	6.6	»	6.8	
16	+18.4	+12.0	+15.6	0.2	45	4.5	12.8	2.5	»	5.8	
17	+21.3	+13.7	+16.8		42	4.4	5.6	3.3	»	2.5	
18	+21.6	+16.4	+17.9	29.7	47	5.7	10.6	3.0	»	2.0	8 o'clock
					48	6.6	8.3	4.0	»	0.9	16 »
					49	7.1	3.5	3.3	»	1.2	20 »
										4.1	

July 1932 (cont.).

Date	Temperature			Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remark
	max.	min.	mean								
19	+23.9	+14.6	+17.9	41.2	49	4.6	19.5	4.6	B	9.0	
20	+18.8	+ 8.0	+13.1	0.8	50	5.0	17.7	8.1	»	8.9	
21	+20.9	+ 6.7	+14.5		50	6.1	9.5	3.4	»	5.8	
22	+23.0	+15.9	+19.0	0.1	50	6.1	9.2	2.3	»	5.6	
23	+23.8	+13.4	+18.2	0.8	50	7.3	9.5	2.3	»	6.9	
24	+24.4	+12.3	+18.3		50	7.3	8.8		E	6.4	
25	+21.9	+12.7	+17.4	0.1	49	5.8	8.1	1.7	B	4.7	
26	+26.7	+15.6	+20.5		48	4.8	7.3	2.9	»	3.5	
27	+27.5	+13.6	+20.8		47	4.9	7.6	2.6	»	3.7	
28	+25.2	+13.5	+19.8		48	6.3	7.8	2.7	»	4.9	
29	+23.7	+13.7	+18.7		48	6 3	10.3	4.7	»	6.5	
30	+21.4	+13.5	+17.2		49	7.7	6.3	2.3	»	4.9	
31	+22.1	+12.0	+17.2		48	7.5	8.8		E	6.6	
Sum for July				79.1						193.0	

August 1932.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+23.9	+16.1	+19.6	0.7	48	8.6	11.3	2.9	B	9.7
2	+22.4	+15.4	+18.3	6.6	47	7.1	6.5	2.3	»	4.6
3	+21.6	+13.1	+16.7	1.9	47	6.2	5.9	2.2	»	3.7
4	+20.8	+12.4	+15.9	0.4	46	5.4	5.3	1.5	»	2.9
5	+19.1	+11.4	+15.0	8.8	47	6.2	5.2	1.9	»	3.2
6	+22.6	+10.8	+16.6	0.1	48	6.8	8.4	2.9	»	5.7
7	+22.6	+ 9.4	+16.0		45	4.7	7.5		E	3.5
8	+25.2	+11.0	+18.1		40	2.0	6.7	2.3	B	1.3
9	+19.3	+12.7	+14.2	18.5	43	2.7	6.4	1.9	»	1.7
10	+19.9	+ 9.1	+13.8	0.2	45	3.9	6.9	1.2	»	2.7
11	+17.2	+10.4	+14.8	3.6	45	4.4	9.8	3.2	»	4.3
12	+24.6	+ 8.9	+16.8		45	3.9	6.3	1.4	»	2.5
13	+26.0	+10.9	+18.9		47	5.0	7.5	1.7	»	3.8
14	+27.1	+13.7	+20.0		47	5.0	7.9		E	4.0
15	+27.5	+15.7	+21.5		46	4.5	8.3	4.3	B	3.7
16	+22.3	+ 9.8	+16.6		46	4.5	5.5	2.8	»	2.5
17	+20.5	+16.6	+18.0	5.3	46	4.5	6.2	1.8	»	2.8
18	+22.8	+15.5	+18.4		49	6.9	7.3	2.3	»	5.0
19	+22.8	+ 9.2	+16.2	0.8	49	6.3	6.7	3.3	»	4.2
20	+22.3	+10.7	+15.6		49	7.5	5.0	2.3	»	3.8
21	+19.0	+12.2	+14.6	0.8	48	7.4	5.3		E	3.9
22	+17.7	+ 4.0	+11.4		48	8.1	5.7	1.8	B	4.6
23	+18.9	+ 4.4	+11.3	0.2	44	4.1	5.4	1.3	»	2.2
24	+20.8	+ 9.0	+14.3		44	3.3	4.8	1.2	»	1.6
25	+18.9	+ 9.2	+14.3		44	3.8	6.0	0.9	»	2.3
26	+23.7	+ 7.4	+15.3		43	5.8	5.0		E	2.9
27	+21.7	+11.2	+15.3		43	4.9	4.1	1.9	B	2.0
28	+20.0	+13.7	+16.1	5.5	44	4.1	6.0		E	2.5
29	+16.3	+ 9.0	+12.5	1.3	43	5.0	7.9	3.9	B	4.0
30	+18.1	+10.1	+13.6		44	6.0	21.2	2.4	»	12.7
31	+17.6	+10.1	+13.7	0.1	39	3.0	9.5	4.9	»	2.9
		Sum for August		54.1						117.2

Remarks. August 30 and 31 the Fyris was dammed up at Ulva; the values in silt contents for these days are therefore not representative.

September 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+22.2	+ 9.1		+15.1		42	4.9	4.3	2.2	B	2.1
2	+20.8	+11.8		+15.9		43	5.9	5.0	1.8	»	3.0
3	+17.1	+13.8		+15.1	5.9	43	5.9	5.1	3.7	»	3.0
4	+17.9	+10.4		+13.2	3.6	43	5.9	4.0		E	2.4
5	+16.0	+ 5.9		+10.5	⁎2.2	42	4.5	2.9	2.1	B	1.3
6	+17.3	+ 7.0		+11.5	1.2	42	5.9	5.8	1.5	»	3.4
7	+15.9	+12.3		+13.6	0.5	45	9.1	4.4	1.4	»	4.0
8	+19.6	+10.6		+14.4	3.5	43	5.9	1.7	5.1	»	1.0
9	+18.3	+ 7.1		+13.0		42	4.9	4.0	1.2	»	2.0
10	+18.7	+11.4		+14.8		42	4.9	6.4	2.5	»	3.1
11	+19.0	+14.3		+16.5	0.6	43	5.9	6.0		E	3.5
12	+16.8	+ 8.4		+11.8	5.5	43	3.6	5.5	1.7	B	2.0
13	+16.8	+ 9.1		+11.9		43	1.8	3.0	2.3	»	0.5
14	+15.1	+ 3.5		+ 8.8		43	2.7	5.4	3.3	»	1.5
15	+14.8	+ 1.1		+ 7.3		43	4.3	4.4	2.5	»	1.9
16	+17.0	+11.1		+14.5		44	3.2	2.9	2.5	»	0.9
17	+16.3	+ 1.5		+ 8.4		44	3.8	3.2	1.8	»	1.2
18	+16.0	+ 3.9		+ 8.8		44	4.9	3.6		E	1.8
19	+13.5	+10.5		+12.2	1.9	47	4.6	4.0	2.5	B	1.8
20	+15.9	+ 7.8		+11.4	1.6	48	5.6	6.1	2.6	»	3.4
21	+13.0	− 0.4	1	+ 6.6	⁎0.4	46	3.5	3.0	1.0	»	1.1
22	+12.0	+ 1.1		+ 5.7		47	4.1	2.4	2.1	»	1.0
23	+11.2	+ 4.4		+ 7.5		49	5.7	3.8	2.6	»	2.2
24	+11.4	+ 4.6		+ 8.0		48	5.1	6.0	2.1	»	3.1
25	+ 9.8	− 0.7	3	+ 4.6		48	4.5	9.5		E	4.3
26	+10.6	+ 5.5		+ 8.9	1.2	50	5.9	12.9	2.9	B	7.6
27	+13.8	+ 9.9		+12.1	12.8	51	3.7	9.5	1.7	»	3.5
28	+13.4	− 0.4	2	+ 6.1	⁎1.7	52	5.3	4.0	2.3	»	2.1
29	+11.3	+ 6.2		+ 9.1		57	8.2	4.1		E	3.3
30	+19.6	+ 5.5		+13.3		54	6.8	4.2	2.3	B	2.9
		Sum for September			47.1						74.9

October 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ o°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+15.7	+11.1		+12.4	4.5	55	7.6	6.5	2.4	B	4.9
2	+13.9	+ 5.4		+10.2	6.1	55	7.0	5.0		E	3.5
3	+ 7.8	− 1.7	6	+ 3.1	0.2	55	5.9	3.5	1.7	B	2.1
4	+ 7.5	− 0.8	6	+ 2.7		55	7.0	6.0	3.4	»	4.2
5	+ 6.3	− 1.3	5	+ 2.3	0.2	54	5.7	3.6	1.1	»	2.1
6	+ 5.7	− 3.5	11	+ 1.0	0.2	55	5.9	4.5	1.8	»	2.7
7	+ 6.7	+ 1.1		+ 4.2	11.2	56	6.3	6.0	1.9	»	3.8
8	+10.3	+ 3.4		+ 7.3		56	6.3	3.2	2.2	»	2.0
9	+11.4	+ 2.7		+ 6.9		56	9.7	5.5		E	5.3
10	+ 8.9	+ 6.0		+ 7.2		55	8.1	7.7	2.0	B	6.2
11	+ 7.5	+ 6.1		+ 6.5	8.1	56	4.5	7.6	2.9	»	3.4
12	+ 9.8	+ 5.1		+ 7.1		58	7.4	7.1	1.2	»	5.3
13	+ 9.6	+ 7.3		+ 8.6	3.9	60	7.4	5.3	1.6	»	3.9
14	+11.3	+ 7.2		+ 9.2		63	12.9	5.1	2.1	»	6.6
15	+10.8	+ 4.8		+ 8.0	12.9	63	14.1	4.3	2.7	»	6.1
16	+11.2	+ 5.9		+ 7.7		64	10.6	3.8		E	4.0
17	+10.4	+ 6.9		+ 8.2	0.2	63	8.9	3.2	0.6	B	2.8
18	+ 9.2	+ 0.2		+ 5.9		62	8.4	4.3	2.2	»	3.6
19	+ 6.4	+ 1.0		+ 3.7		60	6.9	6.3	1.9	»	4.3
20	+ 5.7	− 0.9	6	+ 2.0		59	7.0	4.5	2.2	»	3.2
21	+ 4.0	− 5.8	16	− 1.8		59	7.0	3.7	1.7	»	2.6
22	+ 3.3	− 0.9	2	+ 2.0	✱7.5	60	6.9	6.1	2.7	»	4.2
23	+11.2	+ 1.8		+ 6.3	1.4	64	9.5	8.1		E	7.7
24	+11.8	+ 3.6		+ 7.3	0.2	64	8.5	10.1	3.0	B	8.6
25	+ 4.9	− 2.6	12	+ 1.0		63	7.1	18.4	4.2	»	13.1
26	+ 5.0	− 4.6	14	− 0.2		62	6.5	13.1	2.8	»	8.5
27	+ 3.8	− 3.9	17	− 0.7		61	6.8	17.4	3.9	»	11.8
28	+ 3.3	− 3.1	15	+ 0.1	✱0.2	59	4.7	11.9	4.7	»	5.6
29	+ 2.1	− 2.4	10	± 0.0		60	4.8	13.5	3.7	»	6.5
30	+ 3.1	− 2.1	16	− 0.4		60	4.8	10.7		E	5.1
31	+ 2.2	− 4.7	18	− 2.0		61	5.8	9.9	3.3	B	5.7
			Sum for October		52.5						159.4

November 1932.

Date	Temperature				Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
	max.	min.	number of hours ≤ 0°	mean								
1	+0.7	−4.6	21	−2.1	✳0.2	60	5.1	13.3	3.7	B	10.5	6.8
2	+0.5	−3.0	21	−1.5	✳0.2	60	7.0	13.6	1.8	»	9.6	9.5
3	+3.0	−1.5	4	+1.8	✳3.4	60	7.0	7.5	0.4	»		5.3
4	+3.3	+2.1		+2.4	✳1.8	61	7.8	25.4	3.2	»	22.0	19.8
5	+8.8	+2.8		+6.5	24.8	64	8.6	37.1	5.4	»		31.9
6	+4.8	−2.5	6	+1.9	8.6	86	16.2	37.1		E		60.1
7	+3.1	−1.8	3	+0.8		88	16.6	37.1	15.1	B	29.8	61.6
8	+4.1	+1.0		+2.4		86	15.6	30.8	5.1	»		48.0
9	+3.1	+0.9		+1.9	✳0.2	84	15.4	13.6	3.7	»	9.6	20.9
10	+6.4	+3.7		+5.2	1.9	84	14.7	11.6	2.9	»		17.1
11	+6.8	−0.2	1	+4.0	1.1	84	15.0	15.1	6.3	»	8.9	22.7
12	+5.2	−1.8	11	+0.8		82	13.4	11.2	3.1	»		15.0
13	+1.7	−4.1	18	−1.9		82	13.4	7.8		E		10.5
14	−1.1	−3.9	24	−2.5	✳0.2	83	17.3	4.4	2.4	B	2.7	7.6
15	+0.3	−2.5	18	−0.7		80	12.1	6.9	3.2	»		8.3
16	+4.0	−2.2	6	+1.2		78	11.2	8.9		E	5.9	10.0
17	+2.6	−2.0	7	+0.7	0.4	77	10.1	6.7	0.2	B		6.8
18	+6.3	−4.4	11	+1.0	✳0.4	76	13.2	10.4	1.7	»	10.8	13.7
19	+1.2	−3.4	22	−1.4		76	13.0	10.7	1.3	»		13.9
20	+2.1	−0.2	1	+0.9		74	11.4	8.7		E		9.9
21	+2.3	+0.5		+1.6	0.8	73	11.0	6.6	2.6	B	7.0	7.3
22	+4.9	+2.2		+3.3	4.0	73	12.7	7.3	2.6	»		9.3
23	+4.5	+2.1		+3.0	4.0	80	16.0	12.0	1.7	»	9.9	19.2
24	+3.8	+0.9		+2.7	7.2	75	12.2	18.5	4.0	»	5.0	22.6
25	+3.4	+0.3		+2.0		77	13.5	7.8	1.5	»	4.9	10.5
26	+2.2	−5.5	13	−0.7		77	13.2	13.5	2.9	»		17.8
27	+3.4	−5.0	16	−0.7	2.4	76	12.6	11.7		E		14.7
28	+5.3	+3.5		+4.1	5.2	78	13.4	9.8	1.8	B	9.9	13.1
29	+3.4	−3.9	13	−0.1	1.0	82	15.0	8.5	3.5	»		12.8
30	+9.2	+3.3		+7.8		84	16.0	9.6	2.9	»	10.3	15.4
Sum for November					68.3							542.1

December 1932.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+8.4	+3.4		+6.0	0.7	83	15.3	6.1	3.1	B	9.3
2	+4.3	+3.0		+3.7	1.9	83	15.3	9.7	2.3	»	14.8
3	+5.3	+0.1		+2.2		81	14.4	8.4		E	12.1
4	+4.8	+1.6		+3.8	2.6	81	14.4	7.1		»	10.2
5	+4.5	−0.8	3	+1.5	2.7	81	12.9	5.8	1.0	B	7.5
6	+2.2	+0.2		+1.3		79	12.1	7.0	3.5	»	8.5
7	+0.3	−1.2	18	−0.4	*1.5	78	11.2	5.5	1.9	»	6.2
8	−1.6	−4.2	24	−2.9	*0.2	76	9.4	11.9	2.6	»	11.2
9	−1.2	−5.9	24	−3.3		75	9.0	8.9	1.8	»	8.0
10	+1.1	−5.5	18	−1.5		77	10.4	13.9	1.6	»	14.5
11	+0.2	−4.1	22	−1.7		78	10.7	11.0		E	11.8
12	+3.1	−4.6	12	−0.3		77	11.3	8.1	1.5	B	9.2
13	−2.3	−8.6	24	−5.4	*0.1	77	11.3	12.6	2.3	»	14.2
14	+0.3	−5.3	20	−1.1		76	11.2	10.9	8.6	»	12.2
15	+1.3	±0.0	4	+0.7	*0.2	73	9.9	11.8	0.8	»	11.7
16	+3.1	+0.1		+1.9	2.1	73	10.6	14.0	2.7	»	14.8
17	+5.0	+2.7		+4.2	3.3	73	9.9	8.5	3.2	»	8.4
18	+9.0	+5.6		+7.6	0.3	78	11.3	8.8		E	9.9
19	+9.4	+6.1		+8.2		78	12.6	9.1	3.2	B	11.5
20	+9.4	+4.9		+7.2		78	12.6	9.3		E	11.7
21	+6.6	+1.3		+5.2		77	11.8	9.5	3.9	B	11.2
22	+1.7	−3.1	14	+0.4	0.3	76	10.9	7.5		E	8.2
23	+3.3	+1.9		+3.0	0.6	76	11.4	5.5	2.9	B	6.3
24	+4.0	+0.9		+2.8		74	10.5	5.1	1.6	»	5.4
25	+4.8	+0.9		+3.7		74	10.5	6.5		E	6.8
26	+1.2	−1.0	10	+0.2	0.3	74	10.5	8.0		»	8.4
27	+4.5	+1.2		+2.7		74	10.5	9.5	3.5	B	10.0
28	+5.0	+3.3		+4.4		75	10.9	4.9	1.5	»	5.3
29	+5.8	+4.5		+5.1		75	10.9	14.6	2.9	»	15.9
30	+6.6	+1.9		+4.4		75	11.3	5.6	2.1	»	6.3
31	+1.7	−0.9	16	±0.0		72	11.0	18.6	2.9	»	20.5
Sum for December					16.1						322.0

Remarks. Cover of snow at Uppsala Dec. 7—14, cover of ice on the Fyris Dec. 12—17.

Januari 1933.

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	+ 1.5	− 1.6	19	− 0.4		70	10.6	20.9		E	22.2
2	+ 2.7	+ 1.6		+ 2.3		69	10.6	22.3	2.3	B	23.6
3	+ 3.1	+ 1.6		+ 2.4	0.1	72	12.3	18.1	3.3	»	22.3
4	+ 6.9	+ 2.8		+ 4.9	0.2	69	11.7	18.1	3.3	»	21.2
5	+ 5.2	+ 1.3		+ 3.1	0.1	66	9.5	17.9	2.3	»	17.0
6	+ 3.6	+ 2.3		+ 3.3	1.1	67	10.4	17.9		E	19.5
7	+ 3.8	+ 1.8		+ 3.0		66	9.2	17.9	3.1	B	16.5
8	+ 1.9	+ 0.1		+ 0.9		65	9.2	16.4		E	15.1
9	+ 2.9	+ 1.2		+ 1.8	✳4.5	73	13.0	14.9	3.0	B	19.4
10	+ 1.7	+ 0.5		+ 1.3	✳9.5	68	9.6	14.3	4.4	»	13.7
11	+ 1.7	− 1.0	6	+ 0.7	1.0	72	12.0	13.6	3.8	»	16.3
12	− 0.4	− 1.7	24	− 0.9	✳0.1	72	12.3	12.9	2.1	»	15.9
13	± 0.0	− 2.3	24	− 0.9		72	13.1	6.5	2.0	»	8.5
14	− 1.7	− 2.9	24	− 2.1		69	11.5	4.7	2.1	»	5.4
15	− 1.4	− 3.5	24	− 2.5		71	12.2	5.4		E	6.6
16	− 2.4	− 4.5	24	− 3.1		72	13.3	6.0	0.9	B	8.0
17	− 2.3	− 5.3	24	− 3.6	✳0.2	71	12.9	16.4	4.1	»	21.2
18	− 5.0	− 6.6	24	− 5.5	✳0.4	68	12.4	3.1	0.8	»	3.8
19	− 5.8	− 9.1	24	− 7.4	✳3.9	69	13.2	4.7	0.8	»	6.2
20	− 7.1	− 12.4	24	− 8.7	✳0.8	69	13.2	3.1	0.9	»	4.1
21	− 8.2	− 10.5	24	− 9.5	✳0.3	67	12.2	4.1	1.4	»	5.0
22	− 8.4	− 11.2	24	− 9.8	✳0.4	63	9.1	3.2		E	2.9
23	− 10.0	− 22.3	24	− 15.5		66	10.6	2.2	1.7	B	2.3
24	− 6.6	− 20.3	24	− 10.0		67	12.0	6.5	2.6	»	7.8
25	− 2.9	− 6.3	24	− 4.1	✳1.7	67	12.5	4.6	2.7	»	5.8
26	− 0.5	− 4.3	24	− 2.2		65	13.1	5.1	2.7	»	6.7
27	− 0.7	− 5.7	24	− 2.5		65	13.1	4.9	2.7	»	6.4
28	+ 3.2	− 2.7	14	− 0.1		63	11.5	4.5	1.7	»	5.2
29	+ 5.3	− 4.9	14	± 0.0		58	10.7	5.1		E	5.5
30	+ 0.8	− 6.1	21	− 3.2	✳0.1	60	12.5	5.8	1.4	B	7.3
31	− 3.0	− 5.3	24	− 4.6	✳0.1	59	11.8	4.9	2.5	»	5.8
			Sum for January		26.0						347.2

Remarks. Cover of snow at Uppsala January 9, 17—31, cover of ice on the Fyris from Jan. 14.

February 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hours
1	−0.4	− 4.0	24	− 1.8	✱1.5	59	11.8	5.5	1.6	B	6.5
2	+3.0	− 3.5	5	+ 0.9	5.9	58	11.3	5.2	2.8	»	5.9
3	+3.2	+ 0.6		+ 1.8	✱0.4	58	11.7	4.4	1.3	»	5.1
4	+2.5	− 4.4	15	− 0.8		59	12.4	12.5	1.1	»	15.5
5	+1.8	− 3.0	4	+ 0.4		55	9.7	8.2		E	8.0
6	+1.8	− 9.0	17	− 2.7		57	10.5	3.9	1.5	B	4.1
7	±0.0	−10.8	24	− 5.8		55	10.7	6.7	1.8	»	7.2
8	−1.7	− 9.5	24	− 4.9		55	10.7	7.0	1.9	»	7.5
9	+2.6	− 1.5	2	+ 0.8	0.7	57	13.0	5.3	2.3	»	6.9
10	+6.0	− 2.1	3	+ 3.3	3.9	58	12.5	3.0	2.0	»	3.8
11	−0.2	− 5.1	24	− 2.8		57	11.7	5.4	0.4	»	6.3
12	−0.2	− 7.9	24	− 4.3		53	8.7	6.8		E	5.9
13	+3.0	− 2.7	7	+ 0.8	✱0.5	57	10.5	8.1	1.1	B	8.5
14	+2.8	− 6.7	18	− 2.6	✱0.4	56	10.0	6 1	1.2	»	6.1
15	−1.3	− 7.1	24	− 3.9		54	8.7	5.6	1.1	»	4.9
16	−5.3	−10.4	24	− 7.8	✱4.5	55	8.2	5.7	1.5	»	4.7
17	−6.3	− 9.5	24	− 8.1	✱0.5	55	8.2	5.8	1.9	»	4.8
18	−5.1	−10.9	24	− 7.9	✱0.4	57	8,8	4.6	1.9	»	4.0
19	−5.5	−15.6	24	−10.4	✱0.6	52	6.2	5.0		E	3.1
20	−8.5	−18.3	24	−14.7		56	8.9	5.4	2.5	B	4.8
21	−5.4	−16.1	24	−11.7	✱0.1	56	8.9	7.6	2.3	»	6.8
22	−1.4	−10.8	24	− 4.6	✱0.2	54	9.1	5.1	1.5	»	4.6
23	−4.6	− 9.6	24	− 6.5	✱1.6	54	9.1	5.4	2.8	»	4.9
24	−6.8	− 9.9	24	− 8.5	✱5.0	54	7.9	4.9	1.6	»	3.9
25	−4.9	− 6.5	24	− 5.1	✱0.8	54	9.1	7.3	4.1	»	6.6
26	−4.0	− 6.4	24	− 5.2	✱1.0	50	6.0	7.3		E	4.4
27	−2.6	−12.9	24	− 5.3		52	7.7	4.8	2.6	B	3.7
28	−2.6	−10.9	24	− 4.2		52	8.4	6.4	3.4	»	5.4
			Sum for February		26.5						163.9

Remarks. Cover of snow at Uppsala February 1—5 and 13—28, cover of ice on the Fyris February 1—28.

March 1933.

Date	Temperature				Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
	max.	min.	number of hours ≤ 0°	mean							
1	− 1.0	−14.1	24	−5.6		52	8.7	4.1	2.5	B	3.6
2	+ 1.1	−15.0	21	−7.5		49	6.4	19.8	3.2	»	12.7
3	− 1.7	−11.4	24	−3.1		51	9.7	18.6	2.8	»	18.0
4	− 0.9	− 3.6	24	−2.4		48	6.3	22.6	3.1	»	14.2
5	− 2.3	− 4.9	24	−3.6		46	5.5	22.1		E	12.2
6	− 3.5	− 5.2	24	−4.2	✳ 0.2	49	8.0	21.5	3.3	B	17.2
7	− 2.1	− 5.7	24	−3.6		48	8.2	84.7	7.6	»	69.5
8	− 1.7	− 4.8	24	−3.2		45	5.9	17.9	3.3	»	10.6
9	+ 0.2	− 2.1	22	−1.2		42	3.0	26.6	3.2	»	8.0
10	+ 0.7	− 1.7	19	−0.6		44	7.0	86.4	8.8	»	60.5
11	+ 2.8	+ 0.6		+1.8		43	5.1	30.5	3.8	»	15.6
12	+ 2.9	− 0.7	6	+1.2		42	5.3	53.7		E	28.5
13	+ 7.1	− 0.9	8	+1.6		44	7.9	87.8	7.6	A	69.4
14	+ 4.0	− 1.4	7	+0.9		47	10.5	25.4	4.8	»	26.7
15	+ 5.4	− 0.7	4	+1.3		47	10.5	29.4	4.6	»	30.9
16	+ 6.3	+ 1.2		+3.2		47	10.1	27.5	3.5	B	27.8
17	+ 7.4	+ 3.0		+4.4	0.5	47	11.1	26.6	4.6	»	29.5
18	+ 6.8	+ 2.8		+4.7	9.0	51	13.2	23.4	5.2	»	30.9
19	+ 8.4	− 8.6	16	−0.5	✳11.0	55	13.0	22.5		E	29.3
20	− 2.2	−10.0	24	−6.1	✳ 7.6	68	18.9	21.6	4.7	B	40.8
21	− 2.1	− 9.9	24	−5.1	✳ 0.5	67	18.4	23.4	4.5	»	43.1
22	+ 2.5	− 7.1	19	−2.7		58	14.1	27.3	2.6	»	10.3
23	+ 3.4	−12.1	16	−3.8		58	14.1	39.7	5.0	»	56.0
24	+ 4.2	− 3.7	10	+0.4		56	13.9	17.6	3.5	»	24.5
25	+11.2	+ 1 1		+5.3		53	12.1	30.8	4.5	»	37.3
26	+10.6	+ 0.5		+5.2		55	13.0	40.7		E	52.9
27	+ 9.9	− 0.1	2	+4.3		65	18.3	50.6	4.2	B	92.6
28	+ 9.9	+ 2.1		+5.0		68	18.7	35.5	4.5	»	66.4
29	+14.7	+ 1.0		+7.5		73	20.9	24.6	13.3	»	51.4
30	+10,4	+ 2.4		+7.1	0.2	76	21.4	11.5	2.5	»	24.6
31	+13.8	+ 1.5		+7.0		75	20.7	2.6	2.2	»	5.4
			Sum for March		29.0						1020 4

Remarks. Cover of snow at Uppsala March 1—11 and 19—25, cover of ice on the Fyris March 1—28. From February 29 there were some piling works at the western bank of the Fyris near the sampling place. From March 14 the samples were procured north of that place; the analysis for March 1—13 are not representative.

April 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silts mg/liter	Ignition loss mg/liter	Method	Load in tous/24 hoars
1	+ 8.6	+0.9		+4.1		70	18.2	10.6	1.5	B	19.3
2	+10.7	−0.9	6	+4.4		72	18.3	10.2	3.8	»	18.7
3	+ 2.9	−3.0	17	−1.0		73	19.2	6.4	1.3	»	12.3
4	+ 5.6	−1.6	15	+0.4	✳6.0	70	17.3	9.1	1.2	»	15.7
5	+ 1.7	−0.9	12	+0.2	✳0.1	70	17.3	5.2	4.7	»	9.0
6	+ 6.5	−0.5	4	+1.9		70	17.3	10.5	4.1	»	18.2
7	+ 6.9	−1.4	4	+2.7		68	15.2	9.7	2.6	»	14.7
8	+ 3.1	−6.3	14	−1.2		68	15.2	9.9	6.1	»	15.0
9	+ 9.2	−2.8	5	+3.4		67	14.8	10.7	2.4	»	15.8
10	+13.2	+3.1		+7.2	0.1	68	15.2	9.8	3.3	»	14.9
11	+12.1	+5.5		+8.2		69	15.7	9.7	3.1	»	15.2
12	+10.4	+6.8		+8.8		70	15.5	6.8	—	»	10.5
13	+11.7	+4.8		+7.1	4.2	70	13.5	5.3	2.8	»	7.2
14	+11 3	+0.7		+5.0	0.8	60	8.3	8.6	2.1	»	7.1
15	+ 8.3	−4.7	9	+1.8		66	12.0	10.9	5.0	»	13.1
16	+ 4.9	−1.6	7	+2.0	✳1.1	59	4.0	8.5	3.3	»	3.4
17	− 1.0	−2.6	24	−1.8	✳0.2	57	5.0	6.2	2.4	»	3.1
18	+ 0.6	−1.7	22	−0.8	✳2.4	58	8.1	2.4	2.1	»	1.9
19	+ 0.5	−0,6	9	+0.1	✳0.6	52	4.6	5.4	2.4	»	2.5
20	+ 2.0	−3.4	11	−0.2		53	4.8	10.1	2.4	»	4.8
21	+ 2.0	−5.1	15	−1.5		56	6.5	7.6	2.0	»	4.9
22	+ 7.3	−7.4	10	+0.4		60	9.9	6.5	2.5	»	6.4
23	+11.3	+0.2		+6.3	3.1	59	7.9	9.2	2.0	»	7.3
24	+ 8.9	−0.5	4	+4.0	✳0.2	61	9.4	10.0	1.4	»	9.4
25	+11.5	−2.9	7	+4.4		61	10.5	5.3	2.5	»	5.6
26	+14.1	+0.2		+7.0		61	11.5	6.7	2.6	»	7.7
27	+17.4	−0.1	1	+8.7		61	12.5	6.8	3.9	»	8.5
28	+14.5	−1.2	3	+7.5		61	11.8	7.5		E	8.9
29	+14.8	+0.9		+8.0		60	11.9	8.1	2.2	B	9.6
30	+17.5	−1.0	2	+8.9		58	10.7	7.9	4.8	»	8.5
			Sum for April		19.6						299.2

Remark. Cover of snow at Uppsala April 4, 5 and 16—18.

May 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+15.0	+1.1		+7.6	✱0.8	56	9.7	6.9	2.9	B	6.7
2	+8.6	−2.6	3	+3.5		56	9.5	7.2	3.7	»	6.8
3	+12.0	+1.2		+6.1		56	9.7	8.2	3.6	»	8.0
4	+15.0	−1.4	4	+7.2		53	10.2	5.6	—	»	5.7
5	+12.5	−3.2	5	+5.0		55	11.2	7.9	2.9	»	8.8
6	+16.6	−0.8	1	+8.0		54	10.7	10.0	3.9	»	10.7
7	+19.2	+6.0		+12.9	2.4	51	10.3	4.3	5.2	»	4.4
8	+8.8	+2.5		+4.1	6.7	51	10.3	8.9	2.5	»	9.2
9	+11.0	+0.7		+6.2		50	9.2	8.0	2.9	»	7.4
10	+14.2	+4.9		+8.8	0.7	51	7.2	8.1		E	5.8
11	+14.5	+1.1		+7.8		49	8.3	8.1	2.4	B	6.7
12	+13.6	+3.6		+7.4		47	6.0	8.4	1.3	»	5.0
13	+9.0	+3.1		+5.9	10.5	48	5.8	8.6	3.1	»	5.0
14	+6.8	+4.4		+5.4	2.9	49	5.3	9.1	2.7	»	4.8
15	+7.0	+2.7		+4.6	0.2	53	8.1	8.2	2.6	»	6.6
16	+7.6	+3.0		+4.7		51	6.2	9.0	3.4	»	5.6
17	+6.4	+3.6		+4.9	1.0	51	7.3	8.8	3.1	»	6.4
18	+9.6	+5.7		+6.6	6.9	54	9.5	9.0	3.0	»	8.6
19	+15.5	+1.4		+9.6		54	9.5	9.3	1.9	»	8.8
20	+19.3	+7.1		+13.0		54	9.0	11.6	2.9	»	10.4
21	+19.0	+8.7		+14.2		50	6.5	5.8	3.6	»	3.8
22	+13.8	−0.8	3	+7.9		52	8.0	10.3	2.5	»	8.2
23	+15.8	+1.9		+8.1		47	5.0	10.4	3.6	»	5.2
24	+11.8	+3.2		+8.0		47	5.0	14.7	4.9	»	7.4
25	+17.1	+3.5		+10.4		43	2.9	10.8	3.0	»	3.1
26	+13.7	+5.1		+8.7	0.2	46	5.7	17.3	3.6	»	9.9
27	+18.2	+5.8		+12.2		44	4.7	15.0	1.8	»	8.6
28	+15.7	+3.3		+10.2		43	3.9	11.6	—	»	4.5
29	+17.6	+1.3		+10.9		43	4.6	9.7	3.3	»	4.5
30	+21.8	+9.6		+14.4	0.8	43	5.2	9.4	3.9	»	4.9
31	+19.1	+3.0		+11.8		44	6.2	9.6	5.2	»	6.0
			Sum for May		34.9						207.5

June 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+21.1	+ 7.4		+13.4	2.5	41	3.8	11.7	3.7	B	4.4
2	+17.8	+ 3.5		+10.7	9.0	42	4.2	7.6	4.9	»	3.2
3	+13.7	— 0.1	1	+ 7.6	3.6	42	5.0	10.3	4.9	»	5.2
4	+17.1	+ 5.2		+11.7		42	5.5	9.6	4.2	»	5.3
5	+21.7	+10.6		+15.3	2.2	41	5.1	12.1	3.3	»	6.2
6	+20.4	+ 6.8		+13.3		40	4.8	10.0	2.9	»	4.8
7	+20.9	+ 5.7		+14.5		40	4.8	14.3	3.4	»	6.9
8	+24.3	+ 7.2		+16.5		39	4.0	8.1	3.3	»	3.2
9	+23.4	+ 7.0		+16.5		38	4.3	9.3	3.1	»	4.0
10	+24.0	+10.2		+17.6		37	3.8	9.1	3.2	»	3.5
11	+25.7	+ 9.4		+18.2		35	2.7	6.5	2.1	»	1.8
12	+25.9	+10.0		+18.9		35	3.3	6.2	1.8	»	2.0
13	+24.1	+ 6.6		+16.0		31	1.9	8.4	3.1	»	1.6
14	+24.4	+ 7.2		+16.9		33	2.9	7.0	3.9	»	2.0
15	+26.9	+ 7.1		+18.2		33	3.6	8.6	2.8	»	3.1
16	+26.0	+ 7.9		+18.2		32	3.0	11.4	5.3	»	3.4
17	+26.2	+ 9.6		+18.6		31	3.8	8.2	3.7	»	3.1
18	+23.9	+14.5		+18.4	0.1	29	3.0	8.2	2.4	»	2.5
19	+21.1	+11.7		+16.9		26	2.0	6.6	2.6	»	1.3
20	+25.2	+15.5		+20.5		26	2.2	7.3		E	1.6
21	+23.4	+14.0		+18.3	0.2	25	1.7	8.1	3.3	B	1.4
22	+24.9	+ 5.9		+17.2		25	1.7	8.4	2.4	»	1.4
23	+25.0	+ 5.8		+17.6		25	1.9	3.8	3.3	»	0.7
24	+25.1	+10.5		+18.4		21	1.8	7.2	2.7	»	1.3
25	+17.4	+ 2.8		+11.8		21	1.4	8.1	2.5	»	1.1
26	+20.1	+ 5.7		+11.4	2.0	21	1.7	7.4	1.6	»	1.3
27	+21.7	+11.4		+14.5	0.2	20	1.7	8.8	3.0	»	1.5
28	+19.6	+ 9.9		+13.5	3.1	19	1.4	6.8	2.9	»	1.0
29	+15.5	+ 4.3		+10.1		21	1.7	6.4	2.6	»	1.1
30	+15.5	+11.0		+12.4	3.7	22	1.6	4.6	1.4	»	0.7
			Sum for June		25.1						80.6

July 1933.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours	Remarks
1	+19.4	+10.2	+14.7	1.0	20	1.4	6.4	1.1	B	0.9	
2	+21.6	+14.0	+16.9	0.1	22	1.5	5.5	1.5	»	0.8	
3	+25.2	+11.2	+18.3	1.4	22	1.5	6.5	1.7	»	1.0	
4	+23.5	+ 7.3	+15.3		21	1.4	7.8	2.1	»	1.1	
5	+22.1	+14.3	+17.2		22	1.3	7.2	2.8	»	0.9	
6	+25.2	+12.4	+19.3		23	1.5	8.7	3.2	»	1.3	
7	+29.7	+10.8	+21.4		24	1.6	8.4	2.4	»	1.3	
8	+31.7	+12.5	+23.2		26	1.7	8.6	2.9	»	1.5	
9	+35.0	+17.5	+26.6		28	2.1	7.5	2.3	»	1.6	
10	+37.4	+16.6	+26.8		27	1.9	8.2	2.9	»	1.6	
11	+32.4	+16.0	+24.6		28	2.2	8.8	2.1	»	1.9	
12	+28.9	+17.7	+21.6	0.9	29	2.8	8.1	2.6	»	2.3	
13	+23.5	+15.3	+18.1	3.2	30	3.4	8.2	2.5	»	2.8	
14	+23.9	+14.2	+17.9	2.1	30	2.6	8.0	2.6	»	2.1	
15	+22.5	+13.4	+16.9	0.1	30	2.9	10.7	2.5	»	3.1	
16	+23.0	+13.2	+17.7	1.2	29	2.2	11.6	2.7	»	2.6	
17	+24.0	+12.4	+18.5	0.5	29	2.1	11.4	1.8	»	0.7	
					31	3.2	10.1	2.1	»	0.4	15 o'clock
					33	4.6	14.1	3.1	»	0.8	18 »
					34	5.2	12.5	3.1	»	3.0	21 »
										4.9	
18	+18.0	+12.9	+14.9	22.9	35	3.7	12.1	2.7	»	4.5	
19	+20.8	+10.0	+14.5	6.6	35	2.3	16.3	5.7	»	3.7	
20	+19.8	+12.0	+15.5	12.2	38	3.2	19.8	3.1	»	6.3	
21	+24.6	+12.9	+17.7	6.5	38	3.2	11.7	2.6	»	3.7	
22	+26.4	+13,7	+19.9		40	4.7	11.4	2.9	»	5.4	
23	+28.4	+13.5	+20.6		39	4.1	8.8	2.6	»	3.6	
24	+25.1	+15.3	+19.3	1.3	38	2.4	10.9	2.7	»	2.6	
25	+18.7	+11.5	+14.6	34.8	42	5.5	16.0	4.0	»	8.8	
26	+22.6	+11.9	+16.8	3.9	44	6.0	21.9	3.7	»	13.1	
27	+20.4	+12.3	+15.3	1.9	43	4.5	16.8	3.5	»	7.6	
28	+25.1	+13.6	+19.0		44	6.0	14.9	3.2	»	8.9	
29	+22.4	+15.4	+18.2	5.0	48	1.1	20.7	3.4	»	2.3	
30	+22.0	+11.4	+16.8		45	6.0	17.7		E	10.6	
31	+23.0	+12.1	+16.6	0.5	46	6.3	14.4	2.8	B	9.1	
Sum for July				105.1						121.9	

August 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+23.5	+12.1		+16.8		43	4.4	8.9	3.4	B	3.9
2	+20.9	+13.1		+16.1	0.9	43	4.4	8.3	3.2	»	3.7
3	+22.9	+14.2		+17.9		45	5.0	10.2	4.4	»	5.1
4	+23.0	+14.9		+18.6	4.9	47	5.7	7.6	2.3	»	4.3
5	+20.8	+11.0		+15.1	1.3	44	3.0	9.0	2.4	»	2.7
6	+21.0	+ 9.3		+15.2		43	3.5	7.8	1.8	»	2.7
7	+23.5	+16.2		+18.4		46	5.0	8.2	2.8	»	4.1
8	+23.3	+ 9.4		+14.5	9.7	45	4.6	9.3	2.4	»	4.3
9	+21.9	+ 8.5		+14.4	0.7	45	4.6	9.2	2.6	»	4.2
10	+23.1	+12.3		+17.2	10.5	49	6.4	9.4	3.2	»	6.0
11	+18.1	+ 9.4		+12.7	5.0	50	5.7	9.0		»	5.1
12	+18.5	+ 7.1		+12.7	5.9	49	5.3	8.6	3,4	»	4.6
13	+19.4	+ 6.6		+12.9		48	4.8	2.4	2.0	»	1.2
14	+20.2	+ 9.3		+14.4		50	5.7	6.6	1.9	»	3.8
15	+20.5	+11.5		+15.9		51	6.3	9.6	1.6	»	6.0
16	+22.7	+10.6		+16.0		51	8.1	7.5	2.4	»	6.1
17	+19.8	+12.6		+15.9	0.3	51	8.1	9.0	2.4	»	7.3
18	+20.1	+11.0		+15.3	2.1	51	6.0	9.3	2.7	»	5.6
19	+19.8	+12.3		+15.4	0.1	51	5.1	6.8	2.7	»	3.5
20	+20.3	+ 8.1		+13.9	0.2	51	4.9	6.3	2.0	»	3.1
21	+21.7	+ 5.5		+13.4	0.9	52	6.1	5.8		E	3.5
22	+20.9	+ 5.3		+12.9	0.1	53	6.6	5.3	3.4	B	3.5
23	+21.6	+ 7.4		+14.3	0.1	53	7.0	6.5	2.6	»	4.6
24	+17.4	+12.1		+14.4	14.0	54	4.6	6.8		»	3.1
25	+19.5	+11.1		+14.9		52	3.9	7.1	4.1	»	2.8
26	+16.8	+ 9.1		+13.0		50	2.5	6.8	2.6	»	1.7
27	+20.0	+ 7.8		+13.8		52	5.1	7.4	1.2	»	3.8
28	+22.7	+10.4		+16.4		53	7.3	5.2	2.2	»	3.8
29	+24.7	+14.9		+18.8		55	7.3	6.3	2.2	»	4.6
30	+25.8	+13.1		+18.9		54	7.5	7.1	3.1	»	5.3
31	+25.7	+15.9		+19.6		55	8.9	6.2	2.1	»	5.5
				Sum for August	56.7						129.5

September 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+22.8	+11.7		+16.2		53	8.1	6.3	2.5	B	5.1
2	+18.2	+10.3		+13.6	2.2	51	6.6	6.1	2.5	»	4.0
3	+16.5	+11.1		+13.7	0.8	45	2.8	5.6	2.2	»	1.6
4	+16.7	+ 4.2		+10.4		48	4.8	5.7	1.4	»	2.7
5	+21.6	+ 8.6		+13.9		47	4.2	7.3	2.0	»	3.1
6	+17.0	+ 6.1		+11.9		47	4.2	6.4	1.4	»	2.7
7	+15.0	+ 3.5		+ 9.1		45	3.4	5.7	1.1	»	1.9
8	+15.1	+ 3.4		+ 8.9		45	4.0	5.9	1.7	»	2.4
9	+16.2	+ 5.6		+10.6		44	4.2	7.2	2.2	»	3.0
10	+21.6	+10.4		+14.8		44	4.6	5.7	0.9	»	2.6
11	+26.0	+ 7.4		+15.8		44	4.6	7.1	3.0	»	3.3
12	+19.9	+ 3.7		+11.6		42	4.0	9.6	3.5	»	3.8
13	+18.5	+11.4		+13.8	4.4	46	8.5	7.7		E	6.5
14	+13.9	+ 8.9		+11,2	7.5	40	3.7	6.8	3.1	B	2.5
15	+11.4	+ 1.2		+ 6.7		39	2.8	7.7	3.7	»	2.2
16	+13.7	+ 1.2		+ 6.5		38	2.6	9.6	4.2	»	2.5
17	+13.8	+ 0.9		+ 6.5		34	1.6	8.4	2.6	»	1.3
18	+13.2	+ 8.7		+10.3		36	3.3	2.8	2.3	»	0.9
19	+14.4	− 0.6	4	+ 6.2		34	2.2	5.1	2.8	»	1.1
20	+11.0	+ 6.4		+10.2	3.8	33	2.6	5.8	2.6	»	1.5
21	+12.3	+ 7.0		+10.6	1.2	32	2.2	7.0	1.7	»	1.5
22	+12.8	+ 8.0		+10.1	5.1	34	2.9	13.2	1.4	»	3.8
23	+13.1	+ 9.3		+11.2	7.0	33	2.6	8.8	2.4	»	2.3
24	+14.4	+ 7.4		+11.2	1.6	35	3.5	8.8	5.9	»	3.1
25	+12.2	+10.1		+11.6	3.8	35	3.8	8.2	1.8	»	3.1
26	+15.7	+12.0		+13.4	0.2	33	2.7	7.4	2.9	»	2.0
27	+14.7	+11.6		+12.9	0.1	32	2.5	8.0	1.9	»	2.0
28	+12.7	+10.6		+11.6	0.7	32	2.5	7.3	1.8	»	1.8
29	+12.3	+10.9		+11.6	0.2	32	2.7	35.6	2.3	»	9.6
30	+14.1	+11.1		+12·4	0.1	32	2.7	8.5	2.3	»	2.3
Sum for September					39.0						86.2

October 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge $m^3/sec.$	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+12.7	+8.3		+10.0	0.3	30	2.4	11.0	2.3	B	2.6
2	+12.6	+7.9		+10.0	0.3	30	2.2	8.0	2.0	»	1.8
3	+ 9.9	+1.3		+ 5.2	0.8	28	1.6	6.0	1.9	»	1.0
4	+ 9.2	+1.1		+ 4.7		30	3.7	8.0	2.0	»	3.0
5	+10.3	+3.7		+ 7.2	1.8	28	1.7	11.0	1.5	»	1.9
6	+10.8	+1.2		+ 6.2	3.4	29	2.5	10.8	3.7	»	2.7
7	+11.2	+6.0		+ 8.5		29	2.9	13.1	2.5	»	3.8
8	+13.9	+2.0		+ 7.5		27	1.9	18.0	1.9	»	3.4
9	+ 9.7	−1.5	5	+ 3.4		26	2.5	8.8	1.9	»	2.2
10	+ 7.6	+1.4		+ 4.1		26	2.2	8.8	2.9	»	1.9
11	+14.2	+8.1		+11.8	3.8	31	4.7	5.1	1.6	»	2.4
12	+18.4	+9.0		+13.9	2.3	32	2.3	5.9	1.8	»	1.4
13	+12.3	−0.9	2	+ 5.6		31	4.6	5.5	3.4	»	2.5
14	+10.2	+0.6		+ 4.3		29	2.7	4.9	3.2	»	1.3
15	+11.3	+5.8		+ 9.8		29	3.0	4.6	2.4	»	1.4
16	+13.6	+7.8		+10.1		27	2.2	4.2	2.3	»	0.9
17	+11.8	+3.8		+ 8.1		27	2.2	3.5	0.2	»	0.8
18	+11.0	+6.0		+ 8.2	0.1	28	2.1	3.7	1.4	»	0.8
19	+ 9.6	+1.6		+ 4.5	✱0.3	28	2.0	5.0	—	»	1.0
20	+ 9.2	+3.7		+ 6.9		27	1.7	6.6	1.6	»	1.1
21	+ 7.6	+6.6		+ 7.1		27	1.8	5.9	2.4	»	1.1
22	+ 9.0	+5.1		+ 6.9		27	1.7	5.1	3.8	»	0.9
23	+ 8.4	+4.8		+ 6.2		28	2.2	7.0	3.3	»	1.5
24	+ 7.0	+5.4		+ 6.1		28	2.0	5.9	1.5	»	1.2
25	+ 7.9	+5.8		+ 6.5		29	2.7	5.9	1.4	»	1.6
26	+ 6.4	+2.0		+ 4.9		26	2.4	4.4	1.9	»	1.1
27	+ 6.5	+2.4		+ 4.5	0.2	25	2.1	4.6	1.0	»	1.0
28	+ 5.9	+4.6		+ 5.2	3.9	25	1.8	6.7	2.4	»	1.2
29	+ 7.2	+2.5		+ 4.9	3.1	26	2.0	4.7	1.2	»	0.9
30	+ 8.6	+4.8		+ 5.9	11.4	21	1.5	7.8	2.0	»	1.2
31	+ 7.2	+2.7		+ 5.6	12.5	30	2.1	16.6	2.6	»	3.5
			Sum for October		45.0						53.1

November 1933.

Date	Temperature max.	min.	number of hours ≤ 0°	mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+6.5	+ 1.0		+3.4	1.1	31	3.0	16.6	2.0	B	5.0
2	+8.5	+ 4.9		+6.5	3.2	30	2.2	16.0	3.1	»	3.5
3	+7.0	+ 3.6		+5.1	8.2	30	1.9	15.7	3.3	»	3.0
4	+5.2	+ 0.8		+4.1	2.5	31	2.1	8.9	3.7	»	1.9
5	+3.7	− 0.7	6	+1.5	1.5	38	5.7	28.4	4.5	»	16.2
6	+6.3	− 0.2	2	+3.6	✱0.2	39	7.1	17.0	3.2	»	12.1
7	+2.7	− 1.2	12	+0.5		37	4.9	7.1	3.4	»	3.5
8	+3.1	− 1.7	11	+0.4		34	2.5	10.9	1.8	»	2.7
9	+3.1	− 0.9	6	+1.0	0.8	39	5.4	10.8	3.1	»	5.8
10	+7.6	+ 3.0		+5.2		40	6.6	6.7	0.6	»	4.4
11	+9.3	+ 4.9		+7.1		37	4.1	9.5	1.7	»	3.9
12	+5.0	− 2.5	10	+1.5	1.0	36	3.3	7.4	3.1	»	2.4
13	+1.6	− 6.5	19	−3.3		38	3.5	7.8	3.9	»	2.7
14	−0.9	− 5.0	24	−2.3		37	3.0	6.5	2.4	»	2.0
15	+1.6	− 2.3	10	±0.0	✱0.1	36	3.4	8.2	1.9	»	2.8
16	+0.5	− 2.1	22	−0.9	✱0.1	35	2.0	7.1	1.1	»	1.4
17	−0.7	− 1.6	24	−1.2	✱0.2	36	2.5	7.3	3.7	»	1.8
18	−0.6	− 9.3	24	−4.7		38	3.9	4.3	1.4	»	1.7
19	−2.3	− 9.0	24	−4.9		37	3.8	6.6	2.5	»	2.5
20	−0.6	− 8.4	24	−3.3		38	4.0	9.4	2.1	»	3.8
21	+0.6	− 0.6	8	+0.2		36	3.2	8.3		E	2.7
22	+1.6	− 1.4	10	+0.2		38	4.8	7.1	1.8	B	3.4
23	−0.3	− 2.4	24	−1.1		38	5.4	7.4	1.7	»	4.0
24	±0.0	− 2.0	24	−0.7	✱3.1	33	1.9	7.8	2.6	»	1.5
25	+0.4	− 2.5	18	−0.6	✱3.4	32	2.9	10.7	—	»	3.1
26	−3.7	−14.2	24	−9.8		34	3.5	4.7	0.8	»	1.6
27	−7.6	−12.0	24	−9.8	✱0.1	33	2.8	6.1	0.8	»	1.7
28	+1.3	−11.1	10	−1.4	✱1.9	31	2.4	7.8	2.1	»	1.9
29	+1.3	+ 0.2		+0.7		31	2.4	5.5	0.9	»	1.3
30	+0.8	− 0.7	14	±0.0		32	2.9	5.1	2.0	»	1.5
		Sum for November			26.3						105.8

Remarks. Cover of snow at Uppsala November 16—18 and 24—30, cover of ice on the Fyris November 18—30.

December 1933.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	− 0.9	− 4.7	24	− 3.0		31	3.0	5.7	1.2	B	1.7
2	− 0.7	− 8.5	24	− 3.2		31	4.0	9.0	1.5	»	3.6
3	− 5.3	−11.8	24	− 8.9		29	3.1	10.0	2.4	»	3.1
4	− 3.9	− 8.5	24	− 5.9	✳0.2	29	2.0	7.4	1.8	»	1.5
5	+ 2.9	− 3.1	12	+ 0.1	✳1.0	29	2.8	6.8	1.1	»	1.9
6	+ 4.9	− 2.1	1	+ 2.1		27	2.6	9.0	1.3	»	2.3
7	+ 2.8	− 3.8	20	− 1.7	✳0.6	26	2.4	10.0		E	2.4
8	− 3.4	−11.0	24	− 8.1		27	2.2	11.0	2.3	B	2.4
9	+ 1.4	− 9.6	19	− 2.9		25	2.3	21.2	1.9	»	4.9
10	− 1.9	− 7.9	24	− 4.1		25	2.1	5.8	2.2	»	1.2
11	− 0.1	− 5.7	24	− 3.2		24	1.9	12.7	2.5	»	2.4
12	− 3.1	−11.5	24	− 6.8	✳0.3	24	1.9	6.4	2.1	»	1.2
13	−10.2	−16.9	24	−13.8	✳0.1	23	2.0	5.3	2.3	»	1.1
14	− 3.0	−15.7	24	− 8.8	✳0.5	24	2.3	10.0	2.7	»	2.3
15	− 0.6	− 9.7	24	− 3.5	✳1.3	23	1.9	26.4	2.9	»	5.0
16	− 8.8	−19.5	24	−14.5	✳0.1	21	1.9	15.0	3.0	»	2.9
17	− 2.2	−13.0	24	− 5.1		19	1.2	12.1	2.8	»	1.5
18	− 0.9	− 6.1	24	− 4.0	✳0.1	21	1.9	19.1	3.2	»	3.6
19	− 1.9	− 6.3	24	− 4.2	✳0.1	20	1.8	10.6	2.8	»	1.9
20	+ 1.8	− 6.4	21	− 2.0		20	1.8	12.0	2.1	»	2.2
21	− 2.4	− 7.2	24	− 4.5	✳0.1	19	1.8	10.2	1.1	»	1.8
22	− 0.1	− 5.4	24	− 1.5	0.7	19	1.8	5.9	2.1	»	1.1
23	+ 1.3	− 3.4	16	− 0.6	✳0.8	20	1.7	10.2	—	»	1.7
24	+ 2.9	− 3.3	15	− 0.3		19	1.5	6.7	1.1	»	1.0
25	+ 2.7	− 1.5	10	+ 0.4	1.2	19	1.4	5.9	1.6	»	0.8
26	− 0.3	− 2.8	24	− 1.7	✳0.5	20	1.6	6.6	2.7	»	1.1
27	− 1.9	− 7.2	24	− 4.5	✳0.1	22	1.6	14.2	10.7	»	2.3
28	− 4.5	−16.3	24	− 9.9	✳0.9	23	1.7	11.3		E	1.9
29	− 4.4	−17.3	24	− 7.2	✳0.5	22	1.7	8.4	1.2	B	1.4
30	− 4.7	− 8.1	24	− 6.3	✳1.8	23	1.6	8.0	2.1	»	1.3
31	− 3.9	− 5.1	24	− 4.4		23	1.5	8.8	5.3	»	1.3
			Sum for December		10.9						64.8

Remarks. Cover of snow at Uppsala December 1—31, cover of ice on the Fyris December 1—31.

January 1934.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	−5.1	−6.8	24	−5.7		24	1.7	6.0	3.2	B	1.0
2	−3.2	−8.7	24	−6.3		25	2.0	7.9	2.3	»	1.6
3	+0.1	−2.5	23	−0.7		25	1.8	4.5	3.5	»	0.8
4	+0.1	−1.6	21	−0.7		26	2.0	10.3	2.5	»	2.1
5	−0.3	−1.7	24	−1.1		25	2.7	6.3	2.3	»	1.7
6	+0.8	−4.8	8	−0.4	✳6.8	25	1.9	11.6	2.7	»	2.2
7	+2.3	−5.6	14	−1.7	1.0	24	2.3	10.4	3.7	»	2.4
8	+5.0	+2.4		+3.9		27	2.7	10.1	6.3	»	2.7
9	+4.5	+1.9		+3.1		33	6.8	18.4	3.0	»	12.5
10	+2.1	−6.1	17	−2.2		31	4.0	10.4	2.4	»	4.2
11	+1.0	−4.9	11	−0.4	✳0.1	32	5.0	9.2	4.0	»	4.6
12	+1.3	−2.0	9	+0.2		32	5.2	5.9	1.2	»	3.1
13	+1.2	−0.9	15	−0.1		31	4.5	13.7	2.6	»	6.2
14	−0.7	−2.2	24	−1.4		30	3.3	10.2	8.3	»	3.4
15	+2.4	−1.5	4	+1.0	✳2.5	33	5.7	12.9	4.9	»	7.4
16	+1.3	−2.3	13	−0.4	✳0.3	33	5.7	11.7	3.5	»	6.7
17	+2.2	+1.0		+1.7	✳1.5	35	5.4	11.2	2.8	»	6.0
18	+2.5	−0.1	1	+1.4	✳3.0	36	6.2	13.3	2.7	»	8.2
19	+4.4	+2.5		+3.5	✳3.5	50	14.4	29.4	2.9	»	42.3
20	+3.7	−0.4	3	+2.4	5.0	51	13.3	8.7	1.5	»	11.6
21	+2.9	−6.0	18	−1.7		44	9.8	10.5	2.7	»	10.3
22	+2.0	−5.5	14	−0.5		48	4.3	6.9	4.4	»	3.0
23	+2.5	−1.7	8	+0.6		46	3.2	8.1	3.6	»	2.6
24	+2.5	−2.0	5	+1.1		46	3.2	5.7	2.2	»	1.8
25	+5.0	+2.2		+4.1		45	8.5	7.4	2.4	»	6.3
26	+3.0	−3.5	14	−0.2		45	10.0	6.3	3.0	»	6.3
27	+0.3	−2.4	22	−1.0	✳0.1	45	10.4	5.9	3.4	»	6.1
28	+2.3	−0.1	1	+1.3		42	6.6	2.6	2.4	»	1.7
29	+2.7	−2.1	14	−0.1		44	7.4	6.0	2.8	»	4.4
30	+2.8	−2.3	10	+0.4		43	7.7	4.9	4.6	»	3.8
31	+2.5	−6.2	11	−0.7		43	7.9	5.0	3.6	»	4.0
Sum for January					24.8						181.0

Remarks. Cover of snow at Uppsala January 1—7 and 14—16, cover of ice on the Fyris January 1—31.

February 1934.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	− 3.0	− 8.4	24	−5.5	✱1.0	42	5.8	4.7	2.5	B	2.7
2	− 4.6	−10.3	24	−7.5		41	5.5	4.9	1.0	»	2.7
3	+ 0.7	− 5.4	21	−1.9	2.2	41	5.5	5.9	1.7	»	3.2
4	− 0.6	− 4.8	24	−2.7		41	6.3	4.5	2.8	»	2.8
5	+ 3.3	− 1.2	12	+0.5		42	8.0	4.5	—	»	3.6
6	+ 5.4	− 0.7	1	+3.6		41	5.6	5.5	2.4	»	3.1
7	+ 5.2	− 2.0	5	+1.8	✱0.5	41	7.4	13.9	2.3	»	10.3
8	− 0.4	− 6.2	24	−3.3	✱2.3	40	6.4	6.6	5.5	»	4.2
9	− 2.8	−12.8	24	−7.4	✱8.0	37	2.1	12.0	4.6	»	2.5
10	+ 2.6	−12.2	17	−3.0	✱0.6	42	5.0	6.0	1.9	»	3.0
11	+4.8	− 0.2	3	+2.4		43	5.2	11.2	2.7	»	5.8
12	+ 2.4	− 4.3	18	−1.3		45	6.1	3.8	0.8	»	2.3
13	− 1.3	− 8.9	24	−4.3		45	5.8	4.0	1.7	»	2.3
14	+ 2.9	− 3.1	6	+0.5		46	6.6	5.7	1.1	»	3.8
15	+ 1.0	− 6.1	22	−3.0		45	4.8	6.8	2.9	»	3.3
16	+ 3.6	− 2.5	7	+0.9		46	5.1	10.9	6.7	»	5.6
17	+ 6.3	+ 1.5		+4.1		47	5.8	6.4	2.3	»	9.5
18	+10.6	± 0.0	1	+4.2		47	5.8	10.9	3.6	»	6.3
19	+ 6.3	− 0.1		+3.4		48	6.3	11.4	2.7	»	7.2
20	+ 5.5	− 1.5	7	+1.8		48	5.7	6.4	0.7	»	3.6
21	− 1.3	− 9.6	24	−5.1	✱0.2	49	6.4	7.1	1.2	»	4.5
22	+ 0.4	− 7.9	22	−4.2		50	7.4	12.0	4.7	»	8.9
23	+ 6.4	− 3.0	5	+2.9		50	6.0	7.0	2.3	»	4.2
24	+ 5.4	− 2.3	7	+2.0		50	6.0	13.5	3.1	»	8.1
25	+ 1.9	− 0.5	4	+0.7	✱2.3	50	6.0	64.1	6.6	»	38.5
26	+ 2.8	+ 1.6		+1.9	0.5	55	4.6	75.8	13.4	»	34.9
27	+ 5.7	+ 1.4		+2.9	10.5	73	15.0	77.4	8.1	»	116.1
28	+ 2.9	+ 1.6		+2.2	3.5	84	18.8	63.0	8.3	»	118.4
Sum for February					33.8						421.4

Remarks. Cover of snow at Uppsala February 1, 7—15, 20—22 and 24—25, cover of ice on the Fyris February 1—28.

March 1934.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+2.4	−0.6	4	+1.2	⋇ 3.2	87	19.0	55.7	6.2	B		105.8
2	±0.0	−1.3	24	−0.4	⋇ 1.2	78	14.1	36.3	—	»		51.2
3	−0.7	−1.9	24	−1.4		77	14.2	16.9	4.8	»		24.0
4	+0.8	−1.0	17	−0.3	⋇ 5.0	74	11.6	48.5	4.8	»		56.3
5	+2.6	−2.0	7	+0.8	0.3	74	10.9	49.8	16.1	»		54.3
6	+3.5	+1.7		+2.6	1.0	77	12.8	45.3	10.0	»		58.0
7	+4.0	+0.4		+2.0	2.2	89	17.5	28.4	6.4	»		49.7
8	+3.6	−0.7	3	+1.1		85	15.2	53.8	7.3	»		81.8
9	+2.8	−3.3	15	−0.6	⋇ 0.5	84	13.5	23.6	7.2	»		31.9
10	+1.6	−3.0	20	−1.5	⋇ 0.8	82	13.5	33.3	6.5	»		45.0
11	−0.4	−3.7	24	−2.2	⋇ 1.2	79	11.8	8.9	4.1	»		10.5
12	−1.1	−5.2	24	−2.9	⋇ 2.0	79	11.8	7.6	4.9	»		9.0
13	−0.7	−5.0	24	−2.7		77	11.2	3.7	1.4	»		4.1
14	+0.9	−5.9	20	−2.9	⋇ 9.5	78	11.3	6.5	2.2	»	13.0	7.3
15	−2.1	−6.0	24	−4.5	⋇ 4.5	78	11.3	22.2	3.6	»		25.1
16	+2.4	−4.5	14	−0.9	⋇ 3.5	77	11.2	41.7	4.2	A	23.2	46.7
17	+7.2	+0.4		+2.7		76	11.4	42.9	7.7	»		48.9
18	+7.1	−0.2	3	+2.1		76	12.2	221.5	2.4	»		270.2
19	+1.5	+0.2		+0.8	⋇ 9.5	80	11.9	69.6	11.5	»	45.0	82.8
20	+5.2	−0.8	4	+2.0	0.8	100	19.8	50.3	4.6	»		99.6
21	+8.5	−2.7	8	+2.4		100	18.2	44.8	5.9	»		81.5
22	+9.1	−1.0	11	+2.5	⋇ 1.2	99	18.9	33.9	2.8	»		64.1
23	+1.0	+0.4		+0.7	⋇ 6.0	100	18.8	23.8	3.7	»	16.4	44.7
24	+1.3	+0.1		+0.5		101	19.3	17.5	3.3	B		16.3
25	+3.7	+1.5		+2.5		101	19.3	7.1	1.4	»		13.7
26	+6.8	−3.2	11	+1.3		103	19.7	22.4	2.2	»		44.1
27	+2.8	+0.1		+1.0	⋇ 1.9	102	16.1	16.9	2.7	»		27.2
28	+0.7	−0.2	6	+0.2	⋇13.5	101	15.8	26.9	12.9	»		42.5
29	+1.7	+0.3		+0.7	⋇ 0.3	102	16.1	10.7	0.8	»		17.2
30	+1.8	±0.0		+0.7	⋇ 0.1	101	16.2	16.6	2.0	»		26.9
31	+1.4	−0.4	11	+0.3		100	15.8	25.1	2.2	»		39.7
	Sum for March				65.0							1580.1

Remarks. Cover of snow at Uppsala March 1—5, 11—19 and 27—31, cover of ice on the Fyris March 1—25.

April 1934.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+ 2.3	−1.5	11	+ 0.1		99	15.7	18.3	1.0	B	28.7
2	+ 7.4	−5.0	12	+ 1.0		100	15.7	18.4	1.3	»	28.9
3	+ 8.5	−0.2	2	+ 2.8		103	17.4	23.5	1.3	»	40.9
4	+ 6.2	−3.0	11	+ 1.1		102	17.0	16.5	1.0	»	28.1
5	+ 9.3	+0.9		+ 4.0		104	17.9	16.1	2.9	»	28.8
6	+ 4.7	−1.8	15	+ 0.5	✱2.6	101	17.7	7.3	3.5	»	12.9
7	+ 0.9	−4.7	18	− 1.8		102	17.0	17.1	1.4	»	29.1
8	+ 2.4	−2.3	13	+ 0.2		101	18.3	11.3	2.9	»	20.7
9	+ 6.8	+0.7		+ 3.2	✱0.7	100	16.2	13.4	2.8	»	21.7
10	+ 0.5	−2.8	22	− 1.2	✱0.8	95	15.4	12.0	3.5	»	18.5
11	+ 3.1	−9.3	14	− 2.5		96	16.0	20.3	1.8	»	32.5
12	+ 6.0	−3.2	11	+ 1.3		95	14.0	17.3	2.3	»	24.2
13	+ 6.6	−4.8	11	+ 0.6		94	14.8	14.2	2.6	»	21.0
14	+10.1	−1.0	5	+ 4.2		94	15.4	13.1	2.2	»	20.2
15	+ 9.9	−1.1	4	+ 3.7		92	15.9	14.4	2.2	»	22.9
16	+ 8.3	+2.0		+ 3.9	0.7	92	14.9	10.9	3.5	»	16.2
17	+11.8	+4.7		+ 8.0	0.9	91	14.1	16.8	2.4	»	23.7
18	+18.5	+1.1		+ 9.8		92	15.9	18.0	3.3	»	28.6
19	+16.8	+5.9		+ 9.4	1.1	97	18.0	11.5	2.5	»	20.7
20	+10.9	+6.0		+ 8.3		97	17.7	9.0	2.7	»	15.9
21	+12.4	+2.7		+ 6.9		94	16.0	9.8	3.1	»	15.7
22	+14.5	+3.0		+ 8.1		94	17.0	24.4	2.7	»	41.5
23	+12.7	+4.9		+ 9.1		93	16.5	11.6	2.7	»	19.1
24	+12.2	+4.0		+ 6.4	8.8	94	14.4	10.2		»	14.7
25	+11.8	+3.3		+ 7.2		95	18.3	8.7	2.1	»	15.9
26	+15.3	+5.7		+ 9.1	4.6	93	15.4	14.0	3.7	»	21.6
27	+14.7	+5.2		+ 9.7	0.3	92	15.7	10.9	2.3	»	17.1
28	+11.7	+3.1		+ 7.9	0.4	91	13.6	8.5	2.6	»	11.6
29	+18.0	+3.1		+11.0		89	13.0	9.0	0.8	»	11.7
30	+19.9	+3.2		+11.7		88	13.0	15.7	4.2	»	20.4
				Sum for April	22.6						673.5

Remarks. Cover of snow at Uppsala April 6 and 9.

May 1934.

Date	Temperature max.	Temperature min.	Temperature number of hours ≤ 0°	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m³/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Load in tons/24 hours
1	+19.5	+ 6.8		+13.0	1.7	88	16.8	10.1	2.3	B	17.0
2	+22.5	+ 8.0		+15.2		85	14.7	12.3	4.6	»	18.1
3	+22.7	+ 8.1		+15.7		85	14.7	11.2	1.9	»	16.5
4	+19.8	+ 3.2		+11.4		80	13.2	10.6	2.7	»	14.0
5	+23.5	+ 8.9		+15.2		81	11.1	5.7	2.9	»	6.3
6	+26.1	+10.4		+18.4		79	9.4	6.4	2.7	»	6.0
7	+28.0	+ 9.5		+19.2		80	9.7	8.6	1.9	»	8.3
8	+27.4	+ 8.5		+19.3		79	9.4	5.7	1.3	»	5.4
9	+27.6	+11.4		+20.0		76	9.0	7.7	2.3	»	6.9
10	+24.7	+ 8.9		+17.0		80	9.1	12.5	2.2	»	11.4
11	+20.9	+10.4		+15.3		76	7.6	11.2	2.2	»	8.5
12	+19.3	+ 6.1		+12.7		76	9.0	9.3	2.0	»	8.4
13	+22.5	+ 3.7		+13.7	4.5	72	9.5	11.8	2.4	»	11.2
14	+ 9.3	+ 0.4		+ 5.2		73	9.7	7.6	0.4	»	7.4
15	+13.1	+ 4.0		+ 7.4	1.1	69	8.6	10.0	0.5	»	8.6
16	+ 9.7	+ 1.1		+ 6.2	0.1	69	8.1	11.7	0.4	»	9.5
17	+14.1	+ 5.7		+10.1		72	11.4	8.8	1.4	»	10.0
18	+17.8	+ 3.9		+11.6	2.1	72	9.6	11.7	0.8	»	11.2
19	+14.9	+ 5.1		+10.0		67	12.1	11.4	2.0	»	13.8
20	+17.1	+ 3.4		+11.1		68	9.1	10.4	2.8	»	9.5
21	+19.9	+ 7.2		+13.1	2.9	68	8.1	9 4	2.8	»	7.6
22	+16.4	+ 7.8		+11.0	3.2	66	7.0	9.9	1.9	»	6.9
23	+14.3	+ 4.4		+ 9.2	9.2	65	6.6	7.1	2.2	»	4.7
24	+12.4	+ 4.1		+ 7.1	4.5	64	5.7	13.1	2.1	»	7.5
25	+12.6	± 0.0	1	+ 6.7	0.7	63	7.1	11.8	3.2	»	8.4
26	+15.0	+ 0.3		+ 8.1		63	7.6	7.3	2.4	»	5.5
27	+12.7	+ 0.4		+ 6.5	⋇3.9	61	6.5	10.1	3.0	»	6.6
28	+14.3	+ 1.6		+ 7.8	0.5	62	7.7	7.8	2.5	»	6.0
29	+13.5	− 0.5	3	+ 7.3	0.3	60	7.5	9.3		E	7.0
30	+14.9	+ 1.3		+ 9.3		58	6.5	10.8	2.6	B	7.0
31	+19.5	+ 9.0		+14.3		59	6.5	10.9	2.6	»	7.1
				Sum for May	33.0						282.3

June 1934.

Date	Temperature max.	Temperature min.	Temperature mean	Precipitation in mm.	Uppsala gauge	Discharge m^3/sec.	Contents of silt mg/liter	Ignition loss mg/liter	Method	Filtration mg/liter	Load in tons/24 hours
1	+17.1	+ 8.5	+12.4		59	6.9	6.4	2.6	B	8.0	4.4
2	+18.0	+ 9.4	+13.3	10.0	58	6.5	10.2	3.2	»		6.6
3	+18.3	+ 7.7	+12.6	0.3	55	4.8	16.8	2.9	»		8.1
4	+16.0	+ 4.0	+ 8.9	7.8	54	3.1	33.7	4.8	»	24.0	10.4
5	+10.3	+ 5.2	+ 6.9	6.2	56	6.2	22.2	3.7	»		13.8
6	+14.4	+ 6.4	+10.2		58	8.7	11.5	3.0	»	11.1	10.0
7	+19.2	+ 7.2	+13.6		57	6.6	12.1	2.4	»		8.0
8	+23.8	+ 7.7	+17.1		58	7.5	11.6	2.5	»	9.3	8.7
9	+27.3	+ 6.2	+17.3		57	7.0	11.0	2.8	»		7.7
10	+25.0	+ 8.4	+17.2		55	6.9	10.5	2.9	»		7.2
11	+23.0	+ 6.6	+14.7	0.1	53	6.5	9.0	2.5	»	8.6	5.9
12	+17.1	+ 3.1	+11.5		54	7.6	14.8	3.1	»		11.2
13	+24.0	+ 7.8	+16.5		53	7.4	7.3	2.4	»	6.6	5.4
14	+20.2	+ 7.8	+14.1	0.3	50	5.5	11.3	2.7	»		6.2
15	+12.6	+ 1.3	+ 7.0	0.1	48	4.8	9.4	2.6	»	6.3	4.5
16	+17.4	+ 4.0	+11.6		50	5.8	4.7	2.1	»		2.7
17	+21.2	+11.1	+15.6		52	8.0	7.3	2.1	»		5.8
18	+19.6	+13.2	+16.0	1.5	50	6.3	8.4	2.1	»	6.1	5.3
19	+22.6	+10.0	+16.4	8.9	48	7.0	7.8	3.0	»		5.5
20	+22.4	+12.5	+16.4	0.7	50	9.7	4.5	1.9	»	5.3	4.4
21	+18.9	+10.3	+14.6	9.5	50	8.4	11.9	3.1	»		10.0
22	+17.1	+ 7.2	+12.3	0.7	50	8.4	8.4	2.3	»	8.5	7.1
23	+19.7	+ 9.4	+13.6	0.1	47	8.3	7.3	2.3	»		6.1
24	+17.8	+ 5.7	+12.2		43	2.8	7.6	1.3	»		2.1
25	+21.7	+ 7.3	+14.8		46	4.8	10.0	1.7	»	5.4	4.8
26	+25.6	+10.8	+18.5		46	5.7	7.8	1.5	»		4.4
27	+26.2	+ 9.9	+18.2		44	5.1	6.5	2.2	»	10.0	3.3
28	+21.6	+12.4	+17.2		46	8.1	6.5	2.0	»		5.3
29	+26.9	+13.0	+20.3		45	6.6	5.4	2.3	»	7.0	3.6
30	+30.3	+16.4	+23.1		43	5.7	6.7	2.3	»		3.8
			Sum for June	58.1							192.3

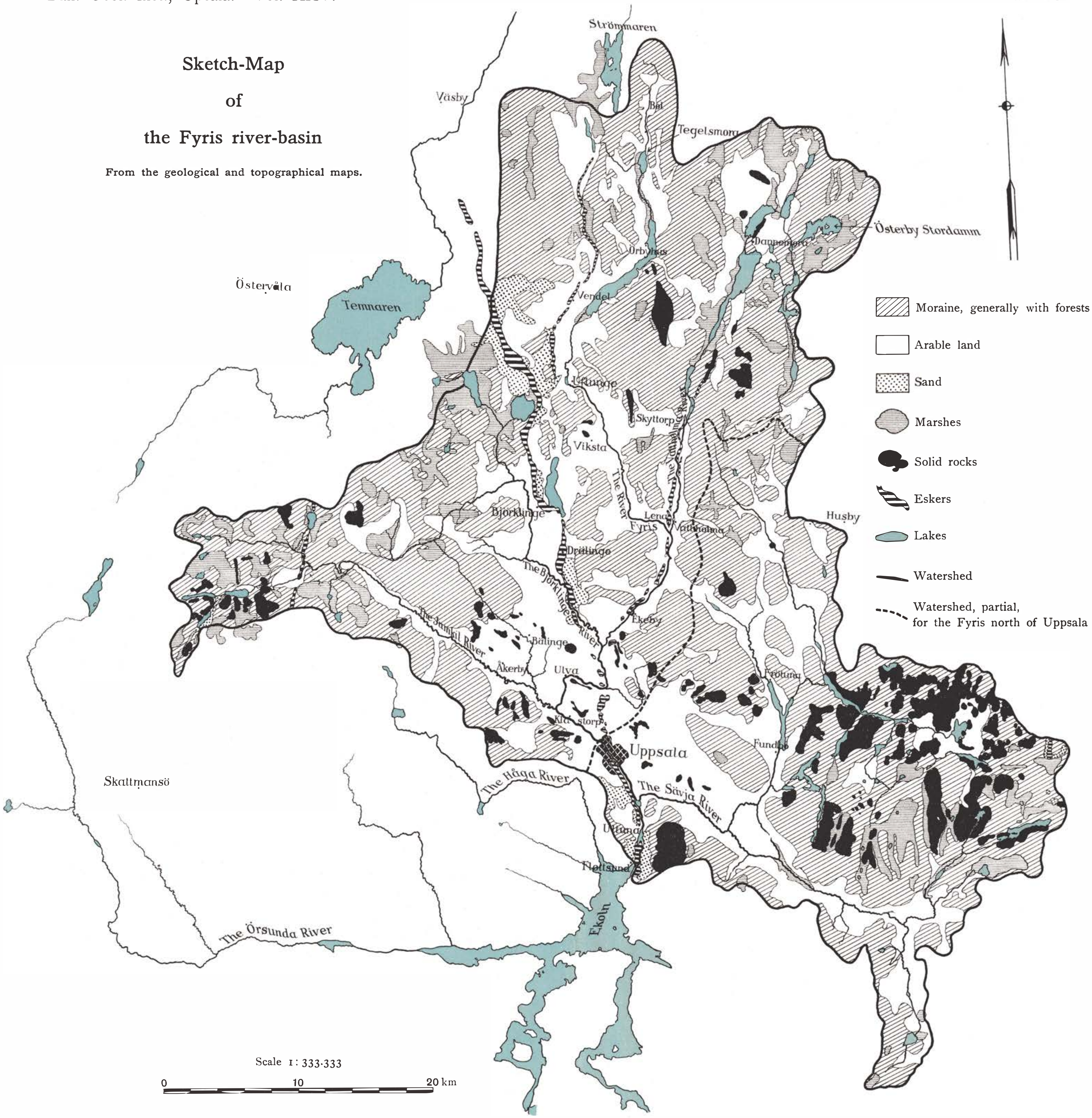
Contents.

Gedruckt 7/5 1935.

Foto F. Hjulström, juni 1932.

Sketch-Map of the Fyris river-basin

From the geological and topographical maps.



Transportation of Silt in the River Fyris during the Period July 1929—June 1934