MINISTRY OF EDUCATION AND SCIENCE OF UKRAINE
ODESA STATE ENVIRONMENTAL UNIVERSITY

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METHODS AND TOOLS OF HYDROMETEROLOGICAL MEASUREMENTS (HYDROLOGICAL MEASUREMENTS)

Summary of lectures

Odesa
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The summary of the lectures set out the issues provided for by the sillabus of the discipline "Methods and tools of hydrometeorological measurements (hydrological measurements)", which are related to the methods of hydrological measurements: water level records, depth measurements, current velocity measurements, water discharge measurements, suspended sediment discharge and bed load discharge measurements, special studies on water bodies.

The summary of the lectures is intended to provide students with the opportunity for independent in-depth study of lecture topics, independent work in preparation for classroom and laboratory classes.

The summary of the lectures is recommended for students of the 1st year of OSENU who are studying in the field of preparation 103 "Earth Sciences".

Яров Я.С.
Методи та засоби гідрометеорологічних вимірювань (гідрологічні вимірювання): конспект лекцій. Одеса: Одеський державний екологічний університет, 2023. 108 с.

У конспекті лекцій викладені питання, передбачені силлабусом дисципліни «Методи та засоби гідрометеорологічних вимірювань (гідрологічні вимірювання)», які пов’язані з методами гідрологічних вимірювань: рівневі спостереження, вимірювання глибин, швидкостей течії, витрат води, завислих і донних наносів, донних відкладів, спеціальні дослідження на водних об'єктах.

Конспект лекцій призначений для забезпечення студентів можливістю самостійного поглибленого вивчення лекційних тем, самостійної роботи при підготовці до аудиторних і лабораторних занять.

Конспект лекцій рекомендується для студентів I курсу ОДЕКУ, які навчаються за спеціальністю 103 «Науки про Землю».

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Recommended by the Methodological Council of Odessa State Environmental University of the Ministry of Education and Sciences of Ukraine as a summary of the lectures
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CONTENT

INTRODUCTION

The summary of the lectures is compiled in accordance with the syllabus of the educational discipline "Methods and tools of hydrometeorological measurements (hydrological measurements)", which belongs to the package of disciplines of the professionally-oriented cycle in the preparation of bachelors in the specialty 103 "Earth Sciences".

The discipline plays an important role in solving issues of organization, measurement and observation of various characteristics of the water regime in rivers, lakes and reservoirs.

The purpose of studying this discipline is to master modern methods and devices for performing various types of measurements and observations of the elements of the regime of water bodies. The tasks of the course also include issues of organization of these measurements and observations and primary data processing.

In the future, the knowledge of this discipline will be used in the study of disciplines, such as "Climatology", "Hydrography" and educational practice of the discipline. This discipline occupies an important place in the training of bachelors in the specialty 103 "Earth Sciences".

As a result of studying this section of the course, students should know the main types of hydrological measurements, such as water level records, depth measurements, current velocity measurements, water discharge measurements, suspended sediment discharge and bed load discharge measurements, measurement of quantitative characteristics of bottom sediments, main field types of hydrochemical measurements.

Students should be able to measure the main hydrological and hydrochemical characteristics of water bodies.

The section "Methods and tools of hydrometeorological measurements (hydrological measurements)" is taught in the first year, based on the disciplines "Higher mathematics", "Geology with the basics of geomorphology", "Methods and tools of hydrometeorological measurements" (other chapters).

1 GENERAL INFORMATION ABOUT HYDROMETRY

1.1 Subject, task, value of hydrometry

Hydrometry (from the Greek words "water" and "to measure") is a branch of hydrology that studies and systematizes the quantitative and qualitative characteristics of water bodies. The results of hydrometric works are the basis of generalizations and conclusions of hydrology.

Tasks of hydrometry:

- development of methods and devices for quantitative determination and accounting of various elements of the regime of water bodies;
- systematic study of the hydrological and hydrochemical regime of water bodies to obtain long-term values of water levels, water flow and sediment yield, temperature and chemical composition of water, ice phenomena.

The materials of hydrometric measurements are basic in carrying out various engineering and scientific calculations.

On the basis of these data, hydrological and water management issues are solved during the design, construction and operation of various hydrotechnical structures, reclamation systems, water supply, industrial development, water transport, modeling of hydrological processes.

The obtained characteristics of water bodies of Ukraine form the basis of the State Water Cadastre.

According to the objects of study, hydrometry is divided into:

1) **atmospheric water hydrometry** - hydrometeorology;

2) **surface water hydrometry**:

- hydrometry of oceans and seas - practical oceanography;
- hydrometry of land waters - rivers, lakes, reservoirs, swamps;

3) **groundwater hydrometry**.

Hydrometry of surface waters is currently the most developed.

1.2 Network of hydrological observations in Ukraine

After the independence of Ukraine in 1991, the State Committee of Ukraine on Hydrometeorology (since 1999 the Committee of Ukraine on Hydrometeorology) was established on the basis of the Ukrainian Hydrometeorological Service Office.

In 2000, the Department of Hydrometeorological Service and Monitoring of the Ministry of Natural Resources of Ukraine was established on the basis of the Hydrometeorological Committee.

Since 2005, the State Hydrometeorological Service (currently known as the Ukrainian Hydrometeorological Center - UHMC) has been part of the State Emergency Service of Ukraine (SES of Ukraine).

On February 18, 1999, the Parliament of Ukraine adopted the Law of Ukraine "On Hydrometeorological Activity", which is the main document regarding the activity and development of the Ukrainian Hydrometeorological Center.

It is known that hydrometeorological elements are constantly changing, in order to obtain the most accurate hydrometeorological characteristics of water bodies, it is necessary to conduct long-term, continuous, stationary and expeditionary observations using uniform permanent methods.

It is on these principles that the work of the Ukrainian Hydrometeorological Center, which manages all hydrometeorological work on the territory of Ukraine, is built.

On the ground, there are regional hydrometeorological centers (RHC), which manage the work of the hydrometeorological network, which is located in the relevant territory.

Methodical centers of the national system of hydrometeorological observations are the Central Geophysical Observatory, the Ukrainian Research Hydrometeorological Institute, the Ukrainian Hydrometeorological Center, the Hydrometeorological Center of the Black and Azov Seas, and the Ukrainian Aviation Meteorological Center.

The State Service of Hydrometeorological Observations consists of stationary and mobile gauges and technical tools of observation that ensure their regularity.

The basis of the observation system consists of: 25 hydrological stations and subdivisions, 14 marine, 124 meteorological, 32 aero-meteorological, 9 aerological stations, 3 specialized agro-meteorological, 2 water balance, 2 precipitation, 2 snow-avalanche, lake stations on reservoirs, 375 river gauges, 60 lake gauges, 16 sea gauges.

The system of hydrological observations consists of hydrological gauges and stations.

A hydrological gauge is a specially equipped point on a water body where the elements of the water regime are systematically monitored (by observers or remote tools).

Hydrological observation stations have a permanent staff of employees and they are manage the work of the gauges attached to them.

Hydrological gauges and stations are basic (support) and special:

1) the main gauges and stations, in turn, are divided into regular (they are comprehensively study the regime of the water body for a long time) and operational (informational: they are should inform consumers about specific hydrological phenomena and ensure their early forecasting);

2) special gauges and stations study the local features of the regime of the water body according to target programs, the term of operation of these gauges and stations depends on the tasks assigned to them.

In addition to state hydrological gauges and stations, there are departmental ones organized by various institutions to meet their own needs (their operation is coordinated with the Ukrainian Hydrometeorological Center).

All hydrological field observations and processing of observation at office at stations and gauges are performed according to the single unified methods given in a series of scientific and methodical manuals ("Instructions for hydrometeorological stations and posts").

Hydrological gauges and stations are placed territorially in such a way that with a minimum number of them it is possible to obtain sufficient and reliable data on the water regime of the water body.

The main factor in placing the hydrological network is the typicality (representativeness) of observations, that is, stations and gauges are placed so that the results of observations at each of them highlight the hydrological regime characteristic of the corresponding section of the reservoir or the district as a whole.

All stations and gauges are divided into types and grades, for each grade there are basic and additional observation programs (Table 1.1).

Table 1.1 – Types and terms of observations at hydrological gauges (HG)

№	Kinds of observation	Terms of observation	Category		
			I	II	III
1	2	3	4	5	6
Hydrological observations:					
1.	a) by the water level height	Every day at 8.00 and 20.00; more often during floods and spring floods *	+	+	+
	b) be the temperature of water	Every day at 8:00 a.m. and 8:00 p.m. when there is no ice *	+	+	+
	c) by the thickness of the ice, slush, the height of the snow on the ice	10, 20 days, at the end of the month; more often *	+	+	+
	d) by wind and excitement	Every day at 8:00 a.m. and 8:00 p.m. when there is no ice	+	+	+
	e) by ice regime phenomena	Every day at 8:00 a.m. and 8:00 p.m.	+	+	+
	f) by the development of aquatic vegetation	10, 20 days, at the end of the month;	+	+	+
	g) by the height of the groundwater level	*	+	+	+

Table 1.1 - Continued

1	2	3	4	5	6
2.	Water discharge measurements, suspended sediment discharge and bed load discharge measurements, water sampling for turbidity, chemical analysis, bottom sediment sampling	According to the plan of the hydrological station	+	–	–
3.	Water surface slope observations	*	+	–	–
4.	Compilation and transmission of telegrams about hydrological regime and precipitation	According to the instructions of the UHMC	+	+	+
Meteorological observations:					
5.	a) by precipitations	Every day at 8:00 a.m. and 8:00 p.m.	+	+	–
	b) by atmospheric phenomena	During the day	+	+	–
	c) by snow cover: - on permanent sites - during snow measuring surveys	at 8.00 according to the plan of the station	+ +	+ +	– –
	d) by weather visibility, cloudy, windy (visual)	According to the instructions of the UHMC	+	+	–
	e) reports about precipitation and dangerous meteorological phenomena in the daylight hours	According to the instructions of the UHMC	+	+	–
6.	Hydrologic and geodetic works	According to the plan of the hydrological station	+	+	+
7.	Processing of observation data	Regularly	+	+	+

(*) Note: according to the instructions of the hydrological station.

Hydrological stations are of the I and II categories, and hydrological gauges, depending on the scope of work, are of 1, 2, or 3 categories.

Stations of the first category study the hydrological regime of water bodies on the territory of their activity, manage the stations of the second category and hydrological gauges assigned to them.

Class II stations conduct field hydrological observations and work, process information from attached posts and transmit regime information.

1.3 Questions for self-control

1. Define the term "hydrometry".
2. The subject and meaning of hydrometry.
3. How do hydrological gauges differ from hydrological stations?
4. What observation programs operate at hydrological gauges?
5. System of hydrological observations in Ukraine.

2 WATER LEVEL OBSERVATIONS

2.1 Water regime and the practical importance of its study

The **hydrological (water) regime** is the character of fluctuations in time of its main elements (water levels, water discharges).

The water level is the most accessible and informative characteristic, which is used in the study of the level regime, river flow calculations based on the relationship between water discharges and water levels.

A **hydrograph** is a graph that shows the change in water levels or water discharges over the course of a year. The water regime is always unstable due to the influence of natural and anthropogenic factors. There are the following natural phases of the water regime: spring flood, floods, low-water period.

Spring flood is a period of prolonged seasonal increase in the water level of the river, caused by melting snow and rains falling at the same time. Also, the spring flood can be formed only by precipitation during the rainy season (Amazon river basin) or by the melting of snow and glaciers.

Floods are periods of intense short-term increases in the water level of rivers (in the warm period due to torrential precipitation; in the winter period during thaws due to thaw-rain or rainwater).

Low-water period - periods of low water during the year, when the surface runoff disappears for a long time in the absence of precipitation and the river is fed only by underground water.

The alternation of regime phases determines the characteristic type of water level fluctuations inherent in the rivers of a particular region. In particular, the level and water regime of rivers is influenced by their size, expressed by the catchment area.

The noted phase features of the regime correspond to seasonal fluctuations of water levels. In addition to climatic factors, seasonal fluctuations can be associated with ice phenomena, the development and dying of aquatic vegetation, as well as caused by the withdrawal of water for irrigation and the influence of hydrotechnical structures.

In addition to seasonal changes, the regime may exhibit multi-year, annual and daily fluctuations. Fluctuations in water levels, caused by changes in water content, are clearly visible in small rivers during the period when the snow melts. In the estuaries of large rivers, the daily fluctuations of the water level are affected by wind-induced surges.

The study of the level regime is of great scientific and practical importance.

The use of rivers for water transport and logging is related to knowledge of water levels; design, construction and operation of hydrotechnical structures require knowledge of changes in the height of levels, the amplitude of their fluctuations. The construction of meliorative channels also requires data on the state of water levels in rivers. Thus, the construction of bridges without sufficient knowledge of the regimes of maximum water levels in rivers can limit the possibilities of navigation when the design marks of both the water level itself and the bridge crossing are underestimated, and this can also lead to flooding of the road adjacent to the bridge. Insufficient knowledge of the regime of water levels in the low-water period may limit the possibilities of water intake from the river due to the drainage of the corresponding structures. Coastal structures and settlements can be submerged and be subject to the devastating effects of floods and ice drifts.

In addition, data on water levels make it possible to establish a graphical relationship between water levels and water discharges (volume of water for reservoirs), which makes it possible to calculate daily water discharges, water volumes, and runoff characteristics from the data of daily water levels, regardless of whether , that the latter are not actually measured.

Water discharges and water levels in rivers are constantly changing. Usually, an increase in water consumption is accompanied by an increase in river water levels and vice versa. However, in addition to the specified reason, the height of the water levels can be affected by deformation or overgrowth of the channel, ice phenomena, hydrotechnical structures, rushes and surges of water.

The influence of the above factors on the change in the height of water levels is complex, therefore, for a full characterization of the regime of water levels in water bodies, it is necessary to have long-term continuous observations.

2.2 Principles of construction of water level gauges

Observations of elements of the hydrological regime are carried out at hydrological (water measuring) gages.

A water level gage is a place on a water body that is specially selected and equipped for the systematic performance of a set of water measuring observations.

Each water level gauge consists of:

- water measuring devices (devices for measuring water levels);
- permanent height marks (benchmarks) - for monitoring the system of height marks of water measuring devices (water-level staffs, piles, etc.).

During the operation of water level gauges, the terms "zero of gauge", "zero of observations", and "registers" are used. They are installed at the gauge design stage.

Water level observations at waterlevel gauges should be organized in such a way that the materials of the gauges for the entire period of their operation can be compared and compared with the materials of observations at different gauges. This is ensured by bringing all observations to one constant for a given gauge, a conditional plane of comparison, which is called the **"zero of gauge"**, the height mark of which is selected during the design of the post and must remain unchanged for the period of the gauges existence.

The water level is the height of the water surface above the "datum plane " of the gauge.

The height position of the "zero of gauge" is set 0.5 m below the possible minimum water level in the cross section of the post. On rivers with an unstable channel, it is additionally necessary to take into account the erosion of the channel. On small rivers, you can take the lowest mark of the bottom in the cross section of the post as the “zero of gauge”. The choice of the mark of “datum plane of gauge” should ensure positive readings of the water level at the lowest levels. If there are several gauges on a section of the river of 5-10 km with a small drop, a common zero of gauge is assigned to all gauges, similarly a “zero of gauge” is also assigned to lake gauges. On reservoirs, the datum plane of gauge is set 0.5-1.0 m below the design level of operation near the dam of the reservoir.

The height marks of the "zero of gauge" may change in exceptional cases (transfer of the gauge to significant distances; in the event of an unsuccessful previous marking; in the event of a change in the level regime under the influence of economic activity; in the event of a change in the marks of the benchmarks).

"Zero of observation" is the height plane from which the water level is calculated at the moment of observation (on a staff gauges station, this is the zero plane of the staff, on a pile gauge - the plane of the pile head, along which observations are made).

"Zero of observations" is an individual characteristic of each water level measuring device, so its changes are possible when replacing or installing new piles (staffs).

"Register" (pile or staff) is the excess of "zero of observations" (piles or staffs) over "datum plane of gauge". Registers, as well as water level readings, are determined in centimeters.

Before starting observations at the water level gauge, the following work must be performed:

1) by leveling from the benchmark, set the marks (conditional or absolute) of the “zeros” of staffs or pile heads (H_m);

2) determine the zero mark of gauge ($H_{„0”g}$);

3) determine and record in the field book the registers of “zeros” of staffs or pile heads (h, cm).

The water level observation is carried out in the following sequence:

- record the date and time of the observation in the field book, the number of the staff (pile) on which the observation is carried out, measure the water level (at the staff gauge, this is done by a permanent staff, at the pile gauge - by a portable staff, which is placed on the head of the pile); the reading of the level

(ΔH) is recorded in the field book in centimeters;

- in the reference table of the field book, find the value of the register of "zero" indication of the devices (h), on which the water level reading was made;
- calculate the height of the fixed water level above the zero of the gauge (the given level of the H_{gl}) as the sum of the reading of the level (on the staff or pile) and the register (of the given staff or pile):

$$H_{gl} = \Delta H + h \ . \tag{2.1}$$

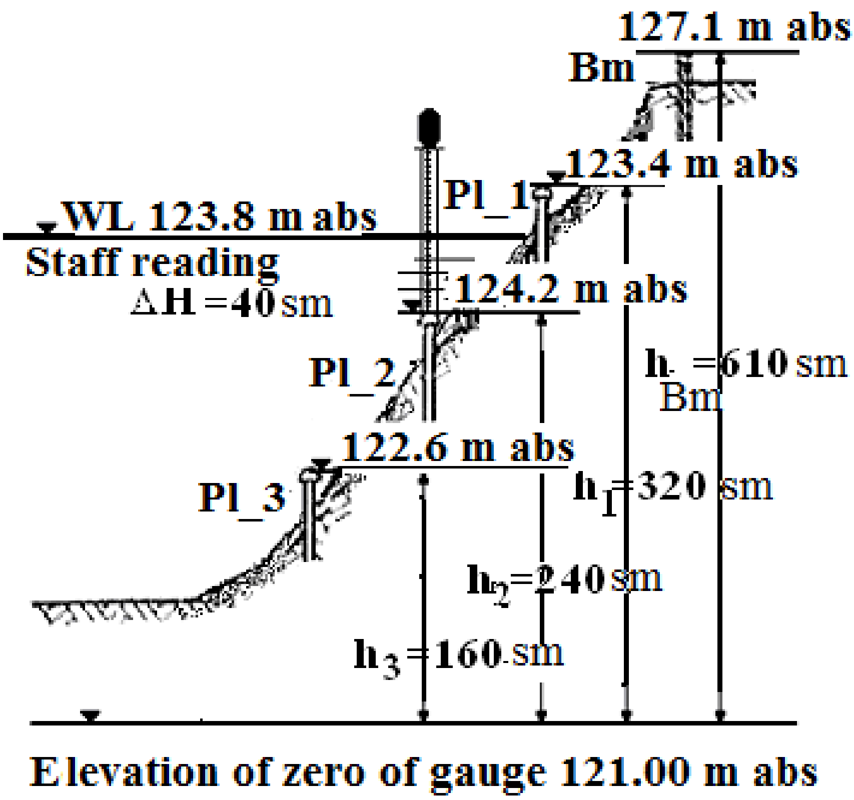


Figure 2.1– Scheme of height markings at the water level gauge

Figure 2.1 shows the scheme of height markings on a pile water level gauge. At the gauge, the mark "zero of the gauge" is 121.00 m abs. Each pile has its own "zero of observation" mark in the absolute system: the registers of piles 1, 2, 3 are marked as h_1, h_2, h_3 respectively.

Based on this schematic, the water level plane is fixed above pile №2, the height of the water level above the "zero of the gauge" is 40+240=280 cm (H_{sr}=2.8 m), the water level mark at the gauge in meters is determined by the formula:

$$H = H_{sr} + H_{„0”g} \, . \tag{2.2}$$

In this example, H = 2.80+121.00 = 123.80 m abs.

2.3 An overview of the main types of water level gauges

Permanent and temporary water level gauges are used in hydrometry:

1) permanent water level gauges are arranged for long-term study of the regime of the water body, these are the main gauges of the state network;

2) temporary water level gauges are arranged for special observations for a relatively short period of time (season, year, several years), they also include mobile water level gauges, which are opened during research along the length of the river only for the period of the location of the search party in the given area.

In hydrometric practice, various water level gauges are used: **simple** (staff, pile, mixed), **tapes** (bridge, cable), **self-recording**, **remote** and **slopes**. Regardless of their design, all types of water level gauges must ensure the registration of the entire possible range of water level fluctuations. Therefore, each gauge is equipped so that it is possible to cover not only the maximum and minimum probable values of water levels throughout the year, but also to provide a reserve of up to 0.5 m for extreme historical levels.

Simple water level gauges are the most popular in hydrometry, the choice of a specific type of simple water level gauge depends on the amplitude of water level fluctuations, the structure and steepness of the river bank, the presence of bridges, hydrotechnical structures.

Simple water level gauges include:

1) staff (the level is determined by divisions of the staff at the height of the water surface);

2) piles (the level is determined by its excess above the pile head);

3) mixed (staff-piled).

A staff water level gauge is installed with a slight fluctuation of water levels (up to 3 m) by fixing the staff in the soil of the bottom or on the walls of hydrotechnical structures, bridge supports, the staffs are protected from damage, marked every 1-2 cm, this ensures the accuracy of the water level measurement ± 1 cm. Staffs are standard made of wood, metal, cast iron (Fig. 2.2).

A pile water level gauge (Fig. 2.3) is installed on rivers with an amplitude of water level fluctuations greater than 3 m. Such a gauge consists of a benchmark and several piles. The piles are installed so that the heads of the first and last piles are respectively 0.5 m above and below the historical maximum and minimum water level in the given line gauge. Intermediate piles are installed so that the overlap of the heads of adjacent piles is no more than 0.8 m, and each pile rises above the surface of the ground (bottom) by no more than 0.15 m. Piles can be made of wood, metal, and reinforced concrete. Standard Pi-20 metal piles have a length of 220 cm, a diameter of 8 cm, a cast iron screw (35 cm) and a turnkey head (10 cm) (Fig. 2.4). You can also use wooden piles, on the head of which you need to drive a nail. The heads of the piles are painted white, and they are numbered starting from the top. Each pile must have its own "register".

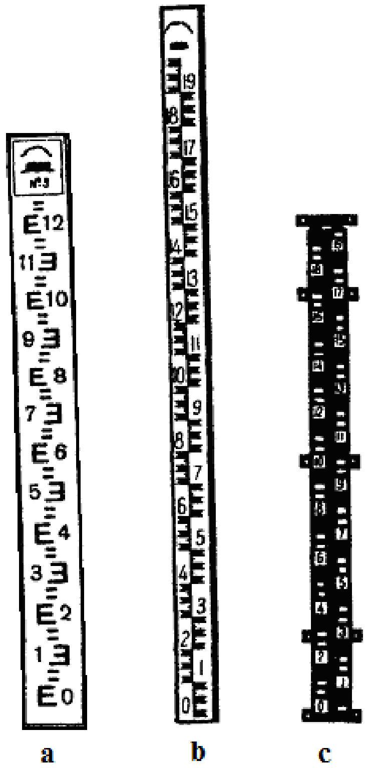
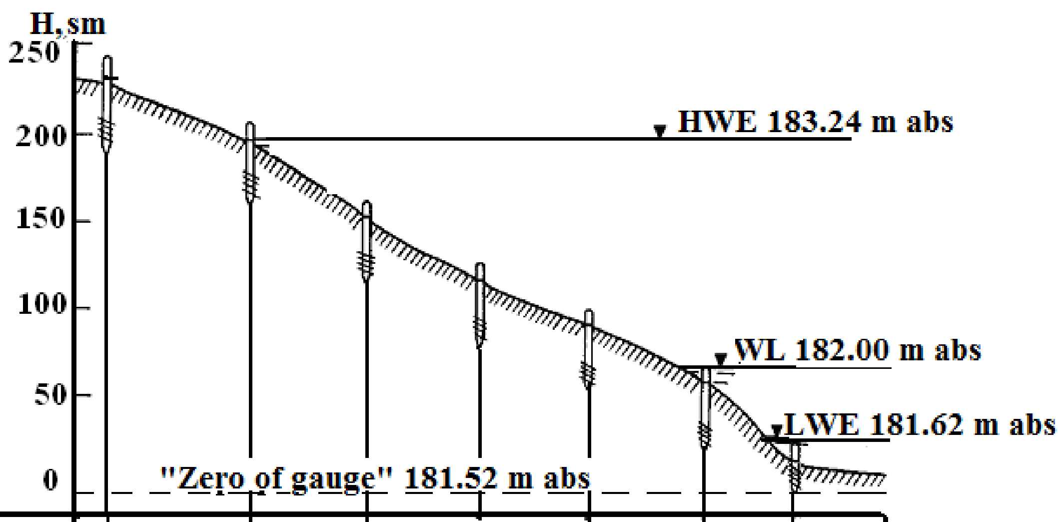


Figure2.2 – Types of gauge staffs on a staff water level gauge:
a) wooden; b) metal; c) cast iron



№ of piles	Bm	1	2	3	4	5	6
Distanse from ip, m	0	4.3	7.8	11.2	14.5	18.0	20.7
Mark, m abs	183.70	183.35	182.91	182.55	182.31	182.02	181.54
Register, sm	245	210	166	130	106	77	29

Figure2.3 – Design profile of the pile water measuring gauge (HWE – high water elevation; WL – water level; LWE – low water elevation)

The height of the water level at the pile water level gauges is determined by portable staffs: GR-104 (duralumin tube), GR-23 (staff with a stabilizer), wooden staff (Fig. 2.4). These staffs are marked every 1 cm, digitized every 10 cm and have a level reading accuracy of ± 1 cm. The water level is the sum of the reading along the staff and the piles register.

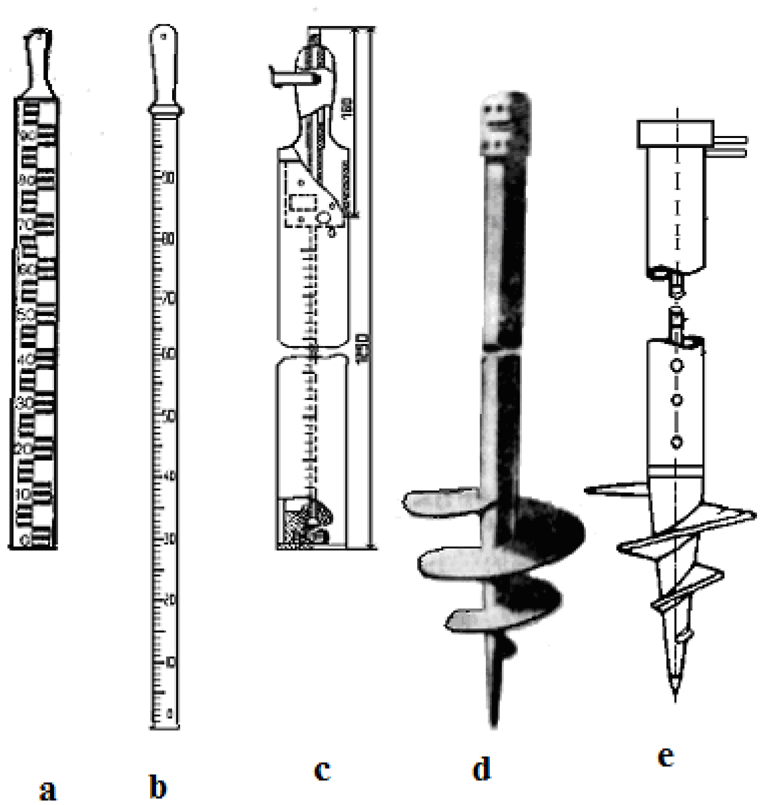


Figure2.4 – Staffs of the pile water level gauge: a) wooden staff; b) standard portable staff (GR-104); c) staff with stabilizer (GR-23); d) standard metal pile (Pi-20); e) maximum staff (GR-45)

Mixed (staff-pile) water level gauges are built on sections of rivers with sharp breaks in the bottom in the cross-section. The staff is placed on the steep part of the bank, and the piles are placed on the gentle side.

At water level gauges, maximum staffs are also used to fix the highest levels between observation periods. The GR-45 standard staff (Fig. 2.4, e) consists of a metal pipe with holes and a screw tip for installation in the ground. In the middle of the staff there is a wading rod with divisions every 1 cm, the surface of which is painted with chalk. The maximum water level is determined by the size of the washed chalk surface.

At the water level gauges, in addition to water measuring devices (piles, staffs, automatic water-level recorders), two benchmarks are installed - the main and control. The main benchmark is needed to check the height of the control benchmark, it is tied by leveling the III or IV class in a double move to the benchmark of the state reference geodetic network, which has an absolute mark. The control benchmark is installed in the line gauge for systematic checks of the height of the “zero of observations” of staffs, pile heads, and other water level measuring devices.

Tape gauges are suitable if the approach to water is difficult. The peculiarity of these gauges is that the “zero of observation” of the water level measuring device is always above the water surface. Common types of these gauges are bridge and cable with an arrow.

The bridge tape gauge (Fig. 2.5) is arranged on a bridge or other structure located above the water. For this, on the side of the bridge (structure), a permanent point (zero of observations) is chosen and fixed with a notch or a nail, relative to which the distance to the water surface is determined. The height position of this point is determined by leveling from the benchmark. To determine the water level, it is enough to measure the distance from the zero of observations to the water surface. To do this, use a portable staff, a thin marked cable or a tape measure with a heavy weight. At the bridge tape gauge, high water levels will correspond to small readings, and low water levels readings will correspond to large readings. In order to have a water level mark, you need to subtract the value of the reading from the mark of zero of observations every time.

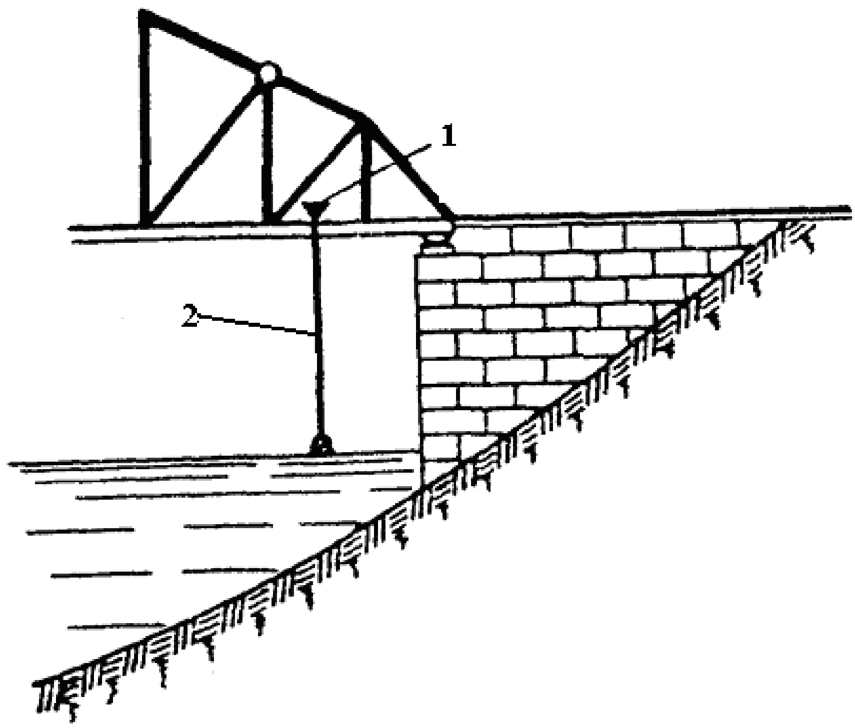


Figure2.5– Scheme of the bridge tape gauge: 1 - permanent mark on the bridge truss; 2 – a marked cable with a weight

A cable tape gauge with an arrow (Fig. 2.6) is arranged on rivers with steep banks, the gauge has an arrow with a cable fixed on piles, on which a staff is fixed, the zero of which is turned towards the river. A cable with a weight on the end passes through the wheel at the end of the arrow. The cable has a pointer against the zero division of the staff. To measure the water level, the weight is lowered to the surface of the water and make water level reading along the staff against the pointer. Touching the water by the weight is recorded with the help of an electric light or sound signal. Water level measurement accuracy is ±2 cm, in the presence of electrical contact ±1 cm.

Autonomous water level gauges provide automatic and continuous fixing of the water level and are installed on water bodies with an unstable water level regime or in areas remote from populated areas. They are necessary in the event of a significant daily course of the level, its sharp fluctuations during the passage of rain floods, rushes – surges phenomena, as well as in the case of regime changes under the influence of the operation of hydrotechnical structures.

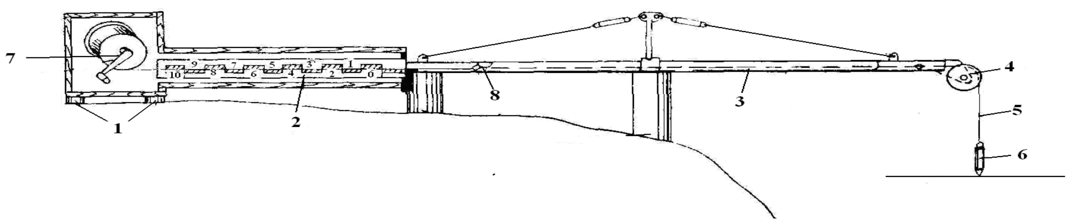


Figure2.6–A cable tape gauge with an arrow: 1 – piles; 2 - staff; 3 - arrow; 4 - block; 5 - cable; 6 - weight; 7 - burden; 8 – mark on the cable

The main device of the self-recording gauge is the *automatic water level recorder (AWLR)*, which consists of three main elements: a level sensor, a recording device and a communication line between the sensor and the recording device.

To record the fluctuation of the water levels, the recorder has a drum with a paper tape wound on it, a carriage with a pen (or pencil) and a clock mechanism that drives the pen. The pen draws a graph of the fluctuation of water levels on the tape in a certain scale. The duration of the AWLR operation without winding the clock is from one day to one month.

The water level sensor can be float, manometric or acoustic. A float sensor is a hollow metal or foam float that sinks into the water with the help of a counterweight and changes its height along with fluctuations in the water level. Manometric sensor - a hollow metal bellows, located at the bottom of a water body, which responds to changes in the pressure of the water layer depending on the fluctuation of the water level. Acoustic sensor - a metal or foam float in which an acoustic vibrator is mounted, which emits ultrasonic pulses and receives them after returning from the bottom. Depending on the water level in the river, the time of passage of the ultrasonic pulse in the water will change.

The communication line "sensor - recording device" can be in the form of:

1. systems of rigid wading rods or flexible cables with rollers;
2. pneumatic pipeline - hydrostatic pressure from the bellows through the pipe with air is transmitted to the manometer or piezometer;
3. hydraulic - based on the principle of connected vessels;
4. electric - an electric cable is used for communication between the sensor and the recording device;
5. radio communication - the change in water level is transmitted through a radio transmitter.

Float sensors became the most widespread as the simplest and most convenient for further conversion of water level fluctuations. Devices can record on paper tape with ink or electronically, work mechanically or from electrical power. The recording scale is selected taking into account the amplitude of level fluctuations and the required detail of their recording.

In Ukraine, the following AWLR are widely used - "Valdai", GR-38, GR-116.

AWLR "Valdai" (daily operation) (Fig. 2.7) consists of a float system and a recording mechanism. The movement of the float under the influence of water level fluctuations is transmitted to the float wheel by means of a thin cable with a counterweight. The float wheel is two paired disks of different sizes, which ensure the recording of water level fluctuations on a paper tape in scales of 1:1 and 1:2. The recording drum with paper tape is fixed horizontally on the same axis as the float wheel. During the rotation of the drum, the pen writes on the tape the water level on a scale of 1:1 if the cable is put on a small disk, on a scale of 1:2 if the cable is put on a large disk. The upgraded Valdai model has another axis that allows you to record the change of water levels in 1:5 and 1:10 scale. The pen of the self-writing device moves along the drum at a speed of 12 or 24 mm per hour with the help of a weight. In order to ensure the operation of the self-recorder, it is necessary to start its clock mechanism in a timely manner and maintain the tape. Accuracy of water level recording at scales 1:1, 1:2, 1:5, 1:10, respectively ±3, 5, 7, 10 mm.

AWLR GR-38 (Fig. 2.8) is designed for continuous registration of the water level of watercourses and reservoirs without changing the paper tape for recording for 8, 16 or 32 days. Record scales are 1:5, 1:10, 1:20 with an accuracy of ± 0.5; 1; 2 cm respectively. It differs from the AWLR "Valdai" only in the mechanism for recording water level fluctuations. In the same way as in the AWLR "Valdai", in the GR-38 the movement of the float, depending on the fluctuation of the water level, is transmitted by means of a thin cable to the float wheel, and then to the recording carriage. The drum with the paper tape is actuated by a clock mechanism.

These self-recorders have the following disadvantages: they do not have electrical signal outputs, which somewhat limits their automatic and remote capabilities; the installation requires significant costs in the construction of wells to accommodate the float sensor. Along with this, it is worth noting that under the condition of regular maintenance by an observer, such AWLR are very reliable due to their unpretentiousness to the conditions of operation and repair.

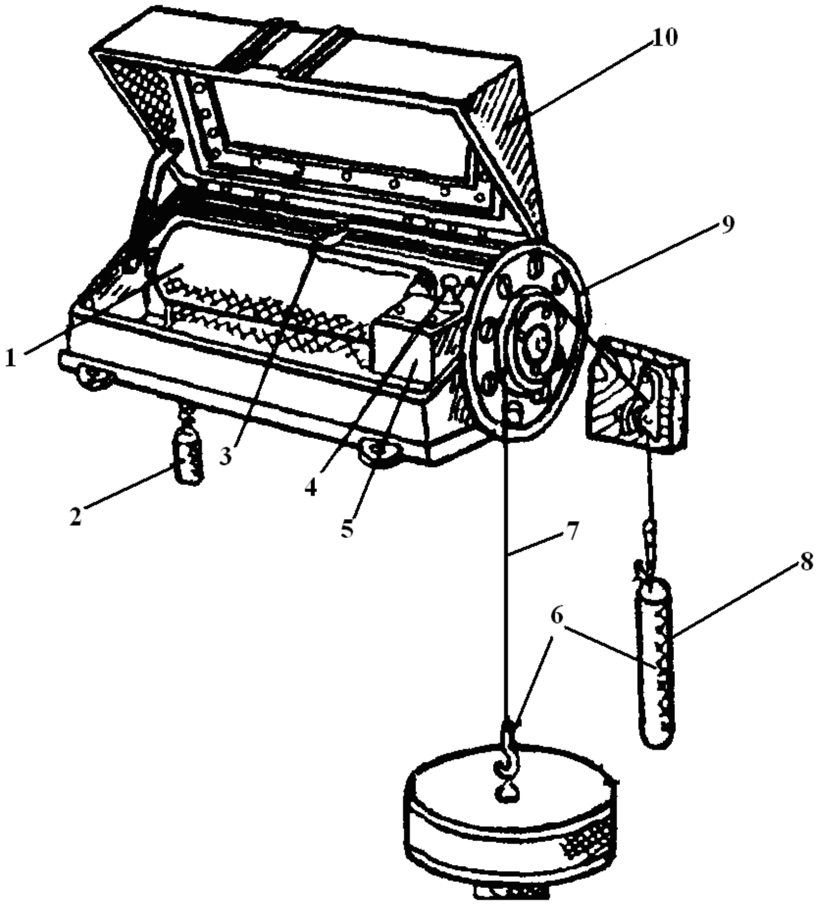


Figure2.7– AWLR "Valdai": 1 - drum; 2 – burden; 3 – a carriage with a pen; 4 – drive head; 5 – clock; 6 – float; 7 – cable; 8 - burden; 9 – float wheel; 10 – protective cover

AWLR GR-116 has both float and hydrostatic water level sensors, an analog recorder, and a water level converter into electrical signals. The device consists of a float suspended on a steel cable, which is thrown over a float wheel, a diverting roller attached to a counterweight. The float is made of foam plastic and treated with a special coating that would prevent it from getting wet. The registration unit includes a drum for fixing the chart tape, a recording device, electronic-mechanical and mechanical clock drives. The electronic-mechanical drive is the main one and is a stepper motor that provides high accuracy of time counting controlled by a quartz pulse generator. A mechanical clock drive is used in cases where there are no power sources. The water level meter has two options for recording the water level: with a graphite wading rod on an ordinary chart tape, or with Mylar calcium and a metal wading rod on a special two-layer paper. Water level registration scales from 1:1 to 1:20 are calculated for five ranges of water level fluctuations from 1 to 20 m. The duration of water level recording without changing the tape is from 16 hours to 32 days. A digital indicator is used to measure the water level in centimeters and millimeters. The water level meter is powered by 9V direct current from a battery or an alternating current electrical network (via a power supply unit). When using a digital indicator, the accuracy of determining the water level increases two times.

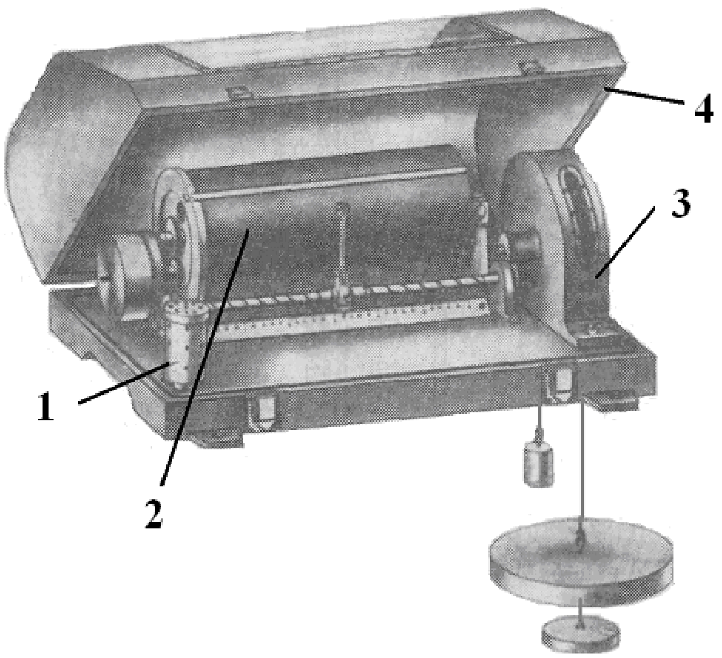


Figure2.8 – AWLR GR-38: 1 - a cartridge with a moisture absorbent substance; 2 - drum; 3 - casing of the float wheel; 4 - protective cover

The experience of operating the AWLR has determined two main types of their installations:

- the coastal type (AWLR is installed "on the shore" above the well, which is connected to the water body by a pipe);
- the island type (AWLR is installed "on the water" in a special structure).

The coastal type of the AWLRinstallation (Fig. 2.9, a) is expensive, but the AWLR can work all year round. A well is built on the shore, the top of which is 0.5-1.0 m higher than the highest mark of water level, and the bottom is 1 m lower than the lowest mark of water level. Above the well, a cabin with a AWLR is installed, the well is connected to the water body with a pipe with a diameter of 5-20 cm, which is buried below the depth of soil freezing, 1 m below the mark of lowest water level, the pipe should be cleaned and washed from sediments. In winter, the AWLR cabin is insulated.

The island type of the AWLR installation (Fig. 2.9, b) consists of a support that is built in a reservoir, a cabin for the AWLR on the support and a pipe for a float. The cabin for the AWLR is installed on the platform of the support, which is 1 m above the highest mark of water level. A pipe with a diameter of 0.35 m is installed 1 m below the lowest mark of water level. A bridge is built or a boat is used to approach the cabin from the AWLR. In winter, the island-type AWLR does not work.

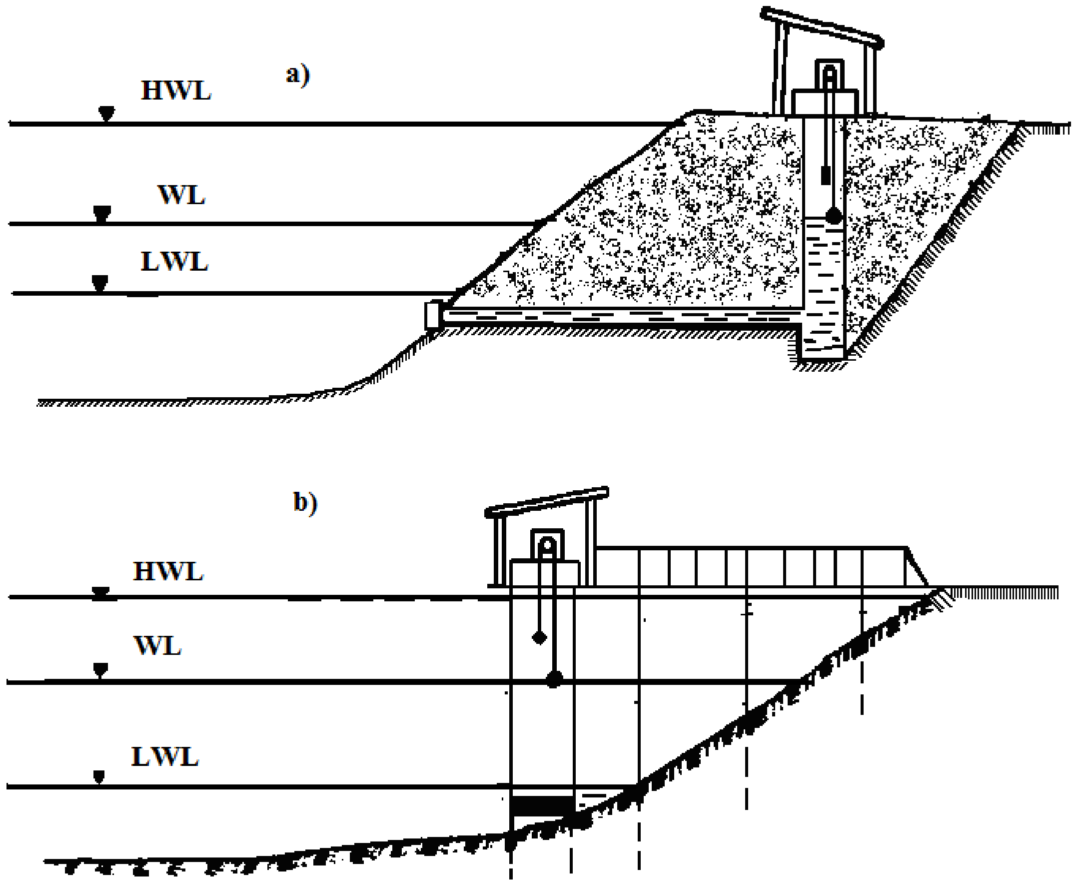


Figure2.9 – Coastal (a) and island (b) installation types of the AWLR (HWL – mark of high water level; WL – mark of water level; LWL – mark of low water)

Remote gauges perform the transfer of water level values over a distance at specified times, continuously or upon request. Remote gauges are of great value for the dispatching service at hydroelectric power stations, locks, reservoirs, irrigation systems and in hard-to-reach places, as they do not require constant maintenance by an observer. They consist of a water level sensor, a communication channel, a recording device and a power source.

The water level sensor receives water level fluctuations with the help of a sensitive element and prepares the information for transmission over the communication channel by means of conversion. The sensitive element can be non-contact electric, electric contact, float, hydrostatic, etc.

A non-contact sensitive element is a capacitor consisting of an insulated elect wading rode and a water medium, the capacity of which is proportional to the height of the water level. Electrical contact sensitive elements can be of continuous, discrete and ohmic type. The transformation of information is carried out into electrical signals - discrete or continuous - for the convenience of transmission via wired or radio communication channels. Information is registered on self-recordings, computers and various types of indexes (scale, numerical). Regardless of the type of automated gauges, simple gauges are stored for each of them, which ensure that the “zeros of observations” the stage gauges are checked. In foreign practice, hydrostatic stage gauges are the most common.

The pneumatic stage gauge "Narthex" (France) has a power supply of 9 V, weight 5 kg, electronic memory card, water level reading accuracy ± 1 cm, unlimited autonomy, amplitude of water level fluctuations up to 20 m, distance from the sensor to the device 300 m.

The pneumatic stage gauge "Nimbus" (the company OTT, Germany) has a power supply of 12 V (or solar batteries), a weight of 5 kg, a memory card for 400,000 water level values, a water level reading accuracy of ± 1 cm, a battery life of 15 months, wireless communication with a PC, additional meteorological sensors.

The pneumatic stage gauge "Archimedes" (OTT company, Germany) has a power supply of 6 V, weighs 1 kg, a memory card for 11,200 water level values, the accuracy of the water level reading is ± 1 cm, the autonomy period is 15 months, wireless communication with a PC.

Autonomous stage meter "ADU-01" (RF) has a power supply of 4.5 V, weight of 0.45 kg, a memory card for 100,000 water level values, water level reading accuracy of ± 1 cm, autonomy of 2 years, switching from a PC by USB port.

The mobile contact stage meter KL-010 (the OTT company, Germany) has a 3 V power supply, a weight of 1 kg, an electronic memory card, a water level reading accuracy of ± 1 cm, a depth of up to 750 m, a built-in water thermometer, an electronic display.

The Kalesto contact radar stage gauge (the OTT company, Germany) has a 12 V power supply (or solar batteries), weighs 10 kg, has an electronic memory for 400,000 water level values, the accuracy of the water level reading is ± 1 cm, autonomy is 2 years, wireless communication connection with PC up to 1000 m, ultrasonic emitter, additional meteorological sensors.

In Ukraine, a *hydrometeorological gauge ("Tehprilad", Lviv)* is gradually being put into operation, which provides automated measurement, processing, coding, archiving and transmission of hydrometeorological information: water levels (0-14 m, accuracy ±1 cm) and waves measurements (0-6 m, accuracy ±

6%); measurement of water temperature (from -2 to + 40 °C, accuracy ±0.15 °C); measurement of air temperature, atmospheric pressure, relative humidity, precipitation; formation and transmission of "Meteo" and "Storm" telegrams; archiving and transmission of hydrometeorological information in real time over the Internet.

Standard water level observations twice a day do not allow recording extreme values of water levels between standard periods, so special maximum staffs (Blyznyak's, Frolova's, Proskov's, staffs at piles) are used at gauges.

The Blyznyak's staff is a pipe made of four boards with holes. One wall of the pipe opens, and on the second wall a rail with divisions is attached, the zero of which is tied to the zero of gauge. The pipe is attached to a pile or to the wall of some building. The inner surface of the pipe is covered with easily washable paint, chalk or charcoal. Under the influence of water, the paint washes off to the height of the maximum water level that occurred between the observation periods. Exceeding this water level at the zero of gauge is determined by a staff with divisions. After recording the height of the maximum water level, the inner surface is painted again.

The Frolov's staffs (Fig. 2.10, a) are used to measure the maximum and minimum water levels between observation periods. They are made of boards. In addition to markings, the staff on the sides has teeth every 1-2 cm. A light float placed on the toothed staff moves along the water level in only one direction: up - on the maximum staff and down - on the minimum staff and remains in this position until the observer arrives. Changing the position of the float is prevented by springs that rest on the teeth of the staff. The Frolov's staff are attached to the pile, and their "zeros of observations" are tied to the gauges benchmark by leveling. After recording the extreme values of the water levels, the floats of both staffs are set to the current water level and left until the next observation period.

The maximum staff in the metal pipe on the pile (Fig. 2.10, b) has a diameter of 5 cm, a length of 2 m and holes in the lower part. The pipe is attached to a pile or structure. An iron wading rod with a diameter of 10-15 mm, whitened with chalk diluted in water, with divisions every 1 cm, is inserted into the pipe. Water enters the pipe through the holes and washes away the chalk to a height that corresponds to the maximum water level between the observation periods. The height is calculated by divisions on the wading rod. The zero of observation on the wading rod is tied by leveling to the gauges benchmark.

Proskov's staff (Fig. 2.10, c) differs from the previous one only in that it is not attached to the structure, but is buried in the ground to a depth of 75 cm. After installing the staff, the height of its head is determined by leveling and the zero mark of its observations is calculated.

In the absence of the above-mentioned devices, the maximum water level can be set according to the high water marks that remain on the river after a flood (deposited garbage on the banks, silt, erosion traces in the channel and valley slopes). High level marks are determined by leveling.

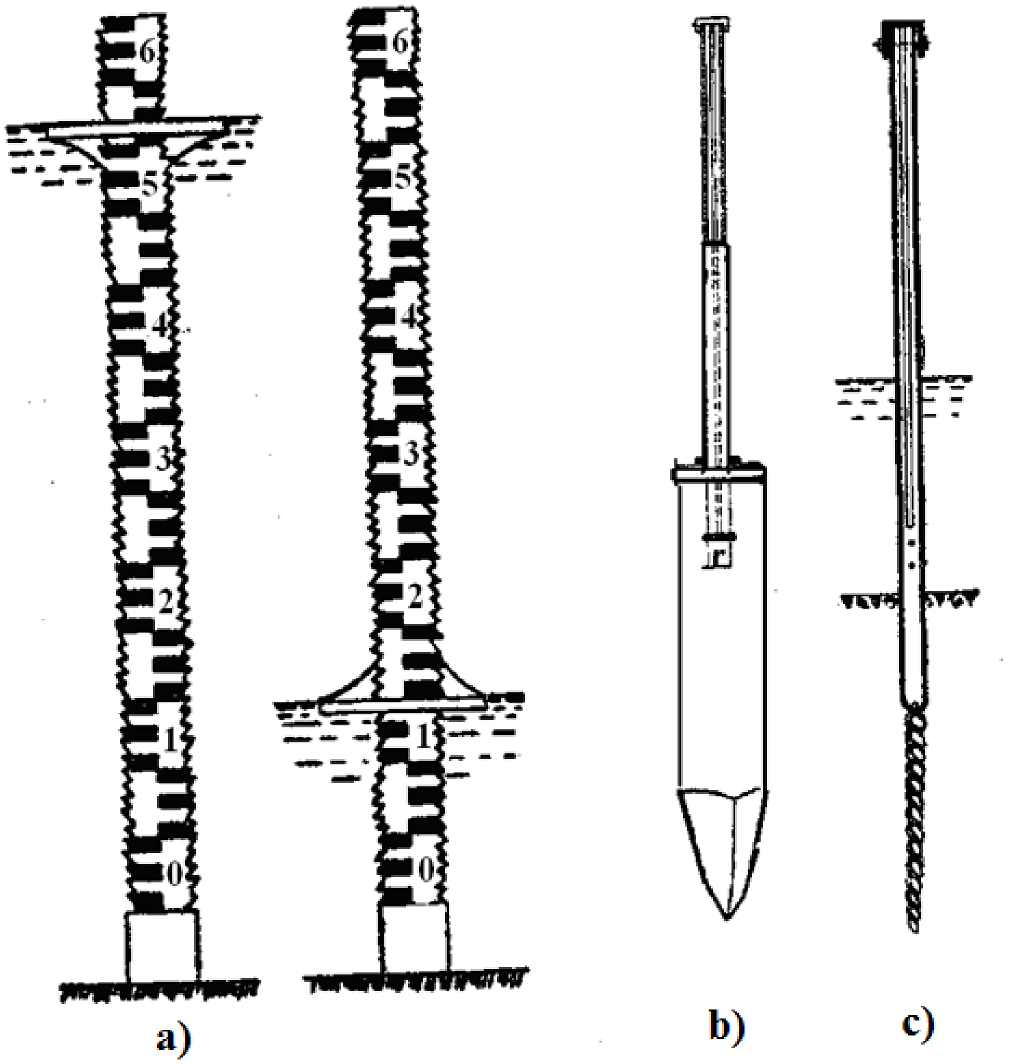


Figure2.10 – Additional staffs: a – Frolov's staffs; b - a staff in a metal pipe on piles; c – Proskov's staff

With fast currents, as well as with the presence of waves, special devices are used to accurately measure the height of the water level.

Staff (pile) in a bucket: on mountain rivers with a high flow rate, the water rushes onto the staff of the gauge and makes it impossible to accurately measure the mark of water level. In such cases, the staff (pile) is arranged in a bucket, which is dug on the shore and connected to the river by a ditch (Fig. 2.11, a). If there is no bucket, you can extinguish the wave around the staff (pile) with the help of a box without a bottom, a pipe with holes at the bottom, wicker baskets, etc.

The hook gauge (Fig. 2.11, b) is designed to measure the water level with an accuracy of up to 1 mm with an amplitude of water level fluctuations up to

1.5 m, consists of a brass tube (1) with a diameter of 10 mm. Divisions are applied to the tube every 1 cm. A wading rod (2) with a hook at the end is installed in the middle of the tube. With the help of bracket (3), the tube is attached to a pile (wall) above the water. The bracket has a bar with divisions (vernier) (4), clamping screw (5) and micrometric nut (6). To measure the height of the level, lower the hook 1-2 mm below the surface of the water, fasten the clamping screw, use the micrometric nut to raise the hook to the level of the water surface and record the height of the water level: centimeters on the staff, and millimeters - on the vernier.

The needle gauge (Fig. 2.11, c) differs from the hook gauge in that it has a needle instead of a hook, the divisions are drawn every 1 mm, and readings can be taken with an accuracy of 0.1 mm on the vernier. The total length of the staff is 0.5 m.

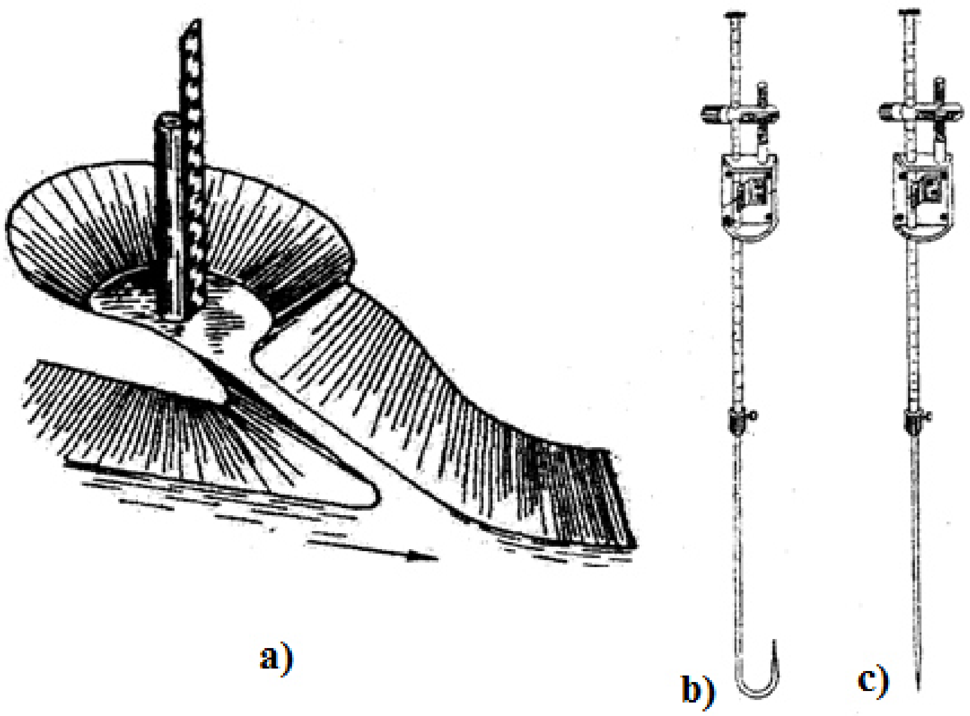


Figure2.11 – Devices for detailed water level readings: a - a staff in a bucket; b - hook gauge; c - needle gauge

2.4 Slope gauges

Such gauges are used in conducting special studies (determining the slope of the water surface in the area of hydrological observations, studying the flow regime and runoff). They have the greatest value in the period of violation of the unequivocal connection of water discharges and water levels, which is characteristic of the phenomena of variable backwater. Similar phenomena occur with unstable water movement (spring floods, floods, subsidence), with backwater from the water intake, ice phenomena, overgrowth of the channel and in other cases.

The slope of the water surface is the ratio of the water level drop in the river section ($h = H_1 - H_2$) to the length of this section (L):

$$I = \frac{h}{L}. \quad (2.3)$$

Determination of the slope of the water surface is carried out in two gauges. One of them is the main gauges, and the second is an slope gauge, which is located upstream or downstream from the main one. In terms of their structure, slope gauges do not differ from basic gauges.

The distance between the gauges can be different, but the shorter it is, the greater the accuracy of the measurements should be. Satisfactory results of the selection of the site between slope gauges can be achieved with a drop in the water level on a plain river of at least 10-20 cm, and on a mountain river of 25-50 cm.

Due to the fact that at high water levels (spring floods, floods) and at the low-water period, the slopes differ significantly, the lengths of the sections, depending on the phases of the regime, can be different. However, in all cases, slope gauges should be appointed in places below and above which the slope of the water surface remains uniform at some distance. When determining the slope of the water surface in the experimental area by leveling, the following requirements should be taken into account:

- synchronicity of driving the flow-line stakes;
- uniform placement of the flow line stikes along the length of the site;
- leveling is carried out by a double pass of IV or III class, depending on the slope drop in the area.

2.5 Designing, opening, relocation of water level gauges

The choice of place for location a water measuring gauge is important, it is necessary to take into account the type of gauge, the convenience of access to water measuring devices, the peculiarities of the hydrological regime of the water body, the requirements for the site:

- representativeness (the site must be typical for a water body so that the water measuring gauges information reliably reflects the water regime);
- exclusion of the influence of factors that violate the unambiguous relationship between water discharges and water levels (variable backwater, channel deformations, channel overgrowth, ice jams, operation of hydrotechnical structures, discharges of industrial water, water intakes, channel quarries);

- when placing water measuring gauges on reservoirs, take into account the variability of water levels under the influence of natural and anthropogenic factors and provide for the protection of gauge devices from destruction by ice or waves;

- on plain rivers, the section should be rectilinear for five times the width of the river with the same width, depth, slopes of the water surface, the correct trough-like shape of the cross section, the influence of rushes and surges of water processes should be taken into account;

- the absence of a floodplain is desirable, the river should flow in one channel, without arms and canals (if there is a floodplain, you should choose such a section where the floodplain is the narrowest, levelest without canals and moats, without trees and bushes, the banks of the floodplain should be parallel);

- large tributaries, islands, unstable rapids, etc. should not flow within the area, which can cause the formation of cross-stream currents, cross-sloping water, traffic jams and ice jams;

- the banks and channel should be unchanged, not washed away, not silted up, not overgrown with water vegetation, the current should be across the entire width of the river, and its direction should be parallel to the banks, in winter the river should be completely covered with ice;

- on rivers with dams, the place should be chosen above the limit of action of the backwater from the dam, on the estuarine areas of the river, water measuring gauges should be located higher than the water intake (sea, lake, river), out of the influence of the backwater processes from it;

- on mountain rivers, a water measuring gauge should be additionally installed higher than rapids, weirs, in a place with a calm watercourse, without boulders and erosion.

It is necessary that the selected area meets these requirements as much as possible.

Reconnaissance survey of the location of the post is the second stage, during which an expeditionary survey of the area of the water body is carried out to select a specific representative location with suitable conditions for the placement of the gauge, to assess the range of changes in hydrological characteristics intended to be determined at this gauge.

The reconnaissance is completed with a topographical survey of the area and an elevational substantiation of the hydrological gauge, which are performed in accordance with the requirements set forth below.

The size of the surveying’s area is limited in width by contour lines that are 0.5-1.0 m higher than the historically maximum water level, and in length is determined by the width of the river (on rivers with a width of up to 100 m, the length of the survey area is taken equal to seven times the width of the river, on wider rivers - two or three times the width of the river).

The scale of the survey is taken on the basis that on the plan the boundary channel has a width of at least 4-5 cm. For the survey, the scales of the plans can be taken from 1:100 to 1:25000, depending on the situation.

For the planned substantiation of the survey of the gauge site, a theodolite course (basis line) is laid along the banks of the river (within the non-flooded part) in the form of a closed landfill or basis line (this is done in conventional coordinates and does not always need to be tied to the points of the state geodetic network), the course is oriented in azimuth using a compass (circumferentor). The basis line is laid along the shore parallel to the current as close as possible to the water cut. The ends and corners of the basis line, characteristic turning points of the surface are fixed on the ground with stakes. After the basis line are laid, 3 transverse profiles are broken, the ends of which should reach heights of 0.5-1 m higher than the maximum water levels. Then, perpendicular to the basis line, 6-10 measured cross-sections are broken, the distances between which are taken from the calculation, so that all the features of the topography of the bottom can be highlighted.

For the height justification of the site, leveling (IV class) of the survey grid is carried out, which consists of the basis line and transverse profiles, which are fixed with special signs (benchmarks, pickets, corner signs) and characteristic points of the relief. If the section of the water measuring gauge is located at a distance of up to 10 km from the benchmark of the state geodetic network, then it is necessary to tie the benchmark of the water measuring gauge to it and give all marks on the survey plan and profiles in the system of absolute marks.

At all cross-sections, depths are measured at 10-20 points on each and the soil composition of the river bed is determined. They are surveying the situation in the area adjacent to them. Also, on the cross-sections, pegs are simultaneously driven flush with the surface of the water (water cut), leveling which get a mark of the instantaneous (simultaneous) water level, to which the measured depths will later lead. The direction and value of the current speed are measured using surface floats.

The points of plan-elevation justification of the survey on the terrain are fixed with appropriate signs. Based on the materials of the works performed on the site, a plan of the post area is drawn up and transverse profiles of the channel are drawn based on the materials of the measurements. The basis line, cross-sections, water cut-off line, relief of the river bed in isobaths or contour lines, direction of water flow, topography of banks, floodplains in contour lines, existing buildings, situation (gardens, meadows, fields) are applied to the plan. After the construction of the water measuring gauge, its benchmarks, piles or staffs and equipment are applied to the plans.

In addition to the plan and profiles, make up the general description of the river section: a) information about the river (name, length, basin, its area); b) information about the site of the gauge (how many kilometers from the mouth, administrative names, availability of telephone, railway, pier); c) characteristics of the site (width of the valley and floodplains, relief, pounds of vegetation cover, channel width, depth, bottom soils, overgrowth of the channel, slopes of the water surface, direction and value of the current, banks); d) the main characteristics of the water regime (amplitude of fluctuation of water levels, probability of drying out and freezing, ice processes); e) use of the river in the area and above the gauge.

Photos, diagrams and sketches are added to the description.

Based on the materials of the reconnaissance survey of the river section, the appropriate type of water measuring gauge is chosen (pile, staff, mixed, self-recording, etc.). Next, they create a water measuring gauge project, where all water measuring devices and benchmarks are placed in the profile and plan versions. After the design, everything is built in kind, after the installation of benchmarks, staffs, piles, etc., the height of the benchmarks of the hydrological gauge is tied to the state geodetic network by grade III or IV leveling.

Water-measuring devices are tied to the gauge benchmark by leveling according to IV class in a closed course from the main benchmark through the control benchmark to the staffs or piles and from them back to the main benchmark. The difference in the sums of the excesses on the forward and reverse courses should not be more than $\pm 3\sqrt{n}$ mm, where n - is the number of stops of the tool in one course. Leveling is carried out in the cross section of the gauge, the leveling staff is placed on the heads of the piles or the top of the staffs (you can direct the leveling simply to the water measuring staff and take the reading along it). If the leveling point is not a benchmark, a pile or a staff, then a stake must be driven into it at ground level. In addition to the gauge equipment, the water cut is leveled at the same time along the peg driven into the gauge at the level of the water (to determine the height of the working level), as well as the high water marks. At the same time as the leveling of the working level, the water level is measured by gauge devices. If the gauge is equipped with a AWLR, then in addition to leveling the gauge devices, the AWLR itself must be leveled.

The leveling data of gauge devices are recorded in the technical leveling log (KG-64), where a schematic outline of the leveling course is also drawn. The received markings of gauge devices and their references are written in the "Technical case of the gauge" and field book KG-1(M). According to the leveling data, a profile of the water measuring gauge is drawn up on graph paper, on which are placed the benchmarks, piles (staffs), registers, extreme water levels marks, and the zero mark of the gauge.

The complete set of devices depends on the grade of the gauge and is carried out in accordance with the regulatory requirements of the "Standard table of instruments and equipment for hydrological gauges".

After the completion of the construction and installation works and the provision of the hydrological gauge with the necessary devices and equipment, the official opening of the water measuring gauge takes place, which is formalized by an act drawn up by the person who opens the gauge, an observer and a representative of the local Council.

At the same time as the act, the "Technical file" is drawn up, which is the basic technical document of the water measuring gauge and which contains the main information about the gauge, a description of the river, a site plan and a cross-sectional profile of the channel in the section line of the gauge, operational characteristics, information about the gauges devices and equipment, types and observation periods, metrological requirements. The hydrological gauge must be fully equipped with standard blank material in accordance with the current regulatory requirements for hydrometeorological gauges.

An observer from local residents is invited to carry out all hydrometric work at the water measuring gauge. The observer, according to the established programs, conducts all observations at the gauge, and a corresponding job description is drawn up for him.

The technician who opens the water measuring gauge and negotiates with the observer about the work is obliged to inform him about the meaning and tasks of the gauge, explain the structure of the gauge, indicate the content and terms of observations at the gauge, the procedure for recording and processing observation data and their forwarding, submission informational telegrams, explain the rules of supervision of the equipment of the gauge, as well as carrying out minor repairs on it.

The technician must, together with the observer, conduct all observations on the place for several days according to the program of the gauge. An observer is allowed to work independently only after checking his knowledge directly at the gauge.

The hydrological gauge in its work is guided by the instructions of the hydrological station, which prepares instructions for the observer, coordinates his work, advises on problematic issues, periodically inspects the gauge, and prepares instructions on safety techniques for hydrometric work at this gauge. Records of field observations are kept in field notebooks in two copies - a draft (filled in during observations) and a final (filled in at the station by rewriting the draft book). At the end of the month, initial data processing is carried out in both copies, draft books are sent to the station by the 2nd of the following month, clean ones - at the end of the year.

To ensure the accuracy of the gauge, the gauge is inspected periodically (at least once a year). During the inspection, the stability of the hydrological regime of the river in the area of the gauge, the correctness and timeliness of observations and entries in the book, the condition of the gauges equipment and the need for repair are checked, control leveling is carried out. The results of the inspection are recorded in the "Technical Case" and an act is drawn up. If the leveling shows a change in the markings of gauge devices, this should be taken into account in the further work of the gauge.

The reasons for moving the water measuring gauge can be: changes in the structure of the river bed and banks, the threat of destruction of the gauges equipment, the construction of a dam or other changes that interfere with the normal operation of the gauge. In such cases, the water measuring gauge must be moved to another place, but with such a calculation that continuity of hydrometric observations (i.e. preservation of homogeneity of series of water level observations at the old and new gauges). For this purpose, when moving a water measuring gauge, you should choose a new place as close as possible to the previous one, as well as connect the observations of the old and new gauges. In those cases, if the conditions at the new gauge are completely different (transfer beyond the backwater limits, or from one beef hydrotechnical node to another), the linking of water levels is not performed. In order to connect the observations of the new and old gauges, parallel observations should be conducted at both gauges during the year. The height of the "zero" of the new gauge for the time of parallel observations can be taken arbitrarily. After building a graph of the connection between the water levels of both gauges, the "zero height" of the new gauge is taken as the final one.

2.6 Processing of the materials of water measurement observations

The results of observations and work at the gauge are recorded in appropriate forms, a field book for recording water measurement observations KG-1M(n), which must be made out in two copies: the original (the results of field observations are recorded) and a copy (the results of observations are transcribed immediately after returning from rivers). All the results of observations to KG-1 M(n) are recorded only with a simple soft pencil, clearly, legibly and without all kinds of errors and corrections made with the help of an eraser or erasers. If the entry is made incorrectly, it must be crossed out once and the correct entry must be written on top or on the side.

Observations of the slope of the water surface at the upper and lower slope gauges consist of time and water level readings, which are recorded in the KG-14M book. Next, the water level marks above the "zero" of the gauge are calculated, the drop of the Z level is determined by the length of the base L_b (the distance between water slope gauges):

$$I = 100 \bullet \frac{Z}{L_b}. \tag{2.4}$$

After returning from the river, the observer must perform the necessary initial processing of the results of observations in the original books and transfer them to copies. At the end of the month, the observer must perform the necessary processing of observations for the month and send the originals of books, tables, tapes of records to the hydrological station no later than the 2nd day of the following month. Copies of books, tables and other forms are sent to the hydrological station at the end of the year.

The materials of water measurement observations (books KG-1, tapes AWLR, tables TG-2) undergo initial processing at the water measuring gauge, analysis and control at the station, preparation for publication in the form of the table "Daily water levels" in the publication "Water Cadastre". The daily primary processing performed by the observer includes zeroing the gauges graph and calculating the average water level and temperature for the day. At the hydroligicsl station, all entries in the water meter book are checked and analyzed after the end of the month and the receipt of observation materials.

In addition to annual tables, based on the results of observations for the year, a comprehensive schedule of the results of hydrometeorological observations for the year is built. On this graph, time is displayed along the horizontal axis, and air temperature, precipitation, height of snow on the ice, ice thickness, water temperature, conventional signs of ice phenomena and formations, water level, daily water discharges, water turbidity, along the vertical axis (from top to bottom). overgrowth coefficients K_{zar} and winter coefficients K_{zym}. This schedule is an important technical document of the hydrological gauge and facilitates the control and analysis of hydrological materials for this gauge.

The design of water measuring gauge, the processing of the AWLR tape and the KG-1 book are considered in laboratory work №. 1.

2.7 Questions for self-control

1. Characteristic phases of the water regime of rivers.
2. The main types of water measuring gauges in Ukraine.
3. Works that precede the opening of the water measuring gauge.
4. Processing of water level observation data

3 DEPTH MEASUREMENTS IN HYDROMETRIC INVESTIGATIONS

3.1 Essence, tasks, methods of depth measurements

Depth measurement allows you to obtain information about the depth of the reservoir at individual points, in a certain direction, across the water area.

Depth is the vertical distance from the surface of the water to the bottom. The complex of sounding works includes: plane basis layout, fixing the water level at the beginning and at the end of the depth measurements, coordinating the sounding verticales, measuring the depths in the discharge section lines, determining the nature of the bottom soil. Coordination allows you to fix the position of sounding verticals in the plan and process the materials of sounding works - to build profiles, to make a plan of the reservoir in contur lines or isobaths (lines of equal depth).

Depth measurement is usually performed:

- at hydrological gauges when determining water discharges, suspended sediments discharges, bed load discharges;
- when performing hydrographic studies of reservoirs;
- in river navigation studies;
- during design works for basis line objects in places where they pass through reservoirs;
- when determining the volume of water in a section of a river, lake or reservoir.

The most convenient time to carry out sounding works is at the low-water period, when it is easier to work due to low water.

If soundings are made during the study of channel deformations or water discharges, suspended sediments discharges, bed load discharges, then they are carried out at any water levels.

There are various manners of performing sounding works, which differ in devices and execution technology. Depths can be measured by mechanical, hydrostatic and acoustic methods:

- **mechanical manner** (the depth is measured by the part of the measuring device immersed in water - wading rods, lot line, etc.);
- **hydrostatic manner** (the depth is determined by the hydrostatic pressure on the sensitive element of the device, which is placed on the bottom);
- **acoustic manner** (the depth is determined by the speed of movement of the ultrasonic pulse from the emitter of the device to the bottom and back).

There are two methods of carrying out of sounding works:

- **method of point (discrete) measurements**;
- **method of continuous depth measurements** (by sonic echo sounders).

The results of measuring depths with devices of the first group allow obtaining the topography of the bottom in a discrete form (sounding verticals are located at a certain distance from each other, and the areas of the bottom between them are not covered by measurements). When using devices of the second group, a continuous record of the profile of the bottom of the water object is obtained - *an echogram*.

3.2 Method of discrete depths measurements

The simplest devices for measuring depths include: a sounding rod, hydrometric wading rod, manual and mechanical lead.

The sounding rod (Fig. 3.1, a) is a wooden pole with a diameter of 4-6 cm, a length of up to 5-7 m, which is marked every 10 cm into red and white divisions. At the lower end of the sounding rod there is an iron shoe weighing up to 1 kg, which facilitates immersion of the sounding rod in water, provides a more stable position and protects it from damage.

If the bottom of the river is muddy, then a protective pallet is attached to the lower end of the sounding rod. The zero division of the sounding rod should be at the level of the bottom of the shoe or pallet. To measure the depth, the sounding rod is thrown with the lower end forward against the current along the course of the boat, and when it takes a vertical position, a reading is taken. Measurement accuracy ± 2-5 cm.

Manual lead LPR-48 (Fig. 3.1, d) - a load 335 mm long, 56 mm in diameter, weighing 4.5 kg, which is attached to the lead line, it is possible to measure depths in rivers up to 25 m, in stagnant water bodies - up to 100 m. Lead-line is a cord with a diameter of 3-5 mm made of yarn, capron or a soft steel cable with a diameter of 1-2 mm.; it is intended for lowering the lead into the water, it must be strong and not change its length; lead-line is marked in decimeters and meters.

When working, the manual lead is thrown forward against the current, and the countdown is made when the lead line takes a vertical position. Measurement accuracy ± 10 cm.

The sounding manual lead has a recess in the lower part, which is lubricated with fat or petroleum jelly during measurements. When the lead touches the bottom of the river, soil particles stick to the lubricant and rise to the surface together with the lead. In this way, you can learn about the composition of the soil at the bottom of the river. If it is necessary to take larger soil samples from the bottom of the river during measurements, then use a **lead with a cone** (pouring) at the end (Fig. 3.1, c).

Such a lead can collect samples with a volume of up to 100 cm^3.

At shallow depths, soundings are made with staffs (water level measuring, leveling) or hydrometric wading rods from a current meter (Fig. 3.1, b).

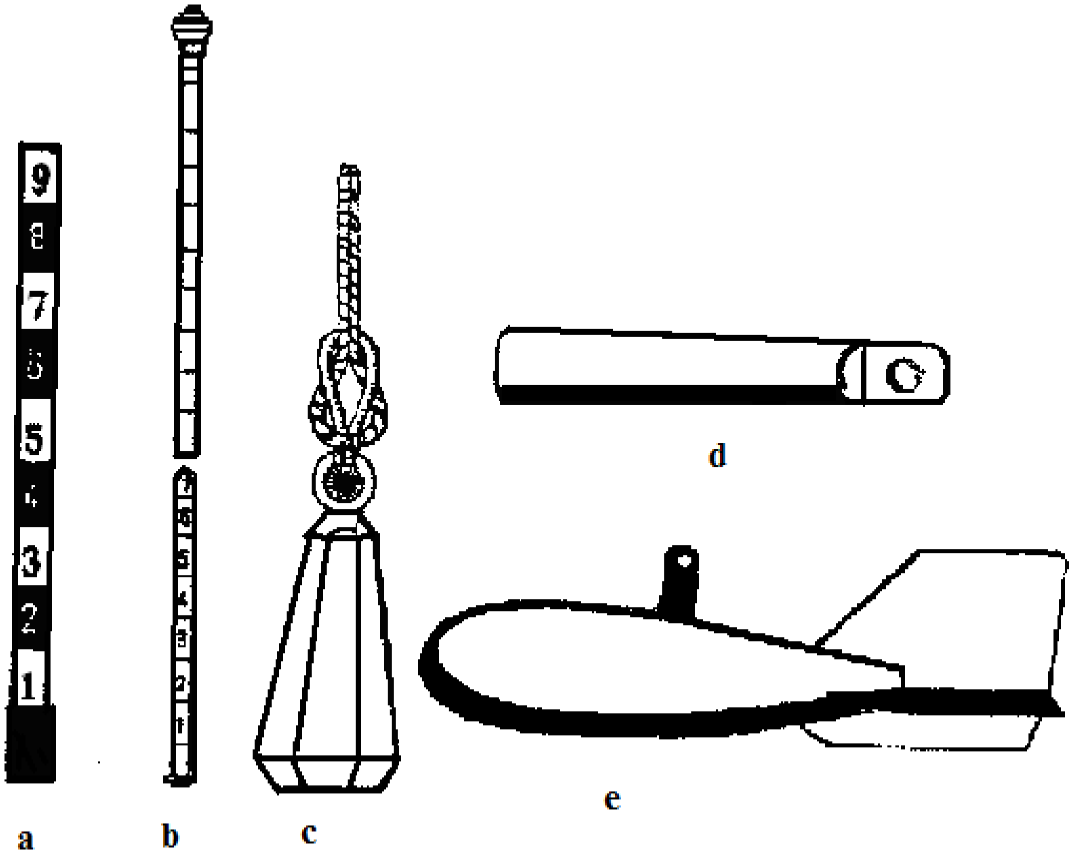


Figure3.1 – Simple devices for soundings: a - sounding rod;
b - hydrometric wading rod; c - lead with a cone; d - manual lead LPR-48;
e - Columbus-type sounding weight

Depending on the depth of the river and the speed of the current, **mechanical leads (hydrometric cranes)** weighing up to 100 kg of any shape are used for depth measurements. They have a depth counter, a rope with a diameter of 1-3 mm for lowering the weight, a Columbus-type sounding weight (weight from 5 to 100 kg). When sounding with cranes while the boat is moving, the cable is not completely removed, but only slightly raised after the next sounding and lowered again.

Hydrometric cranes Pi-23 ("Neva") and Pi-24 ("Luga") are the most common lifting devices on the hydrological network (Fig. 3.2), which are used from gauging footbridges, gauging cars and boats. Each crane consists of the following main parts: a frames, a drum for a cable, an arrow for taking the lead overboard, a depth counter. The difference between these cranes lies in the shape of the frames (supports). The frames of the "Neva" cable are higher, have a hinged support and a variable connection with the arrow, which is also hinged to the frame. The hinged mounting of the frame and the arrow makes it possible to change the angle of inclination of the arrow within 30-60° and the distance of the device from the side of the boat to them. The frame of the “Luga” crane is more portable and is not connected to the arrow. The arrow can be mounted on the side of the boat at any distance from the frame. The counters show the length of the cable lowered into the water with an error of 1 cm. The reset device allows you to set "zero" at any position of the lowered cable. The length of the rope is 22 m, the weight of "Neva" - up to 50 kg, "Luga" - up to 30 kg.

The crane GR-36 (Fig. 3.2, d) has a turning arrow with a 1.2 m extension from the edge of the support and a counter. The design of the crane allows you to rotate the arrow around the vertical axis by 360°. The crane is used for measuring depths up to 25 m, its weight capacity is 100 kg.

Kuznetsov's crane are also used on ships and pontoons, and GR-65 and GR-65 m cranes, which do not have an arrow, are used on gauging cars.

Quite common **LG-1 crane** (Fig. 3.2, c) in modifications:

1) for boats, pontoons and bridges - LG-1-M1-1;
2) for boats - LG-1-M1-2;
3) for gauging cars - LG-1-M1-3;
4) for sea vessels - LG-1-M1-4.

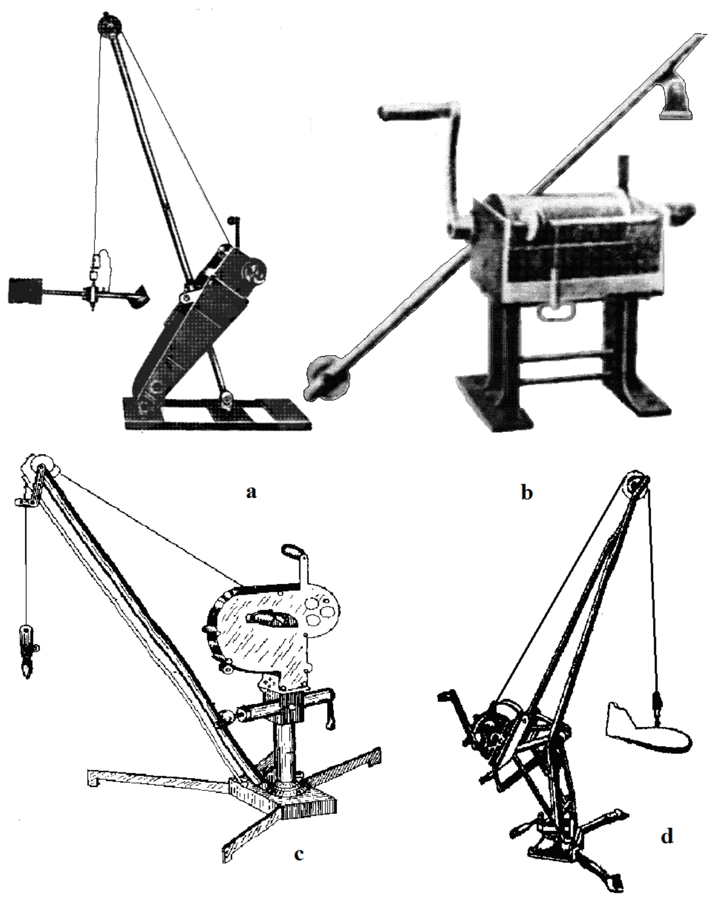


Figure3.2 - Hydrometric cranes: a - Pi-23 "Neva"; b - Pi-24 "Luga"; c - LG-1; d - GR-36

Cranes can have a wire with a conductive core, which allows you to put weights and devices with electrical contact mechanisms to them.

When choosing a weight (Table 3.1), take into account the speed of the current, so that the angle of deviation of the rope does not exceed 10º. The method of measuring depths using a mechanical lead and various types of hydrometric cranes is practically the same in all cases. In order to lower the lead, it is necessary to turn the handle of the crane back, throw back the dog of the ratchet wheel and etch the cable under the weight of the lead, holding (braking) the revolutions of the drum with a gentle or manual brake. When the lower surface of the lead rests on the surface of the water, the drum is braked and the crane counter is reset to “zero”. Then the lead is lowered to the bottom, which is visible from the slack (sag) of the cable and the depth is recorded according to the readings of the counter. To avoid the possibility of steel ropes breaking, their diameter is selected depending on the mass of the lead and the speed of the current (Table 3.2).

Table 3.1 – Dependence of weight mass (M_{max}) on water current speed (V_{max})

V_{max}, m/s	1,0	2,0	3,0	4,0	5,0
M_{max}, kg	15	25	50	75	100

Table 3.2 - Rope diameter depending on lead mass and current speed

Current speed, m/s	Lead mass, kg	Rope diameter, mm
<1	10-15	<1
1-2	25-50	1,5-1,8
2-3	50-75	2-3
>3	75-100	3-4

The following safety rules should be followed when working with cranes:

- avoid sudden braking of the cranes drum;
- when lifting the lead, the dog must be thrown over the ratchet wheel, which excludes the possibility of reverse movement of the cranes drum;
- it is necessary to monitor the laying or etching of the cable, not to allow it to leave the grooves and hit the cranes drum cheeks;
- when etching the cable on the drum, there should always be at least 5-6 turns of the cable.

The composition and order of work when carrying out sounding works can be formulated as follows: it is necessary to prepare devices and equipment, for each sounding vertical determine its planned coordinates, the depth of the reservoir at this sounding vertical, the water level during the measurement and the nature of the soil at the bottom of the reservoir (to assess possible errors measuring depths). Depth measurement is performed using one of the devices discussed above.

The height of the water level during sounding works is fixed at a water level gauge (permanent or temporary), which is located on this section of the river. The water level is determined at the beginning and at the end of each sounding stroke (transverse, tack), and in case of significant fluctuation, the water level is measured more often.

At the same time as the measurements, the nature of the soil of the river bottom is determined with the help of devices or visually.

The position of the sounding verticals in the plan during soundings is determined by measuring the distance from a initial point (benchmark, base, basis line) with a measuring tape, along a cable, and a serif with a protractor.

The coordinates of the sounding verticals can be determined:

- on a marked cable or floating chain (on reservoirs);
- with the help of serifs of points from the shore with protractor tools;
- serifs with a sextant of coastal landmarks from the ship;
- by radiogeodetic methods (GPS).

Measuring steps can be located:

- along the transverse profiles;
- on oblique tacks;
- along longitudinal profiles;
- by mixed means.

Depth measurements along transverse profiles are performed to determine the area of the water section as part of determining water discharges. The coordination of sounding verticals and the distribution of depths are quite detailed. Disadvantage of the method: laboriousness, impossibility of application on large fast rivers. For such soundings, a basis line is laid along the river bank and fixed with benchmarks (it is drawn parallel to the direction of the current and closer to the water cut). Cross-sections are cut perpendicular to the basis line for depth measurements, they are fixed on the main line and on the cuts with water sticks. The distance between the cross-sections is taken depending on the width and shape of the river (through 1/2 of the width of the river when its width is up to 100 m and through 1/3 when the river width is up to 1000 m; if the bottom is uneven and the depth changes sharply, the cross-sections are broken more often, and when sounding of demarcated sites the distance between the cross-sections is taken to be 2 times smaller).

The sounding verticals on each cross section are chosen evenly, their number depends on the purpose of sounding work and the nature of the topography of the river bottom (on rivers up to 50 m wide: 10-20 verticals; 100-300 m wide: 20-30 verticals; with a width of 1000 m: 40-50 verticals; the number of sounding verticals is increased by 2 times on hydrological section lines).

Depending on the local conditions (river width, current speed, etc.), soundings of transverse profiles can be carried out on a cable, from a gauging footbridges, gauging cars, from ice, with the help of remote installations GR-70 and GR-64, by serifs with a protractor from the shore or a ship.

The soundings from a boat along a marked cable are used on rivers with a width of up to 100-150 m and a current speed of no more than 1.5 m/s. To do this, a cable with a diameter of 3-5 mm, marked after 1 m, is stretched across the cross section. One end of the cable is fixed to the piles in the basis line with a zero division, and the other - to the piles on the opposite bank. To move the boat between the shores, the driving cable is pulled 5 m higher than the sounding one.

During the soundings, the boat moves from one bank to the other on the driving cable; the depth of the river is measured against the corresponding marks of the measuring cable and the nature of the bottom is recorded. The sounding data is recorded in a logbook and the height of the water level at the beginning and at the end of the soundings on each cross section is noted on the water level gauge. After measuring on one cross-section, the cables (measured and driving) are transferred to another.

On hydrological cross lines and line gauges the soundings are made twice, the difference between both soundings should not exceed 2%.

On small rivers with a width of up to 25 m, instead of a rope with marks on a sounding cross-section, a cable with a diameter of 8-12 mm can be stretched, and when wade sounding - a measuring tape can be used.

Sounding from the from gauging footbridges are carried out on small rivers, where suspension or beam bridges are equipped. In such cases, the distance is counted from the initial point (benchmark) according to the marks on the platform of the bridge.

Sounding from ice allow precise coordination of sounding verticales, recommended on rivers with complex topography of the bottom and significant current speed. The distance to the sounding verticals from the basis line (benchmark) is determined with a measuring tape, and the depth at each sounding vertical on the cross section is measured from the water surface level in the hole.

Soundings along the cross-sections with serif points with a protractor are used on rivers with a width of 150-250 m, when it is impossible to use a rope to determine the position of the sounding verticals. For this, use a compass with cypregel or a theodolite for serifs from the shore or a sextant for serifs from a ship.

Cross profiles are fixed with clearing marks (poles painted in white and black). On rivers with a width of up to 500 m, clearing marks are installed on one bank, and on rivers with a greater width - two clearing marks on each bank. The distance between adjacent clearing marks depends on the width of the river, namely (Table 3.3):

Table 3.3 - Distance between cleared marks

The width of the river, m	< 100	100-200	200-500	500-1000
Distance between cleared marks, m	5	5-10	10-20	20-50

When soundings with serifs, first, on one of the banks, a basis line is layout along the river, then the sounding cross lines are layouted and fixed with cleared marks. The basis line and cross-lines are drawn to scale on the plan of the river section. At one of the ends of the basis line, a place is chosen for the installation of protractor with such a calculation that the angle between the cross section and the sighting beam is not less than 30° (Fig. 3.3, a). Soundings can also be performed with the help of two protractors, which are installed at both ends of the basis line (Fig. 3.3, b).

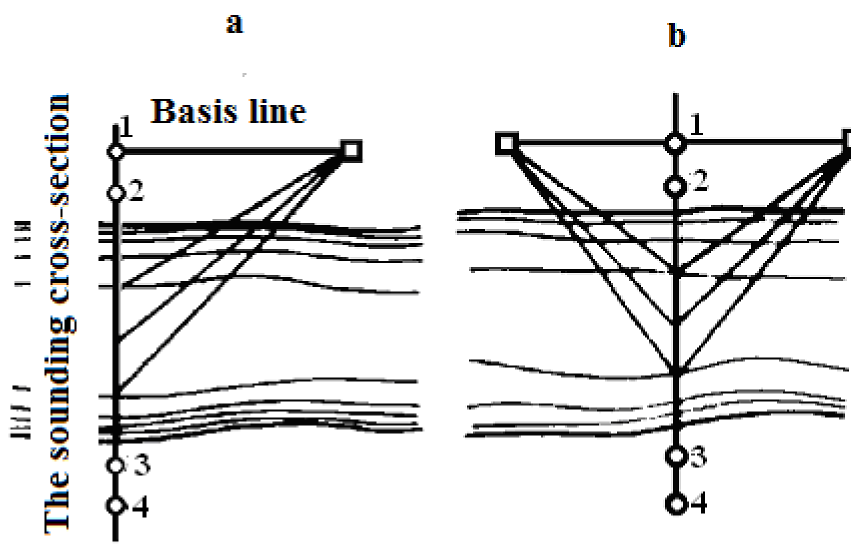


Figure3.3 – Scheme of section lines angular serifs of sounding verticals from the shore: a - with one tool; b - with two tools

When sounding with serifs, the boat moves from one shore to the other exactly across the width along the line of the cleared marks. Serifs of sounding verticals can be done either by a signal from the boat or by a signal from the shore. In the first case, the boat is watched from the bracket through the cypregel pipe, and at the moment of sounding, a signal from the boat is used to make a serif. Soundings from the boat are performed at certain time intervals or after a certain number of oar strokes. According to the second method, the position of sounding verticals on the tablet is marked in advance and the depth is measured by a signal from the shore when the boat is at the intended measuring point. This method makes it possible to more evenly distribute sounding verticals on the cross section.

On soundings on a wide river with hard-to-reach banks, serifs can be made **using a sextant from a boat** (Fig. 3.4). The boat moves along the section line, the observer at the sounding verticals determines the angle between the cross section line and the line of visions to the coastal landmark with a sextant.

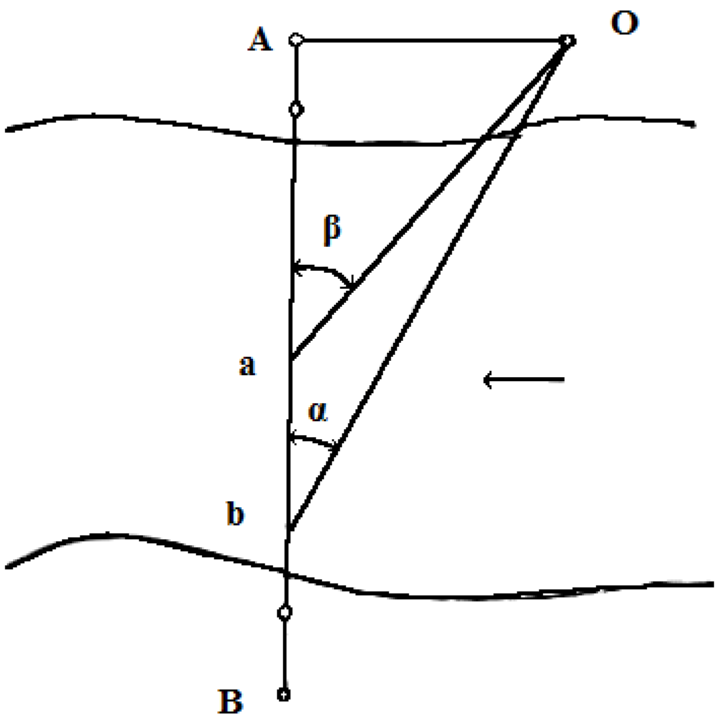


Figure3.4– Scheme of serifs of sounding verticals with a sextant along coastal landmarks (A, O)

The soundings along oblique tacks are used at significant water flow speeds, which makes it difficult to sounding along transverse profiles. When sounding along oblique tacks, the boat crosses the river in the fan direction (Fig. 3.5, a) at an angle of no more than 30°. The tacks are drawn through 1/4-1/2 of the width of the river. The position of the sounding verticals on the tacks is detected from the basis line with the help of two protractors. With a significant width and high current speed, a system of cross tacks is recommended.

The soundings along longitudinal profiles are organized when it is necessary to survey a significant area of the river with less accuracy, sometimes with simultaneous measurement of the direction and speed of the current. Longitudinal profiles are drawn evenly along the width of the river, approximately 1/10 - 1/25 of its width with an increase near the banks. During these soundings, the boat freely descends downstream. The position of the sounding verticals is fixed with serifs on two protractors from the shore (Fig. 3.5, b).

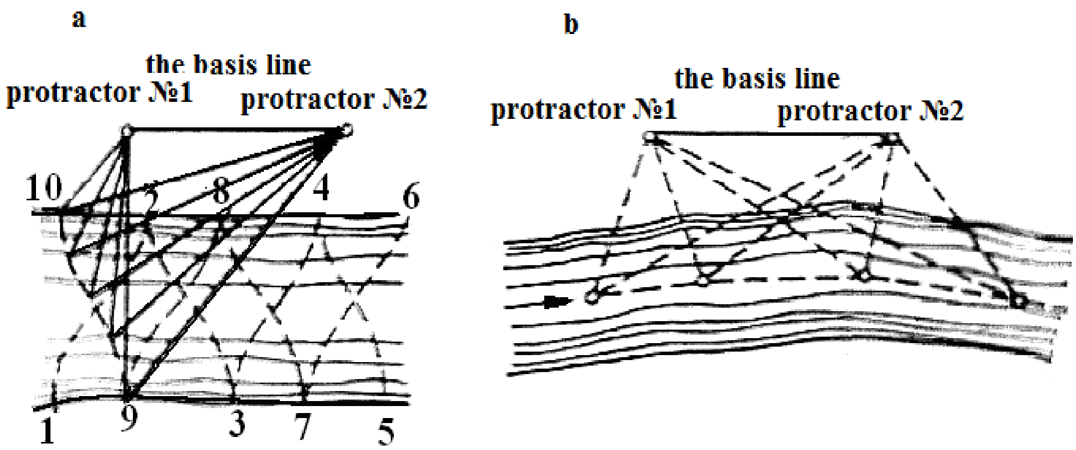


Figure3.5– Scheme of soundings: a - along oblique tacks; b - along the longitudinal lines

The most complete coverage of the topography of the bottom with a complex structure of the channel is achieved **by a mixed method**, which combines soundings along oblique tacks and along longitudinal lines.

In winter conditions, with stable ice, sounding is characterized by high accuracy. The main disadvantage of winter soundings is their high labor cost. Winter soundings on rivers are usually carried out by transverse profiles, and on lakes - also by method of squares.

3.3 Method of continuous depths survey

This method involves the use of sonic echo sounders that work on the basis of the acoustic method of determining depths. These devices provide automated soundings with high accuracy, speed, and are quite easy to use. The topography of the bottom is recorded on a paper tape or in memory. The determination of the depth by the sonic echo sounder is based on the relationship of the time of passage of ultrasonic pulses from the vibrator-emitter through the water medium to the bottom and back to the vibrator-receiver. In fig. 3.6 shows the scheme for measuring depths by the acoustic method, from which the formula for determining the depth is derived from geometric relationships:

$$h = \sqrt{(\frac{C \vartriangle t}{2})^2 - (\frac{l}{2})^2} + d\,, \qquad (3.1)$$

where C - the speed of sound propagation in water, m/sec;

t - the time of passage of the pulse from the emitter vibrator to the bottom and back to the receiver vibrator;

l – distance between vibrators, m;

d - immersion depth of vibrators, m.

The dependence of depth on time is realized with the help of mechanical or electrical reversing devices. The speed of ultrasound propagation in water depends on its temperature and salinity and varies between 1420-1500 m/sec (at a temperature of +14 °C in fresh water, the speed of ultrasound is 1462 m/sec). Therefore, to ensure the necessary depth measurement accuracy, before starting the measurements, the sonic echo sounder is calibrated according to the temperature and salinity of the water at the place of work.

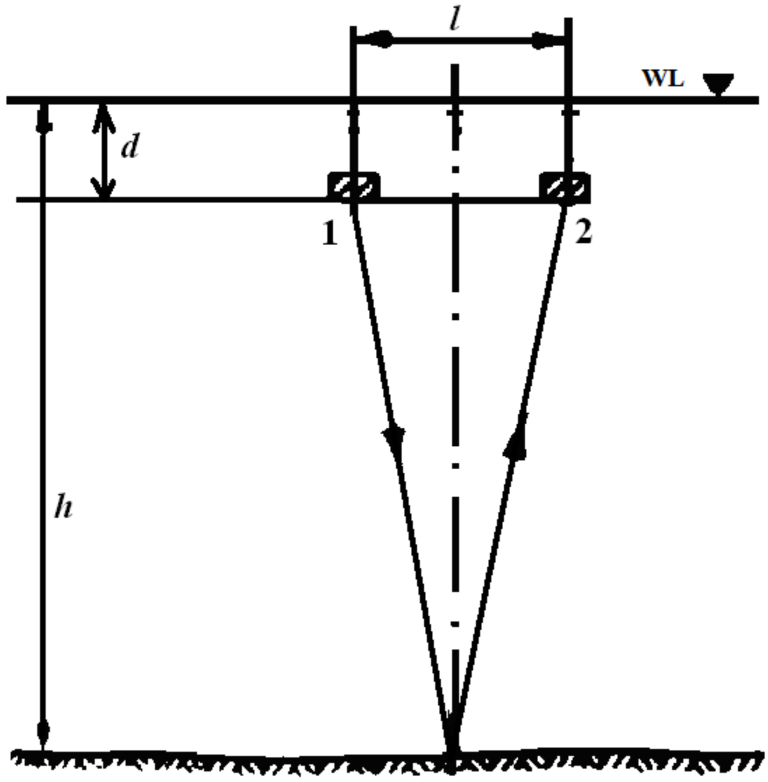


Figure3.6– Scheme of soundings by acoustic method: 1 – emitter (vibrator); 2 - receiver (vibrator): WL – water level

For small rivers, small sonic echo sounders, which consist of compact central and outboard devices, are widely used (Fig. 3.7). The **TOR-5** sonic echo sounder uses the pulse method to measure depths. Impulses directed into the water are reflected from the bottom, the depth in meters is recorded on the scale. If the instructions are followed, this sonic echo sounder measures the depth within 0.2-5 m with an accuracy of 0.1 m. The measurement accuracy is about 2%, the speed of measurements is up to 15-17 km/h. Disadvantages of this device: instability of the horizontal scale of profile recording, insufficient reliability of depth measurement in case of significant turbidity and the presence of aquatic vegetation.

For sounding work on medium and large rivers, the **EPO-10m** sonic echo sounder is convenient: on large rivers, lakes and reservoirs with depths up to

20 m - **IREL, EIR, "Kuban"**, and at greater depths - **PEL-3, "Yaz"**. The main characteristics of sonic echo sounders, which are used for hydrometric work, are given in the table 3.4.

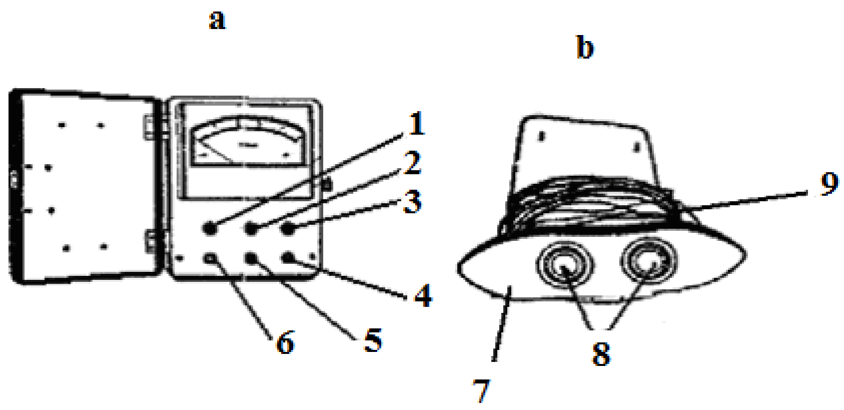


Figure3.7 – Small sonic echo sounder: a) central device (1 – “zero setting” knob; 2 – “calibration” button; 3 – “depth setting” knob; 4 – cable connector “receiver”; 5 – cable connector “ power"; 6 - cable connector "transmitter"); b) outboard device (7 - fairing; 8 - radiator; 9 - connection cable)

Table 3.4 – Main characteristics of sonic echo sounders

Type of sonic echo sounder	Indicator of depths	Range of measuring depths, m	The weight of device, kg	Accumulator voltage, volts	Power supply, vatts
PEL-3	Self recorder	0,4-200	90	24	80
IREL	Self recorder	0,2-20	34	12	80
EIR	Self recorder	0,5-20	55	27	120
EPO-10m	Arrow depth indicator	0,3-10	8,8	12	3
Kuban	Self recorder	0,2-20	63,8	24	75
NEL-4m	Self recorder	0,2-36	110	127/220	110
Yas	Self recorder	0,2-160	4,7	12	5
Fishfinder	Electronic scoreboard	0,1-360	5	12	12

The main parts of sonic echo sounders: central device, power supply unit, vibrator, auxiliary devices. The central device automatically records depths and controls ultrasonic pulses. The profile of the bottom is recorded by self-recorder on a paper tape using the burning method or on an electronic scoreboard and in the device's memory. Arrow depth indicators can also be used.

The **IREL-1M** hand sonic echo sounder is used to measure depths from 0.2 to 20 m with an accuracy of 5-10 cm, the bottom profile is recorded on ETP-2 paper using the electrothermal method at a scale of 1:100. Measurement error is 2%, battery powered.

The **EPO-10** sonic echo sounder is compact, measures depths up to 10 m, weighs 15 kg, is powered by 12 V. It is used on ships or boats, the measurement error is 1%, the operating temperature is from -10 to + 40 °C.

The **PEL-3** sonic echo sounder is a portable device that is used for measurements in reservoirs up to 40 m depth. The bottom profile is fixed on thermal paper using the electrothermal method. Mains or 24 V battery power supply, 2 scales - 1:200, 1:1000, measurement error ± 0.25 m (for stormy conditions, depth range 10-40 m).

Preparatory work when using sonic echo sounders includes: installation of the central device and vibrators in the working position, preparation and connection of power supply, self-recording check, field calibration. All operations are performed according to the instructions for the sonic echo sounder. In the process of surveying, the sonic echo sounder is serviced by one operator, who turns on the device, makes operational notes on the echogram when making a mark, and turns off the device when the tack is finished. The working water level is fixed on the echogram.

The coordination of sonic echo sounder measurements, depending on the working conditions, can be performed by geodetic and radiogeodetic methods.

On narrow rivers and lakes, soundings are taken along a marked cable, when the vessel passes along the cable, the operator makes operational marks on the echogram at the moments of alignment of the vibrator with the marks on the cable. At the same time, the coastal shoals remain untouched (it is impossible to approach with the device), the width of such sandy areas is determined with a tape measure and fixed on the echogram. On wider rivers and lakes, soundings are coordinated with serifs of 1, 2, 3 theodolites from the shore or serifs with a sextant of coastal landmarks from a measuring vessel. The moment of serif is marked on the echogram with an operational mark. GPS technology is also used for coordination.

Radiogeodetic methods are used on large water bodies, these methods ensure coordination of measurements in the absence of direct visibility of the shores. Radiogeodetic equipment can be used in two versions: radiolog and phase probe. In the first version, the increase in the distance from the coastal radio stations to the measuring vessel is recorded, and in the second - the increase in the water levels and specified distances.

With the help of sonic echo sounders, it is possible to study the bottom soils, taking advantage of the fact that soils of different mechanical composition transmit ultrasound differently.

The decoding of the soundings echogram is considered in laboratory work №. 2.

3.4 Hydrographical survey

Hydrographical (channel) surveys are carried out to obtain a plan of the river section or to determine the water discharges of spring and rainy floods in temporary watercourses. The need for this type of work is determined by studies of channel processes, design of engineering structures in channel and coastal zones, needs of river navigation, etc.

Hydrographical surveying is a complex of geodetic and sounding works.

Geodetic works include the layout of the plan and elevation base and topographical surveying of the site. The planned base is usually built on one or both banks of the river, depending on the size of the river, and is placed in a place where there is no flooding. For the convenience of work, the direction of the basis line is set parallel to the direction of the river. Cross-sections are assigned perpendicularly to the basis line at equal distances. The distance between them, depending on the width of the river, is regulated by the "Instructions for Hydrometeorological stations and gauges". The plan basis is performed with a theodolite or bracket in compliance with the requirements accepted in geodesy. Points of height justification are combined with the plan base and fixed with benchmarks in accordance with the requirements of the current instructions. Elevation and plan justification are tied to the State geodetic grid. The cross-sections are leveled with the IV-th class in two steps from the cut of the water in the river to the marks of the highest water level marks by 0.5-1.0 m above.

Sounding works on rivers are usually carried out along cross-sections, oblique tacks and longitudinal profiles. These tools are described earlier.

3.5 Processing of the materials of the measured depths

When performing field sounding works, measurement data is recorded in the sounding book KG-2. For each transverse profile, tack, longitudinal profile, a separate page is set aside in the journal, at the beginning of which the following information is recorded:

- location of the profile relative to the basis line;
- the method of determining the coordinates of sounding verticals;
- device used to measure depths;
- the start and end time of the sounding;
- the height of the water level at the gauge and on the profile before and after measurements;
- the state of the weather and the river during the sounding.

Sounding materials are usually used to construction:

- transverse channel profiles;
- plan of the water body in contur lines or isobaths;
- longitudinal profile of the river section.

- calculation of the complex of morphometric characteristics.

The method of constructing a **cross-sectional profile and calculating morphometric characteristics** is considered in detail in laboratory work № 2. An example of building a profile is shown in fig. 3.8.

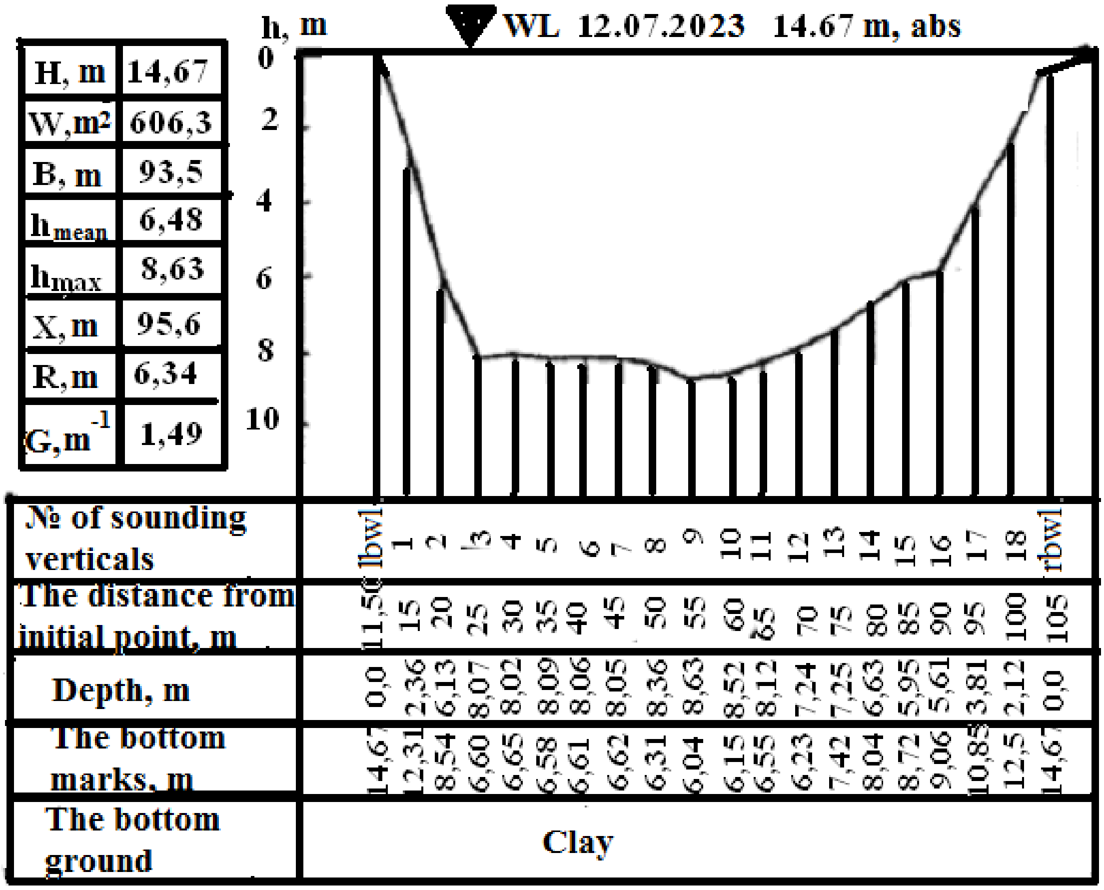


Figure3.8 – The profile of rivers cross-section (WL – water level; lbwl – left bank water line, rbwl – right bank water line)

The construction of the river plan in contur lines (isobaths) is considered in laboratory work № 2 (an example is shown in fig. 3.9).

The longitudinal profile is built based on the data of depth measurements brought to a conventional water level and leveling. The profile shows the marks of the river bottom, the conditional level and the level of high water, as well as the marks of the water lines of the right and left banks of the river, respectively, where the cross-sections are placed. A table is placed under the profile, which is called the profile grid, in which the numerical values of the characteristics are given - the basis for building the profile. Scales (vertical, horizontal) for the profile are chosen based on visibility and in formativeness.

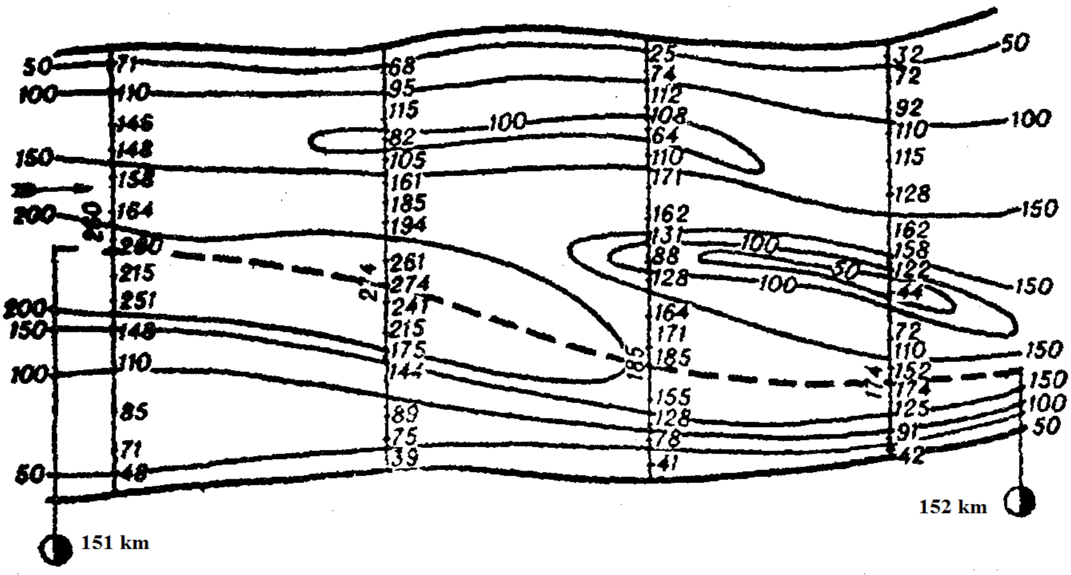


Figure3.9 – Plan of the channel section in isobaths

The processing of the results of soundings of reservoirs consists in data analysis, construction of a plan in contour lines (isobaths), calculations of morphometric characteristics. First, the depths are brought to a conventional level, the bottom marks are calculated at the sounding verticals and plotted on the plan. The sounding verticals, determined by the sextant are applied to the plan with a protractor, an instrument consisting of a circle with a limb, one stationary and two movable rulers equipped with micrometric screws and a vernier for measuring angles with an error of up to 1'.

Sounding verticals, which are fixed from the shore with a theodolite, are found by solving triangles, and the sound verticals that were marked with cypregel are transferred from the working tablets to the contour plan of the reservoir. The intersection of contour lines or isobaths is selected so that the main features of the bottom relief are reflected when constructing the plan.

The layout of sounding cross sections and the plan of the reservoir in isobaths are shown in fig. 3.10.

The main morphometric characteristics of the reservoir: length, average width, ruggedness of the shoreline, area of the water mirror, water volume.

The length of the reservoir is the shortest distance between two distant points of the coastline.

The average width of the reservoir B_{mean} is the ratio of area to length:

$$B_{mean} = \frac{F}{L}, \qquad (3.2)$$

where F – area of reservoir, km^2;

L – its length, km.

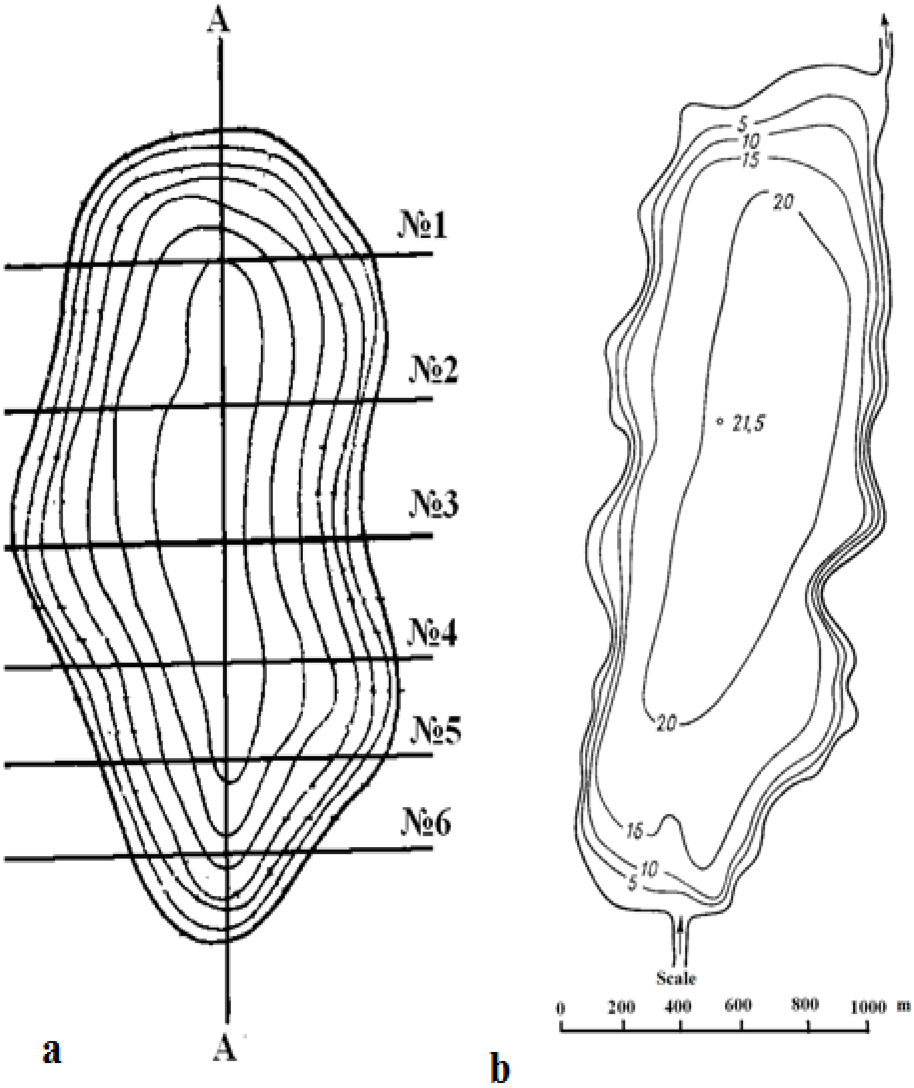


Figure3.10 – Processing of soundings of the reservoir: a) scheme of placement of sounding cross lines on the water area; b) reservoir plan in isobaths

The ruggedness of the shorelinek is the ratio of the length of the shoreline S to the length of a circle that has an area equal to the area of the reservoir:

$$k = \frac{S}{2\pi\sqrt{\frac{F}{\pi}}}. \tag{3.3}$$

The area of the water mirror of the reservoir *F* is determined by a planimeter or palette (the area of the islands is not included in the area of the water mirror).

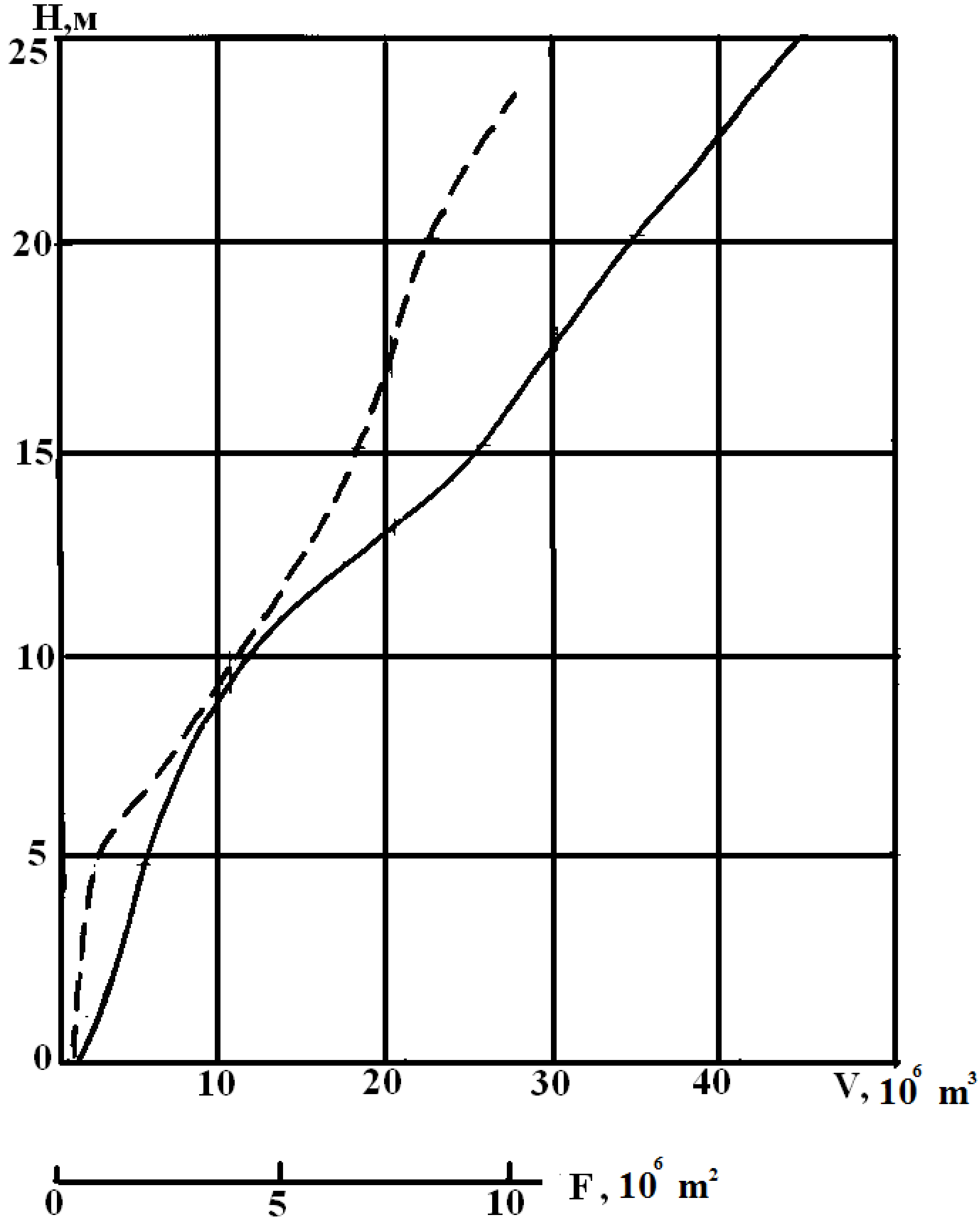


Figure3.11– Dependencies: 1) *F=f(H)*, 2) *V=f(H)*

The volume of water in the reservoir *V* is calculated by adding partial volumes between isobaths (contour lines) equal to $v_1, v_2, ..., v_n$.

Partial volumes are determined from the formula:

$$V_i = \frac{F_1 + F_2}{2} h_z, \tag{3.4}$$

where F_i - the area bounded by the i-th isobath;

h_z - distance between isobaths in height.

The average depth of the reservoir h_{mean} is determined as a fraction of the volume of water divided by the area of its mirror

$$h_{mean} = \frac{V}{F}. \tag{3.5}$$

To solve hydrological and water management problems, it is convenient to have curves of dependence between the water level in the reservoir and its areas and volumes (Fig. 3.11), i.e. *F=f(H)* and *V=f(H)*. They are built by area and volume at different level marks.

3.6 Questions for self-control

1. What does the complex of sounding works include?
2. Basic methods and devices for measuring depths.
3. The main types of sinic echo sounders for measuring depths.
4. Ways of fixing sounding verticals on the section lines.
5. Conducting and processing the results of channel surveys.
6. The main morphometric characteristics of the cross section.

4 CURRENT VELOCITY MEASUREMENTS

4.1 Peculiarities of the current velocity field in channel stream

Measurements of current velocity are carried out to determine water discharge, during the construction of hydrotechnical structures, bridges, when using watercourses for shipping, logging, when studies of the current velocity field, channel deformations, etc. are carried out.

The methodological issues of this type of measurement are related to the peculiarity of the water flow, which is determined by its kinematic structure.

Nonuniform movement of water is observed in rivers. Depending on the contours of the channel, depths, nature of the banks, the presence of aquatic vegetation and ice, the distribution of velocities in the river can be very diverse. If there are protrusions in the river bed or significant expansion of the width of the bed, deformations or even reverse currents may occur. The complexity of the nature of the water movement in rivers also lies in the fact that at each point the speed is constantly changing in value and direction. This phenomenon is called **velocity pulsation**, it is characteristic of watercourses with a turbulent flow regime. If you observe the velocity on the vertical, you can establish that the pulsation of the velocity increases from the surface to the bottom. Along the width of the river, the velocity pulsation increases from its middle to the banks. At each point in the flow, there is an instantaneous velocity and a local velocity due to pulsations.

Instantaneous velocity is the velocity at a given point in the flow at a given instant of time.

If we take the instantaneous velocities for a certain period of time and calculate the average from them, we will get **the local flow velocity** at this point.

The period of time corresponding to this condition is called **the period of determining the average local speed**. From the point of view of accuracy, the duration of speed measurement at a separate point should not be less than the period of determining the average value of speed (100 seconds). With high turbulence, the measurement duration of 100 seconds may not be enough, in which case it is increased, this is taken into account when using hydrometric current meters. In the future, we will consider local velocities and their distribution in the flow. Rivers of different types and channels have morphological and hydraulic features that determine the diversity of the nature of the flow speed in channel streams. But at the same time, there are also some regularities regarding the distribution of speed over the depth and width of the stream.

If we take any vertical line in the river and place the values of the velocities measured at different points along the depth from the surface to the bottom, and then connect the ends of the velocity vectors, we will get a graph (profile) of the distribution of velocities along the depth, which is called a **velocity curve**. Velocity curve can be built for any flow velocity vectors – at the surface, at the certain depths (Fig. 4.1).

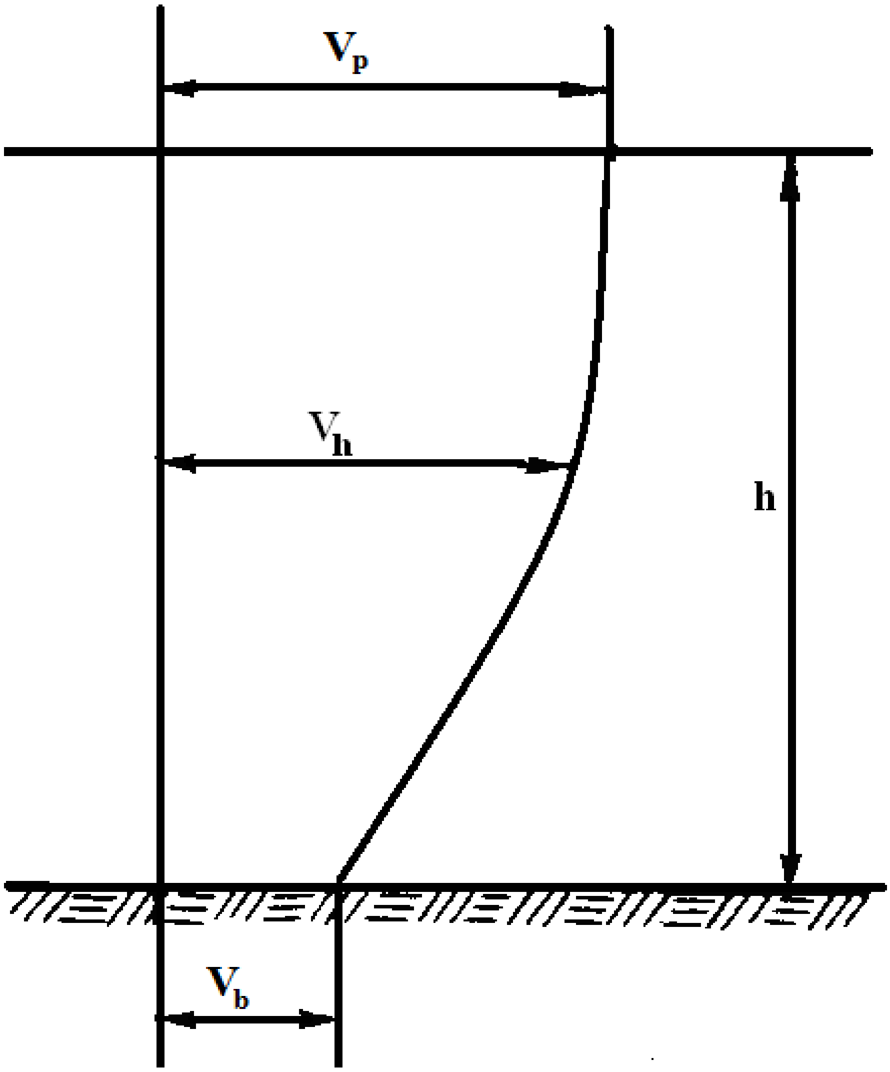


Figure4.1|– Flow velocity curve on vertical (Vs – current velocity at water plane; V_b – current velocity at water bottom layer; V_h – current velocity at some depth on vertical)

As the figure shows, in an open stream with uniform water movement, the highest speed is usually observed at the water plane or slightly below. The speed near the bottom (in bottom layer) is the lowest, it characterizes the speed of the current at a short distance from the bottom. In the presence of irregularities, in front of obstacles, the speed near the bottom decreases sharply (Fig. 4.2), in some places the opposite direction is observed.

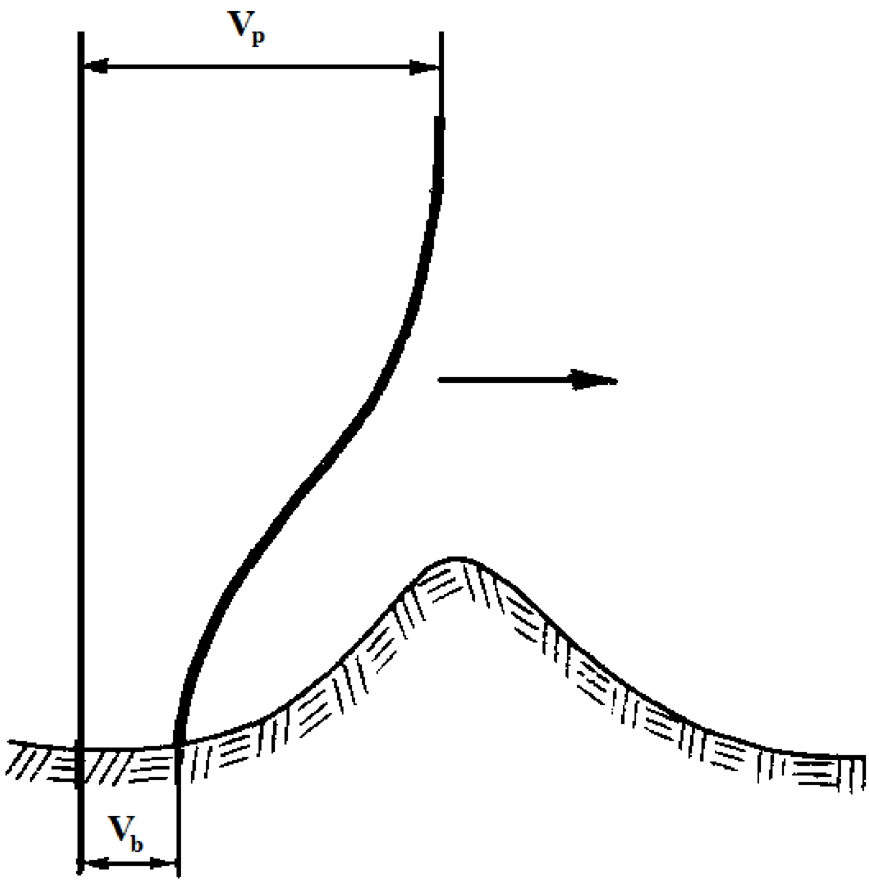


Figure4.2– Flow velocity curve on the vertical near the barrier

The roughness of the bottom determines the formation of a complex kinematic and turbulent flow structure in the natural area - the so-called bottom layer. Its thickness is related to the height of the protrusions and unevenness of the bottom. During hydrometric measurements, the velocity is determined slightly above the bottom layer and the line of the velocity profile is graphically extrapolated to the bottom.

In hydrometric practice, an important characteristic is the average velocity on the vertical V_{mean}, which can be determined by dividing the area of the flow velocity curve F_{fvc} by the depth h_{vv}, as well as using formulas. In addition, in many cases it is necessary to know the distribution of average local velocities on the vertical. The distribution of average local velocities in the flow is affected by many factors, which prevents its strict description. Parabola, ellipse, logarithmic curve, and other equations have been proposed for the mathematical representation of the velocity profile, but the formula based on the hypothesis of momentum transfer and the theory of vortices transfer is considered to be the most theoretically justified. Practical tasks are solved with the help of simpler empirical formulas, which sufficiently fully describe the distribution of longitudinal velocities on the vertical of the open stream.

The wind regime also affects the change in vertical speed, only in the upper layer of water. Depending on the strength and direction, the wind can increase or decrease the surface speed. At the same time, the value of the water level will change, but in the opposite direction.

At river estuaries in the area of the coastal plains, under the influence of tidal phenomena, a wedge of sea water in the natural layer can move up the river, which leads to a complex configuration of the flow velocity curve on the vertical.

In the presence of an ice cover, the influence of the roughness of the lower surface of the ice causes a shift of the highest velocity to a certain depth from the surface, usually by 0.3-0.4 vertical depth. And if there is a slough under the ice, then such displacement can reach 0.6-0.7 depth from the surface (Fig. 4.3 a,b). The distribution of velocities varies vertically and along the length of the river. So, on the flat, where the depths are the greatest, the speed is much lower than on the roll with minimal depths.

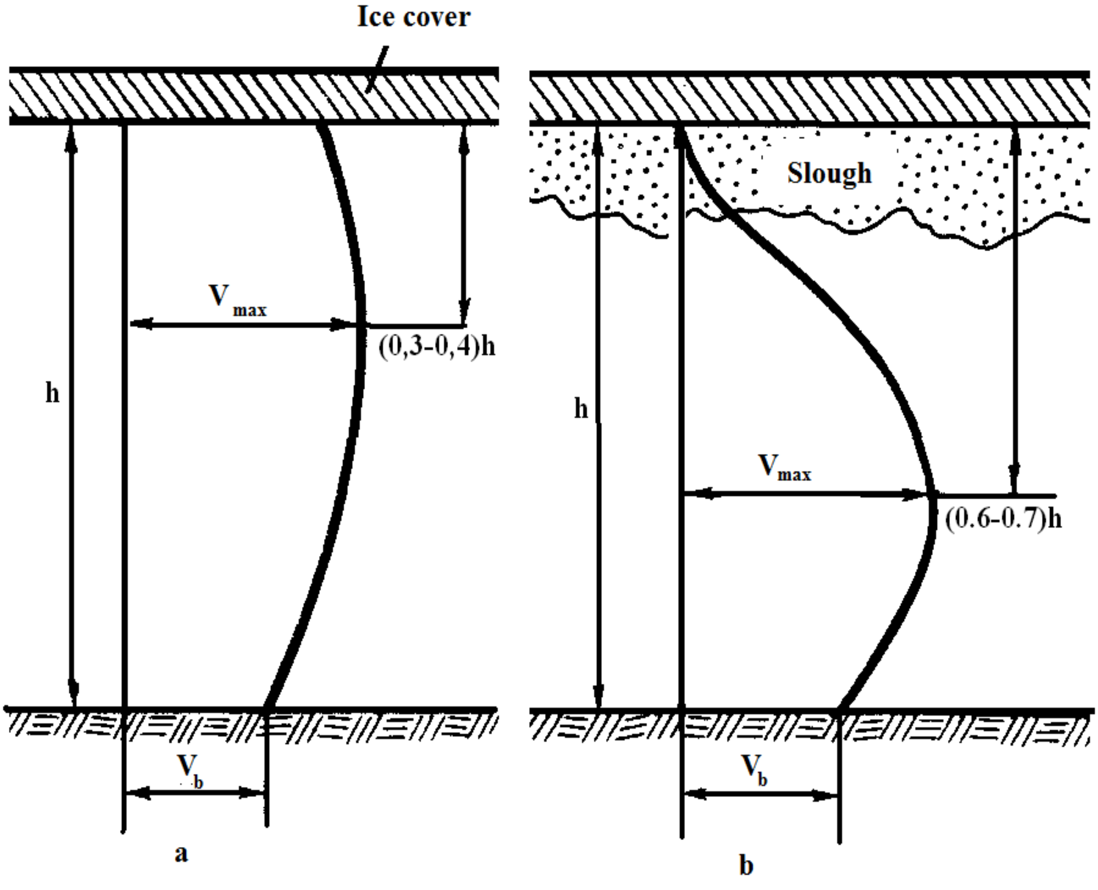
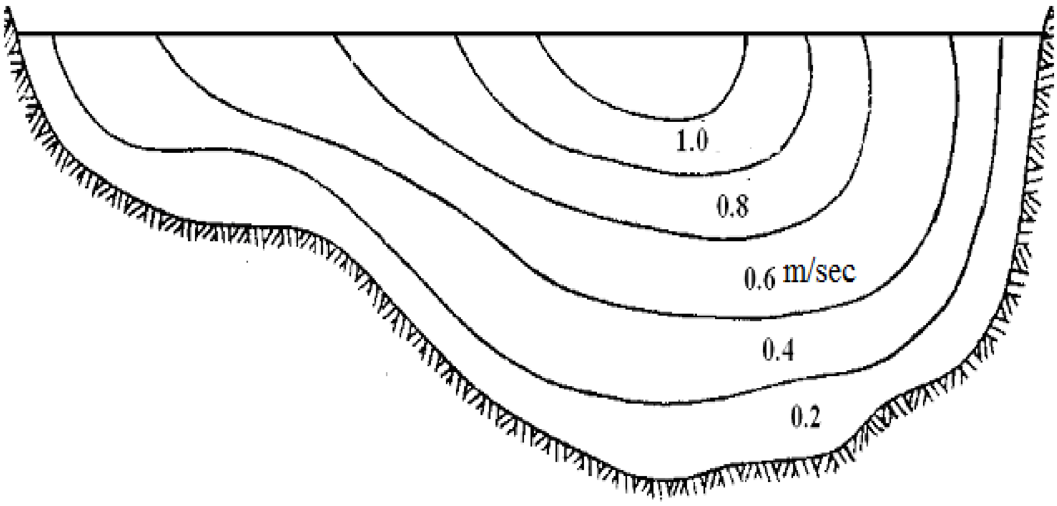


Figure4.3 –Flow velocity curve on the vertical: a - with ice cover; b - in the presence of slough

The distribution of velocities along the live section of the flow is described by **isotachs** (lines of equal velocities drawn on the profile of the live section). Isotachs are built based on the data of velocity measurements at individual points on the velocity verticals in the cross section. For open streams with uniform water movement, isotachs have a smooth appearance and do not close within the live section (Fig. 4.4, a). With an ice cover, some of the isotachs form closed curves (Fig. 4.4, b). The influence of the roughness of the bottom, shores, and ice (slough) on the distribution of isotachs is marked by their thickening.



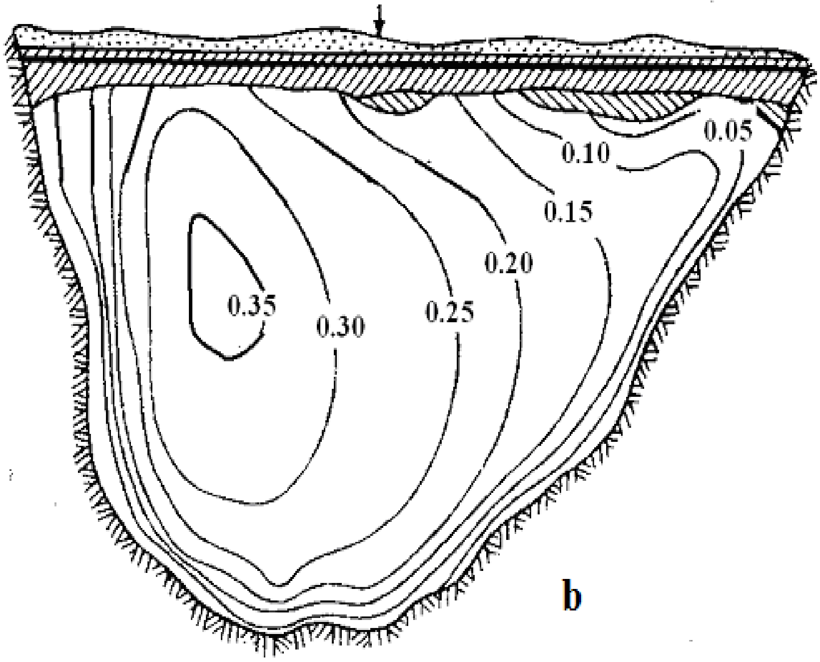


Figure4.4– Isotachs: a – in an open channel; b - with ice cover

4.2 Current velocity measurement methods

Current velocity is measured by various methods.

1) The method of recording the number of revolutions of a vane wheel.

This method is based on the principle of operation of hydrometric current meters, which have a vane wheel (rotor); during measurements, the number of revolutions of the vane wheel and the corresponding measurement duration are recorded. The number of revolutions is recorded by a converter that transform the rotational movement into electrical signals that are sent to the registration device. The velocity value is determined according to the graduation graph or table. The velocity is measured at individual points or integrated on verticals.

2) Method of registering a floating body.

The velocity is measured by surface or depth floats and is taken as equal to the speed of the float. The obtained speed is the average along the trajectory of the float.

3) Method of registration of high-velocity pressure.

Velocity is measured by hydrometric tubes (for example, Pitot tube) depending on the velocity pressure. To do this, the tube is inserted into the water flow with an opening facing the flow and the pressure is measured directly by the height of the level rise in the tube. Hydrometric tubes give values of the local velocity at individual points in the stream.

4) Ultrasonic method.

The water flow velocity is determined by the difference in the propagation time of the ultrasonic wave downstream and against it, it is used for hydraulic determination of pipelines, water discharges at hydroelectric power plants.

5) The method of registering the force action of the flow.

For velocity measurements, devices are used that have a sensitive element that perceives the force of the water flow. Such devices are used for scientific research with the aim of measuring and continuously recording the velocity values at individual points of the flow, for example, to study of velocity pulsations.

6) Heat exchange method.

For water flow velocity measurements, devices are used that use a heated element, which is intending reduced into the flow, as a working body. The velocity of the flow is determined depending on the cooling of the sensitive element: the higher the velocity, the higher the cooling rate. Such devices are used, as a rule, in laboratory conditions.

7) Non-contact methods.

The feature and advantage of these methods is the possibility of measurements without the intending reduction of measuring devices into the water flow, which disturb the velocity field. These methods include: measuring water velocity using an induction flow meter, using a laser, etc.

The method of indicator labels in the stream is also used.

4.3 Hydrometric current meters: types, constructions, properties

Hydrometric current meters are the best measuring devices for determining the current velocity in open streams, the principle of their operation is based on measuring the current velocity depending on the number of revolutions of the vane wheel (rotor); there are about 200 models of current meters in total.

Hydrometric current meters are classified: according to the direction of the axis of rotation of the rotor (horizontal, vertical); according to the structure of the vane wheel (rotor); on the structure of the contact and accounting mechanism; means of immersion in water, etc.

In most countries of the world, current meters with a horizontal axis of rotation of the rotor are used, because they allow you to directly determine the longitudinal component of the flow velocity. The second type (with a vertical axis) includes current meters of the Price type (USA).

According to the design of the rotor, current meters are divided into two main groups:

- with a vane wheel formed by a helical surface;
- with a rotor in the form of cone-shaped cups.

Some types of sea current meters have a rotor in the form of propeller runners. Most modern current meters have vane wheels formed by a parabolic-type screw surface. Only Price current meters have a cup rotor.

According to the structure of the counting-contact mechanism, there are current meters with a mechanical (GR-21), electric (IST), self-writing (BPV-2r) method of registration of revolutions.

According to the means of immersion in water, there are wading rod and cable current meters, but most are universal.

The main parts of current meters are:

- running part with rotor and counter-contact mechanism;
- body;
- direction stabilizer (tail fin);
- signaling device;
- auxiliary devices and spare parts

The running part of the current meter is represented by a vane wheel (rotor). The vane are of different sizes (diameter from 4 to 20 cm), provide velocity measurement. Closing of the contacts occurs after a certain number of revolutions, which is indicated by a light or sound signal or a pulse, which is recorded in the counter-pulse mechanism. In most hydrometric current meters, the vanes are mounted on an axis on which or with which they rotate together. To reduce friction, the axle rests on ball bearings and rockers made of agate, etc.

The counter-contact mechanism is designed to count the number of rotations of the vanes of the current meter. In some current meters, the number of revolutions of the vanes is fixed by a mechanical counter directly on the scales of the gear wheels. Most current meters are equipped with an electric counter and the number of revolutions of the vanes is fixed by connecting an electric circuit to a bell, light bulb or buzzer. In current meters with mechanical counters (sea current meter VM-M), the number of revolutions is determined by reading on the scale of the counter. The readings of current meters with electrical signaling can be recorded on a paper tape using a chronograph, or on an oscilloscope tape.

The body of the current meter has a streamlined shape and unites its separate parts, ensures the attachment of the current meter to the wading rod or cable. The body contains the axis of the current meter and the counter-contact mechanism. To keep the current meter in the direction of the flow, a direction stabilizer (tail fin) is used, which is fixed in the rear part of the body. The signal device serves to transmit signals when the current meter contacts are closed. A sound alarm is used through a bell, to which the wires from the terminals on the current meter body are connected. A stabilizer (tail, rudder) is required to install a hydrometric current meter against the current. To work with a hydrometric current meter, you need to have: a wading rod, a current direction indicator, a cable, a swivel, karabiners, a weight, a cable, an electric bell (buzzer, light bulb), batteries, a stopwatch (chronograph).

The hydrometric wading rod is intended for installing the hydrometric current meter to the required depth on the vertical. The wading rod with current meter is operated at a river depth of up to 3 m and a current velocity of up to 1.5 m/s. Wading rods are made of steel pipes with a diameter of 2-3 cm and a length of 3-4 m (two parts of 1.5-2 m each). The wading rod are marked with divisions after 5-10 m and numbers after 10 cm. During operation, the wading rod can stand on the bottom of the river (persistent) or be in a suspended state (suspended). The suspended wading rod together with the current meter is fixed on the boat with the help of a wading rod holder in a suspended state. To set the current meter to the required depth, the wading rod is moved up or down together with it.

At depths of more than 3 m, as well as when working from a gauging footbridges, gauging cars, the current meters are lowered into the water on a cable manually or with the help of cranes. Steel cables with a diameter of 1-4 mm or special cables with conductive wires woven into them are used. In this case, the cable simultaneously performs the function of a cable for transmitting signals from the running part to the signaling device.

Flow direction indicator (visor) - used to install the current meter parallel to the flow, it is a metal bar with a pointed end and a round hole for passing through the upper end of the wading rod.

The swivel is used to attach the cable and weight to the current meter. The swivel consists of a vertical pivot with round holes at the ends and a sleeve that rotates freely around the pivot. A hydrometric current meter is attached to the sleeve, and a cable and weight are attached to the pivot using carabiners. The cable diameter and weight are selected depending on the current velocity (Table 4.1).

Table 4.1 – Requirements for the weight and diameter of the cranes cable at different flow velocities

The flow velocity, m/s	<1	1-2	2-3	>3
Weight, kg	10-15	25-30	0-75	75-100
Diameter of the cranes cable, mm	1,0	1,5-1,8	2-3	3-4

The weight reduces the deviation from the vertical of the cable on which the current meter is lowered. The weight are of different shapes (most often fish-shaped). To avoid backwater, the weight is attached 20-30 cm below the current meter.

A cable, an electric bell (buzzer, light bulb), batteries are needed to register the number of revolutions of the vanes of the hydrometric current meter, and a **stopwatch** is needed to record the time of the current meter works.

The relationship between the rotor revolutions and the current velocity is not uniform - at low velocity it is curvilinear, because hydraulic and mechanical resistance forces act on the rotor (the initial rotation of the rotor is uneven).

As the current velocity increases, the effect of the resistance decreases and the dependence becomes linear (the rotation of the rotor becomes uniform), with a further increase in the current velocity, the rotor experiences the effect of cavitation and friction, which again violates the linearity of the connection.

According to N.P. Burtsev, the upper critical speed for various current meters is quite high - from 5 m/s (GR-55) to 8 m/s (GR-21M).

Let's consider the most important properties of current meters, which are of practical importance.

The inertia of the hydrometric current meter is the ability of the vane to "react to the flow" (to change revolutions according to the change in the current velocity). Current meters with relatively small moments of inertia of the vane wheel (GR-55, GR-99) are recommended for use in streams with a high intensity of turbulence. On flat rivers with little turbulence, current meters are used, in which vane wheels have relatively large moments of inertia (GR-21M).

The component of the current meter is the ability to register the longitudinal component of the current velocity in a cross-stream flow. Current meters GR-21M, GR-55, GR-99 have a component content of 5% at an oblique current of 40°, therefore, in terms of component properties, these current meters are the most suitable for field measurements.

Grading (taring) of hydrometric current meters is the determination of the relationship between the water flow velocity and the number of revolutions of the vane wheel per second, which is performed experimentally and presented in the form of a graph, table or equation. In Ukraine, this is done by the "KB of Laser Technology" (Kyiv) - an automatic calibration and verification unit simultaneously tests 2 current meters for 10 minutes with an error of 2-10% in a wind tunnel. The certificate (Fig. 4.5) is an official document of the current meter. For practical purposes, a working table of the transition from the speed of rotation of the rotor (n, r/s) to the speed of the flow (V, m/s) is also compiled (Table 4.2) - the reference values of the speeds are taken from the curve, and the intermediate values are calculated by interpolation.

Graduation is considered in detail in laboratory work № 3.

Table 4.2 – Grading table of hydrometric current meter

n, r/s	V, m/s									
	0,00	0,01	0,02	0,03	0,04	0,05	0,06	0,07	0,08	0,09
0,10	0,070	0,075	0.079	0,081	0,083	0,085	0,087	0,089	0,09	0,09
0,20	0,095	0,099	0,101	0,103	0,106	0,109	0,112	0,115	0.11	0,12
…										

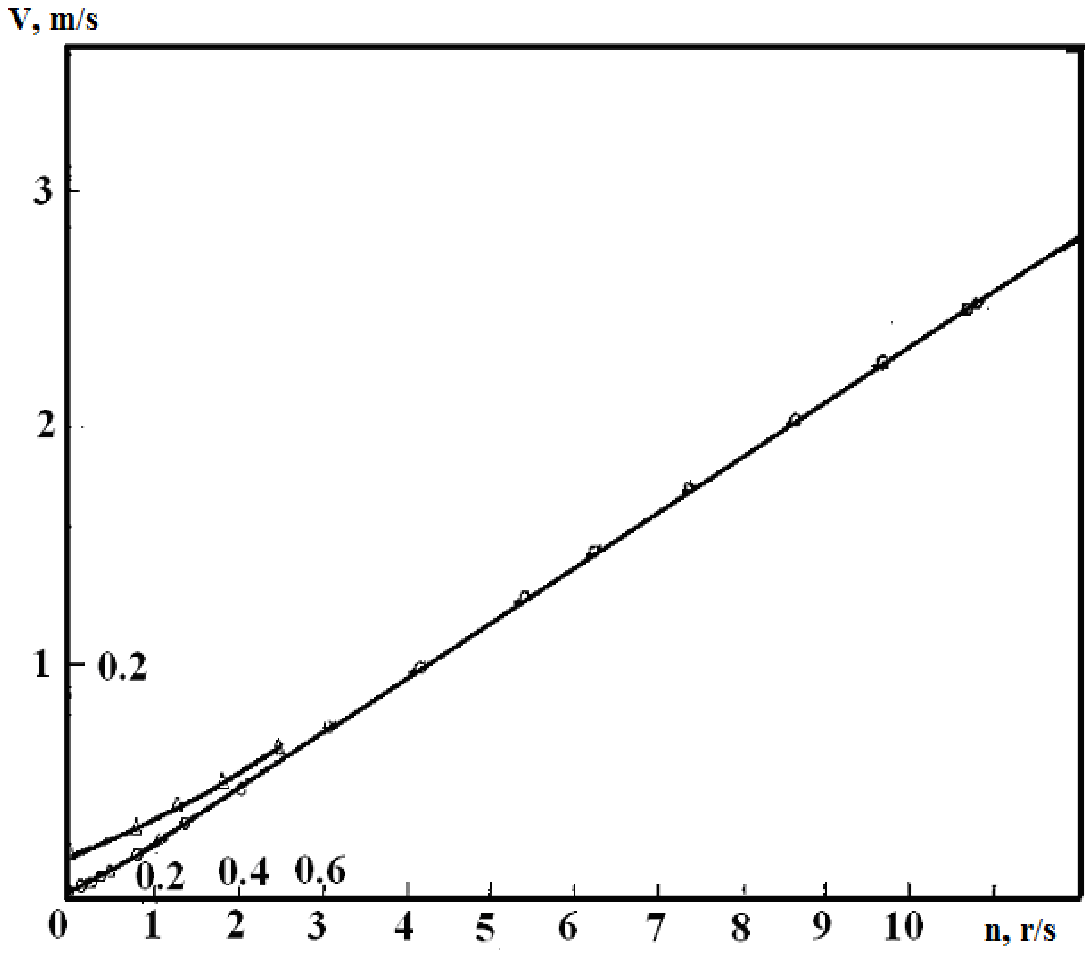


Figure4.5 – Grading curve of hydrometric current meter

4.4 An overview of the main types of hydrometric current meters

The total number of types and designs of hydrometric current meters is large. Let's consider the main types of current meters used in hydrometry.

Hydrometric current meter GR-21 M (Fig. 4.6) - consists of a body, a running part with a contact mechanism and a tail.

In the front part of the body there is a cylindrical cavity into which the axis of the chassis is inserted and fixed. There are two terminals on the body for connecting the alarm cable. In the middle part of the bode there is a hole for attaching the current meter to a wading rod or a swivel when working with a cable. At the end of the body, a tail is attached in the form of two concave plates. The running part of the current meter consists of a vane wheel, an axis with a contact mechanism, two ball bearings, an external thrust tube, an axial nut, and a sleeve with a worm sleeve. The contact mechanism is located in the inner chamber of the axle, which is filled with transformer oil. It consists of a worm gear with 20 teeth, on the axis of which an ebonite disk with one contact pin of a contact spring, a current-conducting pivot isolated from the body is put on; the pivot connects the contact spring to the socket of the plug.

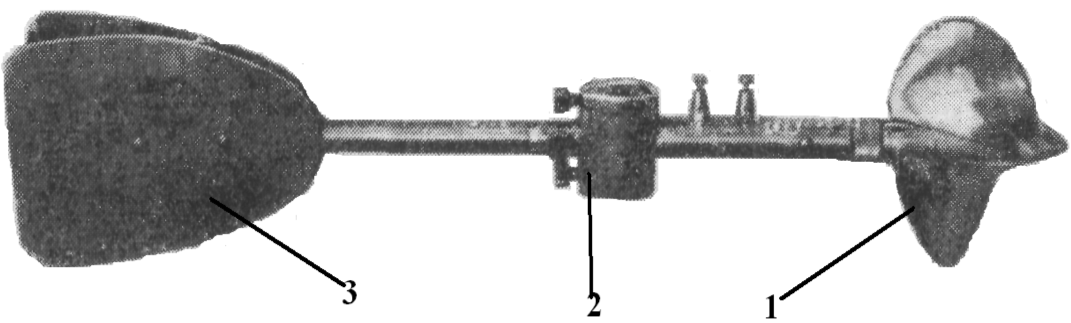


Figure4.6 – Hydrometric current meter GR-21M: 1 - running part (rotor); 2 - body; 3 - direction stabilizer

The electrical circuit diagram of the current meter is shown in Fig. 4.7. The contact mechanism of the current meter closes the electrical circuit every 20 revolutions of the vane wheel, which is notified by the signal system of the current meter, which has a lamp and a bell. Powering the electric circuit from galvanic elements with a voltage of 3V.

Current meter GR-21M has two vane wheels:

wheel № 1 – main, component, with a diameter of 120 mm, a geometric step of 215 mm, it is used when working from a wading rod without a direction stabilizer at current velocitys from 0.1 to 2.0 m/s;

wheel № 2 – non-component, with a diameter of 120 mm, a geometric step of 500 mm, it is used when working with a cable at current velocity's of 2 m/s or more.

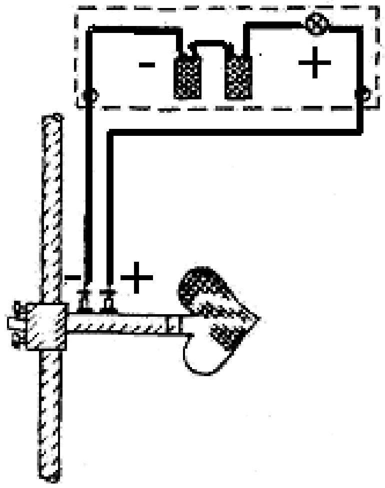


Figure4.7 - Electric circuit diagram of the current meter

Burtsev's hydrometric current meter (GR-55) consists of a body, a running part, a contact mechanism and a tail (Fig. 4.8). Signals after 20 revolutions of the vane wheel are transmitted to a bell or a light bulb. The vane wheel rotates on two ball bearings, the wheels cavity is filled with transformer oil. During the rotation of the vane wheel, the axis remains stationary. The device is recommended for use on small rivers and watercourses.

The current meter is equipped with vane wheels with a diameter of 70 mm: 1 – component, geometric step of 110 mm, used at speeds from 0.05 to 2.5 m/s, measurement error up to 5%; 2 - geometric step of 200 mm, used from a cable at speeds of 2.5 - 5 m/s.

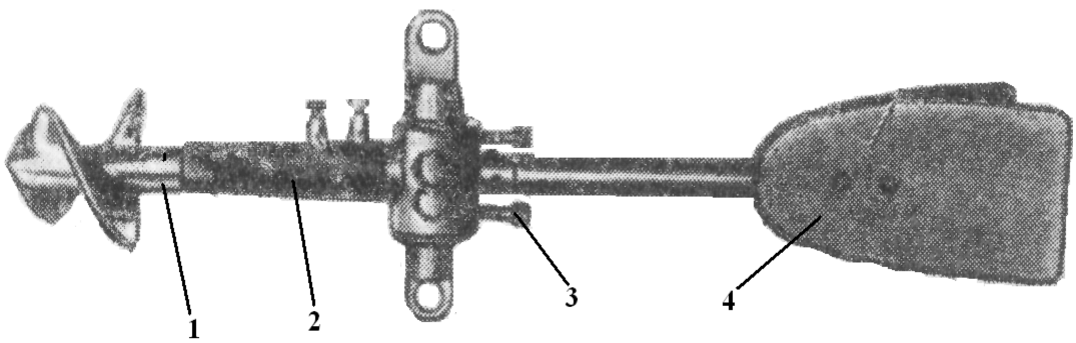


Figure4.8 – Hydrometric current meter GR-55: 1 - running part;
2 - body; 3 - clamps; 4 - stabilizer

The GR-99 hydrometric current meter has a component wheel with three vanes, 80 mm in diameter, with a geometric step of 130 mm, which allows you to measure the projection of the velocity vector with an error of up to 5% at an oblique flow of up to 40°. The range of velocity measurements is 0.6-5 m/s. Instrument error at velocity's up to 0.2 m/s is no more than 6%, at higher velocity's - within 2%. The vane wheel has a small moment of inertia, which allows the current meter to be used in flows with increased turbulence. The contact mechanism is located in the body, makes contact with each rotation of the vane wheel. Pulse - the counting mechanism consists of an electromagnetic pulse counter, a stopwatch and a lever device for switching the device on and off.

When measuring velocity, the device is turned on for a specified time and then the number of revolutions of the vane wheel is recorded on the counter scale, and the number of seconds is recorded on the stopwatch. The number of revolutions per second is found, and the water flow velocity is determined based on the gradient dependence.

Flow velocity meter ("IST") – the flow meter kit includes a current meter VG - 1-120/70, which consists of: a body, a vane wheel and a converter of vane wheel revolutions into electrical pulses. The two vane wheels have a diameter of 120 mm and 70 mm. There is a stabilizer for orientation of the current meter in the stream.

An important part of the flow velocity meter is the calculator, which is used to calculate the flow velocity based on the number of electrical pulses received from the measuring transducer. The result of the measurement is displayed on the scoreboard.

On the front panel of the calculator there are: power switch, terminals for connecting the signal chain of the current meter, dashboard, operating mode switch, "Start" button, "Ind" button, measurement mode alarm and current meter alarm. The operating mode switch ensures the operation of the device in the control mode, in the measurement mode when the duration of the speed determination period is up to 60 and 100 seconds, as well as in the mode of counting the number of signals from the current meter.

The measurement mode indicator, made in the form of an LED, turns on after 60 or 100 seconds. The indicator of the operation of the current meter is two LEDs that turn on one after the other.

Current meters with a horizontal axis of rotation dominate in the world.

Current meters of the OTT series (the company OTT, Germany) are produced in several modifications, they are compact and universal, they are used in laboratory conditions and on small watercourses. For example, the S-31 model has an electromagnetic counting and counting mechanism, each revolution of the wheel is fixed, in a set of 6 wheels of different diameter

In laboratory and field studies, micro current meters are widely used, which allow measuring the flow velocity with great accuracy. They are small in size, used in series on wading rods, readings are recorded on an oscilloscope. Typical representatives of this class are GR-96 and OTT series current meters. They are mounted on micro wading rods, during measurements, the counting-pulse mechanism closes the contact through each revolution of the wheel, the range of measurement of flow velocities is from 0.025 to 2 m/s. At the same time, the error does not exceed 5%.

The "Neurflux" current meter (Neurpic, France) has a plastic vane wheel and a steel body. The diameter of the vane wheel is 100 mm, the geometric step is 250 mm. The intermediate converter is a magnetically controlled contact. The recording device is a counter with a stopwatch, which are switched on synchronously. The velocity measurement range is 0.04 - 6 m/s.

Small-sized current meter № 180 (ROST company) is used on a pole in very small watercourses with polluted water and the presence of deposits (Fig. 4.9). A vane wheel with a diameter of 30 mm is fixed on a protective arc, the contact closes every 50 revolutions, which is signaled by a light.

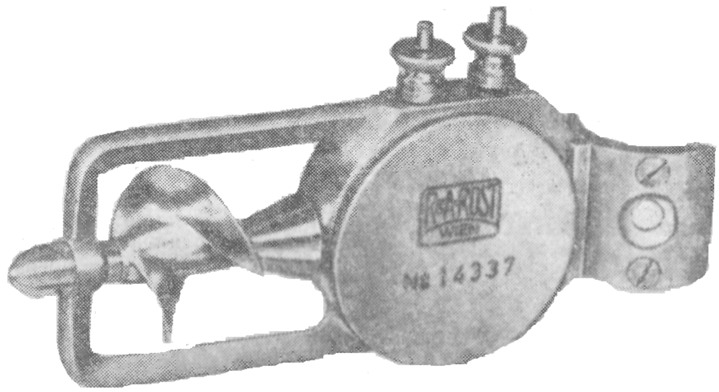


Figure4.9 – Small-sized current meter ROST

The Price current meter (USA, models F582, F584) consists of a running part with a cup rotor, a body, a direction stabilizer (Fig. 4.10). The rotor consists of six cone-shaped cups, which are fixed on a vertical axis, the end of which enters the contact chamber, which is hermetically sealed against water ingress. To measure the current velocity, the current meter is lowered on a wading rod or cable (when using a wading rod, the depth must be up to 3 m, the velocity must be up to 1.5 m/s; a crane and a hydrometric weight are used to lower the current meter on the cable. The correct direction and horizontal position of the current meter in the stream is ensured with a stabilizer of the direction and a float, which is fixed on the remote wading rod.

The VMM marine current meter (Fig. 4.11) is used to measure the velocity and direction of the current in seas, lakes and rivers at a depth of more than 1.5 m. The device consists of a body, a rotor, a counting mechanism, a compass box and a tail. The counter of revolutions of the rotor has three gears with arrows for counting units, tens and hundreds of revolutions of the wheel. Above the counting mechanism there is a tube into which 20-23 bronze balls are placed. During the rotation of the vane wheel, the balls pass through the counting mechanism (three balls per 100 revolutions) and fall into the compass box through the holes in its cover. The balls always roll in the north direction (according to the compass arrow), but since the compass box turns with the current meter in the direction of the current, the balls fall in different sectors of the compass each time. The sea current meter is installed at a point on the cable with a weight of 10, 25, 50 kg or more depending on the current velocity. The revolution counter is turned on and off with the help of a sending weight, and to record the number of revolutions and the direction of the flow, the current meter is taken out of the water. There are two vane wheels for high and low velocity operation with initial velocity’s of 2 cm/s and 4.5 cm/s, a stopper to prevent the vane wheel from idling.

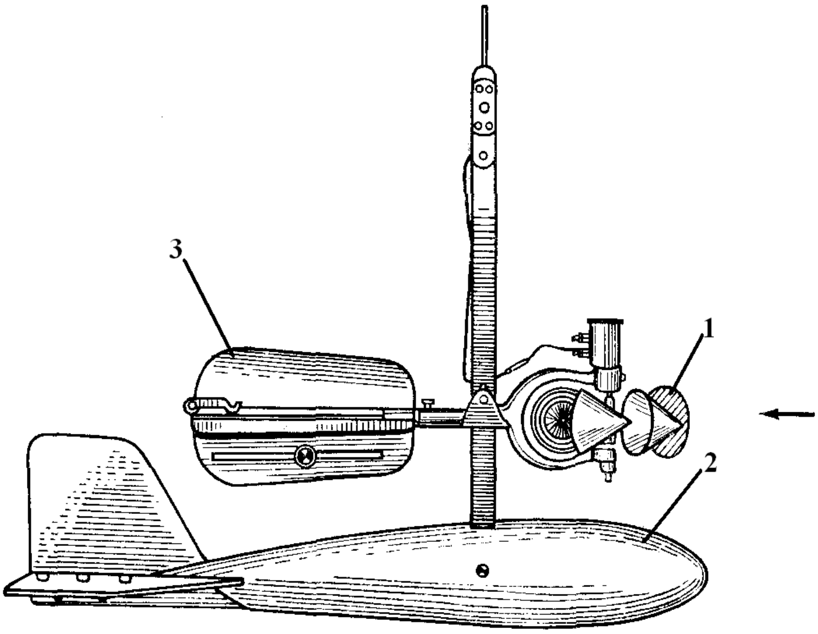


Figure4.10 – Price's current meter: 1 - rotor; 2 - weight; 3 - stabilizer

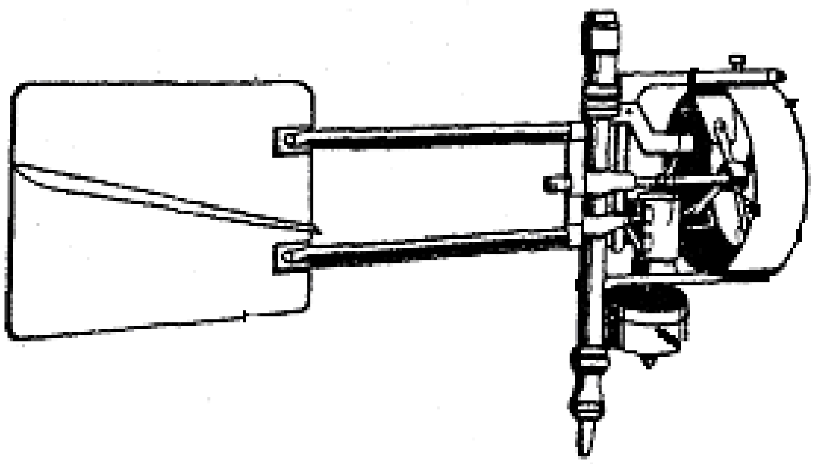


Figure4.11 – Sea current meter VM-M

The ISPV-1 current meter (RF) - registration of revolutions is electromagnetic, the PSV-1 recorder can be integrated with other types of current meters instead of bells. The running part is lubricated with water. Currently, the model is in the final stage, with high turbidity it gives a significant error, there is a lot of wear of electromagnetic contacts and bearings, it does not work well in winter.

Vector-2 current meter (RF), the current meter has an open running part, the electronic recorder fixes the velocity, direction of the current, water temperature, immersion depth, and the inclination of the device. Works poorly in winter.

PIST-1 (portable current velocity meter, Ukraine) Current velocity from 0.005 to 5 m/s with an error of ±5%, water temperature from -2 to + 35°C with an error of ±0.6°C, depth from 0 to 30 m. It consists of immersion block (2 kg), an on-board block (1 kg), a 50 m cable. The water level sensor is hydrostatic, the flow velocity sensor is acoustic. The data is shows on the display and recorded on a flash memory card, integration with a PC through the COM port, integration with GPS, the software provides the possibility of inputting a graduated coefficients, processing and graphical presentation of measurement results. It is used from a wading rod and cable, works in telemetric and automatic modes.

4.5 The hydrometric floats

Floats are used in hydrometry to measure the current velocity on the assumption that the current velocity is equal to the velocity of the float. Of course, a body that floats downstream moves faster than the fluid that surrounds it. This phenomenon depends on the mass, shape of the floating body and the slope of the water surface. The sizes of the floats used in hydrometry are usually small, so the velocity determination errors are within the maximum permissible limits.

There are surface, bottom and integrating floats (Fig. 4.12).

Surface floats are used to measure the velocities and direction of the current on the surface of the river: they are made in the form of circles of dry wood with a diameter of 15-30 cm and a thickness of 3-5 cm, or in the form of planks (for rivers with a width of 100-300 m) (Fig. 4.12, a). They should be clearly visible, so they are sometimes equipped with flags, and for stability, a weight is hung from below. A bottle almost filled with water with a flag near the cap can also serve as a float. During the ice drift, the float can be an iceberg that moves separately. Surface floats should not be used in windy weather (at a wind speed of more than 6 m/s).

The velocity measured by the surface floats is the average along the trajectory of the surface float and is taken as the local speed at the point of intersection of the section line and the trajectory of the surface float.

Bottom floats are used to measure the velocity and direction of the current at a certain depth. Such floats consist of two - surface and deep, connected by thin twine (Fig. 4.12, b). The upper float is made of cork or a board, and the lower one is made of a wooden ball boiled in oil, a glass ball or of celluloid plates fastened crosswise. The upper float of a small size is an indicator of the movement of the entire system and is equal to the lower float in terms of current velocity at depth. Bottom floats are most often used to measure low velocities that cannot be measured by a hydrometric current meter.

Integrating floats are used to measure average vertical velocities, they are used at current velocities up to 0.2 m/s.

The principle of operation of the integrator float is that the float, submerged vertically at a point near the bottom, fly away with the current and comes to the surface at a certain distance from the vertical - the starting point, and this distance is proportional to the velocity of the current on the vertical. To measure the current velocity, it is necessary to determine the distance from the given vertical to the point of appearance of the float on the surface of the water ***l*** and the time from the moment of launch to the appearance of the float on the surface ***t***. Then the average vertical velocity can be determined by formula 4.1:

$$v_{mean} = \frac{l}{t}. \qquad (4.1)$$

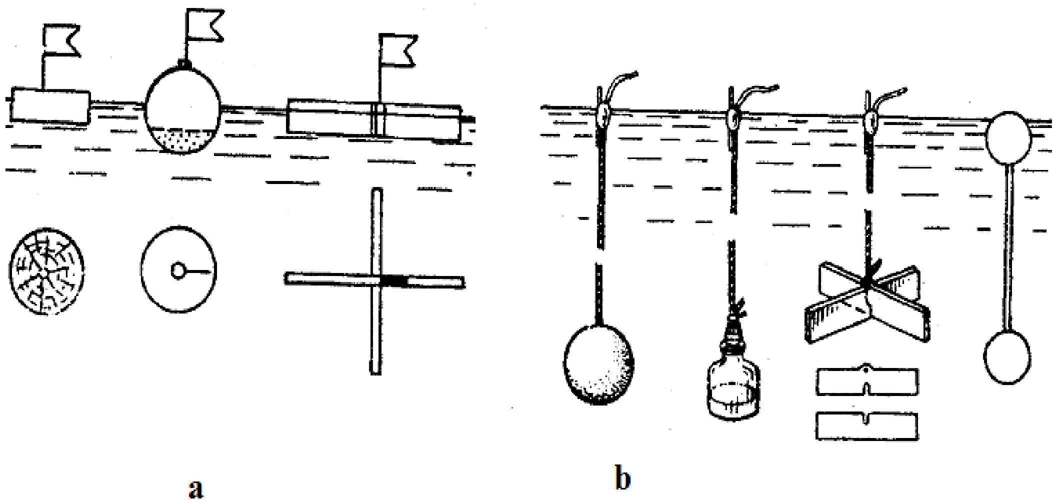


Figure4.12 - Hydrometric floats: a - surface; b - bottom

4.6 Current velocity measurements on the velocity vertical

The methods of flow velocity measuring in the vertical are divided into points and integrations. First, the working vertical depth is set, which is the distance from the surface of the water to the bottom, and in the presence of ice - from the lower surface of the ice to the bottom. Next (with the points method) the locations of the points where the current velocity should be measured are plotted and the immersion depths of the hydrometric current meter are calculated for them.

The points method is implemented in the form of detailed, basic, abbreviated and special methods, which are discussed in detail in laboratory work № 3.

After installing the hydrometric current meter at the velocity measurement point, you should skip 1-2 signals and turn on the stopwatch at the next ("zero") signal. Time is recorded at the beginning or end of the signal (better at the beginning) without stopping the stopwatch.

At a significant current velocity, when the signals follow one another, the time recording is carried out after 1-3 signals. The number of signals that arrive during the time interval between recordings is called **reception**.

At high flow velocity, when signals arrive more often than every 2 s, the measurement can be stopped after 1000 revolutions of the current meter wheels, without waiting for 100 s to pass. If the duration between the signals is more than 80 s (the current is too small), then the current meter cannot be used, they switch to bottom floats.

Analytical and graphic (more accurate) methods are used to calculate the vertical flow velocities measured by the hydrometric current meter. They are discussed in detail in laboratory work № 3.

The integration method is discussed in the laboratory work №3.

4.6 Questions for self-control

1. Features of the velocity field in a turbulent flow.
2. Basic methods of measuring current velocities.
3. Components of hydrometric current meters.
4. The principle of operation of the hydrometric current meter.
5. Grading of hydrometric current meters and processing of its results.
6. Types of hydrometric floats.
7. Methods of determining the average vertical flow velocity.

5 WATER DISCHARGE MEASUREMENTS

5.1 Water discharge measurement methods

Water discharge is the volume of water averaged over the time of measurement, which flows through the cross section of the stream in one second. Water consumption is expressed in m^3/s or l/s and is the most important characteristic of rivers and watercourses, which determines its parameters such as water level, current velocity, slope of the water surface, etc.

On the basis of measurements of water discharge, surface water resources are determined and their distribution is carried out according to the needs of certain branches of the national economy. Distinguish between direct and indirect methods of determining water discharge.

Direct measurements include the volumetric method, based on the measurement of flow velocity with measuring vessels that are placed under a stream of water, while measuring the time it takes to fill the measuring vessel. Water discharge is determined by dividing the volume of water in the vessel by the filling time. This method is used on small watercourses - streams, springs, laboratory trays with a water flow of 5-10 l/s, where the flow can be separated from the stream and directed into a vessel. Also, the same principle is used when calculating the water discharge through holes in hydraulic structures in order to account for the flow of water at hydraulic nodes. This method gives maximum accuracy.

The essence of **indirect measurements** is the measurement of certain flow elements and the subsequent calculation of the water discharge. These methods include:

- determination of the water discharge based on the measured current velocities and cross-sectional area of the flow according to the "velocity - area" model. The method gives accuracy: 6% - with detailed, 10% - with basic, 12% - with abbreviated methods of measurements;

- determination of water discharge using measuring devices: hydrometric trays and spillways; at the same time, the pressure on spillways and tray inlets is measured, and the water discharge is determined according to hydraulic dependencies, accuracy 5%;

- the remaining indirect methods (mixing method, physical methods, radioactive, aerial photography) are not widely used.

The "velocity - area" method forms the metrological basis of modern river hydrometry. The section line is divided by sounding and velocity verticals into separate segments, in which partial water discharge flows, which in sum are equal to the full water discharge of river in this cross section.

The merit of this model is that it assumes a different degree of discretization of the field of velocities and depths; the number of sounding verticals, as a rule, is assigned 2-3 times more than velocity verticals.

5.2 Hydrometric section: types, projecting, equipment

Discharge section line is a cross-section across a river fixed on the ground, in which water discharges measurements and suspended sediment discharge and bed load discharge measurements are conducted, which is an integral part of a hydrological gauge and is located directly in it or nearby.

The discharge section line should be placed on the site with the most favorable conditions. They coincide with the conditions before the placement of the water level gauge and have some features:

- the channel should be single-armed, preferably without a floodplain within the hollow;
- water movement should be uniform at speeds from 0.08 to 4 m/s;
- the direction of the current in the low water period and flood should be, if possible, perpendicular to the cross-section and vary little along the width of the channel (deviation or oblique current up to 20º);
- there should be no dead space, reverse currents, they should have clear boundaries and not occupy more than 10% of the plane of the water section;
- absence of aquatic vegetation in the strip of section line up to 30 m above and below;
- in the winter period, a continuous ice cover must form or the river must not freeze at all; impermissible accumulation of scum, which occupies more than 25% of the area of the water section;
- the section must be outside the zone of unstable movement and variable backwater.

Discharge section lines are fixed on two banks with strong pillars-benchmarks. One of the benchmark serves as initial point, from which the distance to the sounding and velocity verticals is determined. On large rivers, in addition to benchmarks, clearing marks are placed on two or one bank, depending on the topography of the area and visibility; vegetation is removed 5-10 m above and below the section line. Also, 20 m above and below the section line, the bottom is cleaned of driftwood and stones.

The scheme of the hydrological gauging and the discharge section line are shown in Figure 5.1.

A picket line is broken up along the line of cross-section and the shores are leveled to unfloodable marks, and depths are measured in the riverbed, old channels and active canals. According to the data of measurements and leveling of the banks, a cross-sectional profile is constructed along the hydrometric plot, which shows the placement of high-speed verticals, the nature of the bottom soils and the lands on the floodplain.

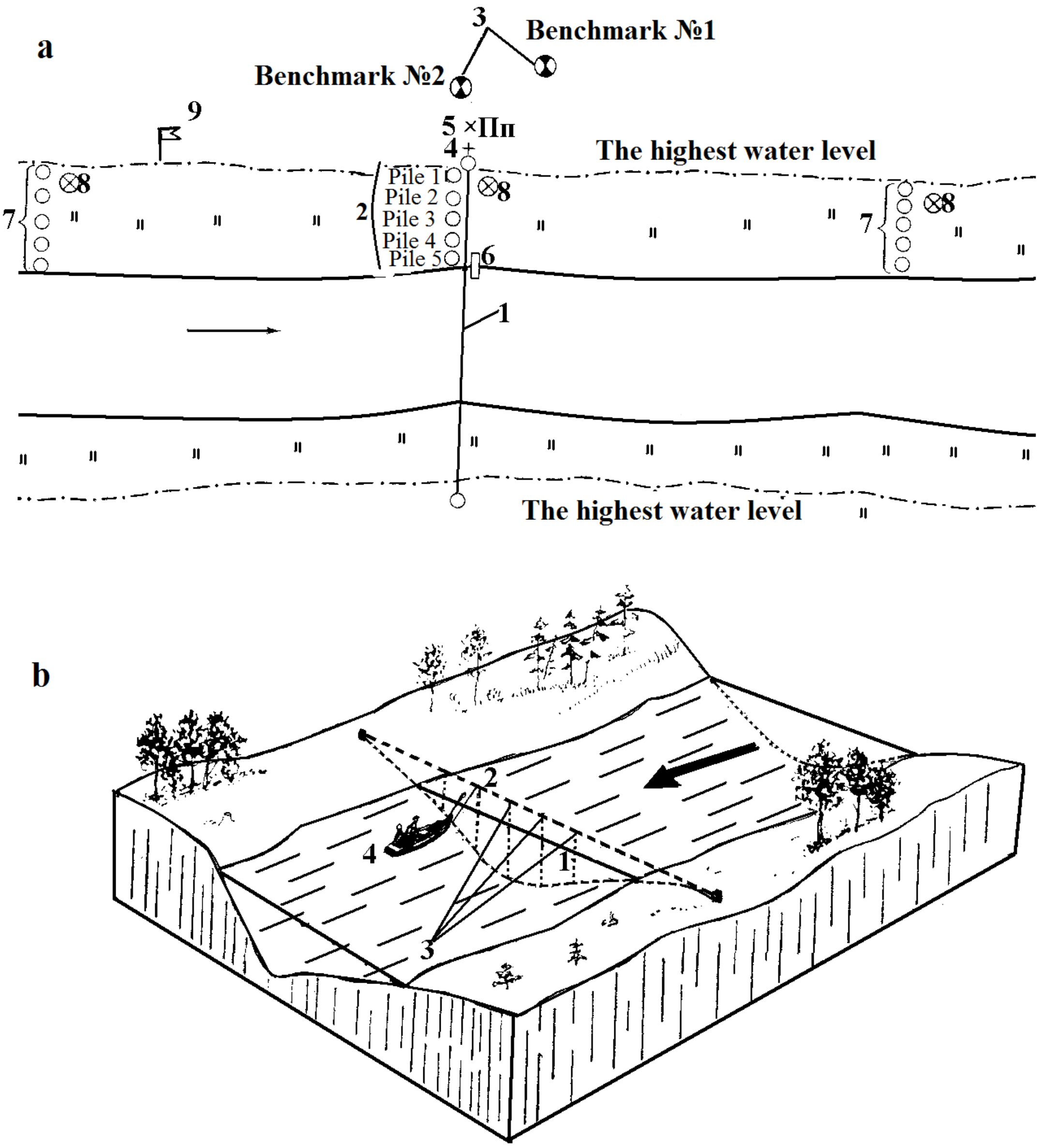


Figure5.1 – The scheme of the equipment of the hydrological gauge and discharge section line:

a) hydrological gauge: 1 – discharge section line; 2 - pile-type water measuring device; 3 - main and control benchmarks of gauge; 4 - place of air temperature measurement; 5 – the initial point; 6 - place of water temperature measurement; 7 – water slope gauges; 8 - maximum staffs; 9 - a place for observing ice phenomena;

b) discharge section line: 1 - line of the discharge cross section; 2 - driving cable; 3 – measuring verticals; 4 - a boat with a crane and a current meter on a cable

For the correctly determine the water discharges its necessary to set the direction of the discharge section line. The direction of discharge section line must be located perpendicular to the average direction of the flow in the selected section of the river. On rivers that have a wide floodplain, the direction of the low-water period cross line (mainly the channel) may not coincide with the general direction of the flow on the floodplain, forming an angle with it. At an angle of less than 10º, it is possible to designate one direction for the channel and the floodplain; at an angle greater than 10º, the direction of the discharge section line is designated as a broken line, each segment of which is perpendicular to the direction of the flow of the part of the channel crossed by it.

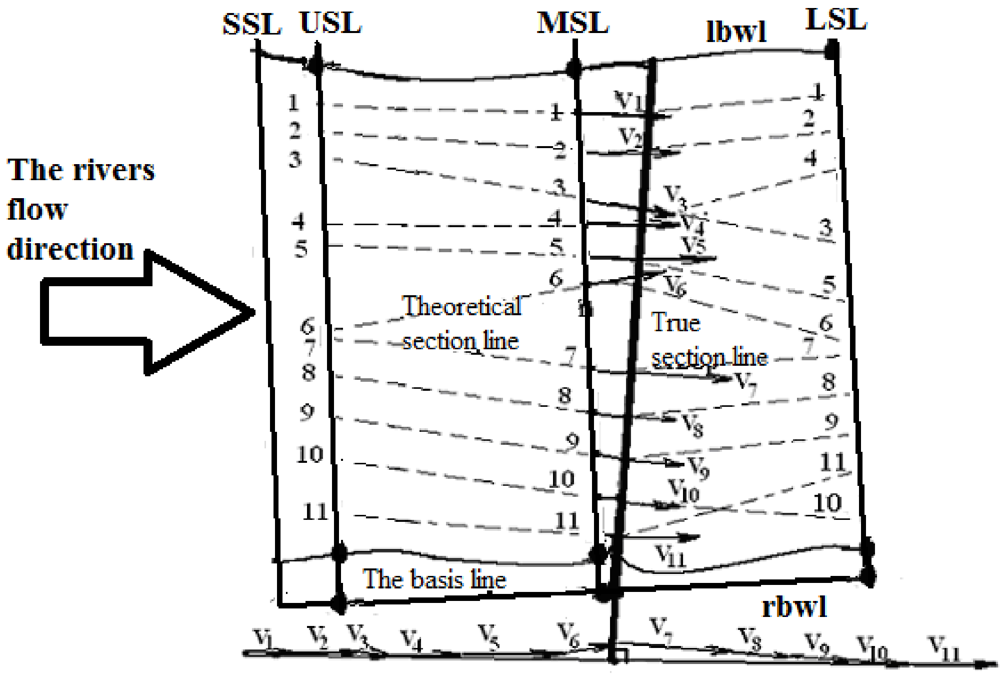


Figure5.2 – Scheme of determining the direction of the discharge section line by surface floats (SSL – starting section line; USL – upper section line; MSL – middle section line; LSL – lower section line; rbwl – right bank water line; lbwl – left bank water line)

At the measurement district its necessary to designate one discharge section line, which should be nearby or coincide with the water level measuring gauges line. In some cases, several discharge section lines are installed.

If the discharge section line is far from the cross-section of main water level measuring gauge, a water level measuring gauge is equipped at the discharge section line, the "datum plane of gauge" of the main and installed gauges must coincide.

The direction of the discharge section line must be chosen so that the average skewness on the velocity verticals does not exceed ±10º, the determination of the direction of the discharge section line by surface floats (Fig. 5.2) is considered in detail in laboratory work № 4.

The discharge section line is equipped with: a section lined water measuring gauge (if the main gauge is far from the section line); benchmarks, clearing marks, pillars; hydrometric crossing for soundings, measurements of current velocities; sloped water measuring gauges.

After determining and attaching the discharge section lines, they are equipped. The discharge section lines of regular hydrological gauges are equipped with hydrometric crossings of various types – gauging footbridges, gauging cable cars, boats, cetters, ferry's (Fig. 5.3).

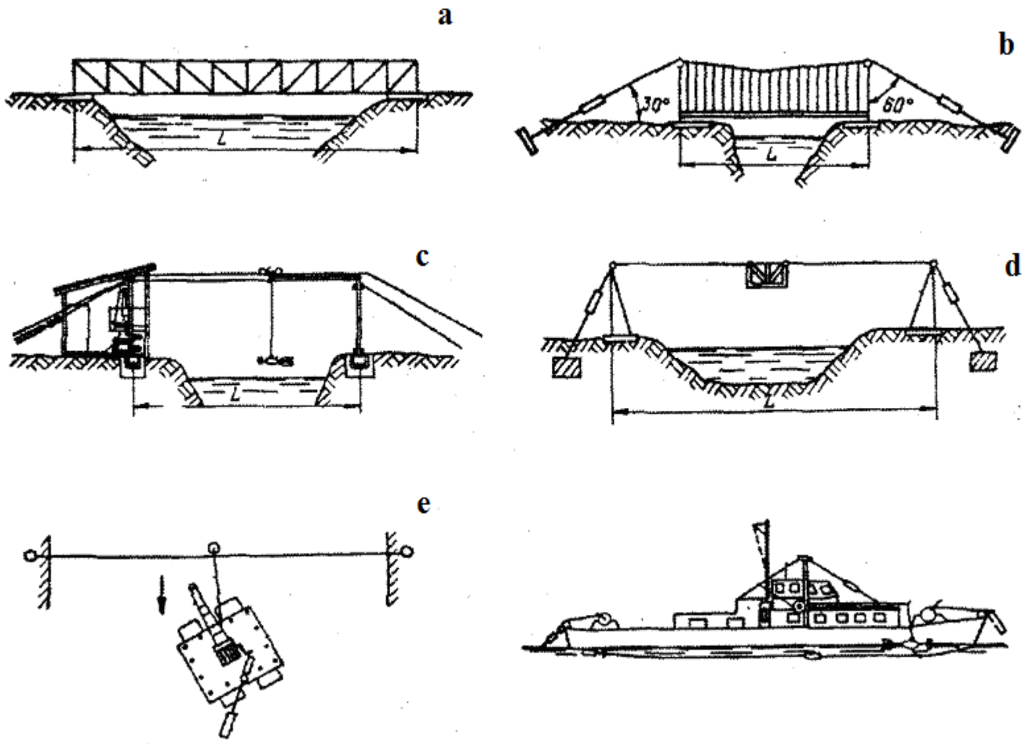


Figure5.3 – The main types of equipment of discharge section lines: a, b) hydrometric gauging footbridges; c) remote devices; d) gauging cable cars; e) pontoon; f) cutter

Hydrometric gauging footbridges are girder and suspended. Girger footbridges are used on rivers up to 15 m wide. Suspended footbridges are arranged on wider rivers. In this case, the decking of the footbridge is attached to two cables with a diameter of 10-15 mm, which are anchored on the banks.

Remote devices are built according to typical projects, they allow simultaneous measurement of depths, velocities, temperature, sampling on rivers up to 100 m wide and up to 12 m deep.

The GR-64M device (Fig. 5.4) consists of shore supports, a system of steel ropes thrown between them, a crane with an electric drive, a carriage, block counters of depths and horizontal distances. To determine the depth, the hydrometric weight is provided with surface and bottom contacts, the switching on of which allows determining the moment of contact with the water surface and the bottom by closing the electrical circuit and lighting up the corresponding lamps on the instrument panel. The weight is stable in the flow thanks to the float stabilizer at the back. The hydrometric current meter is fixed in front of the weight. The revolutions of the vane wheel are recorded by the pulse counter, which automatically turns on and off during velocity measurements synchronously with the stopwatch.

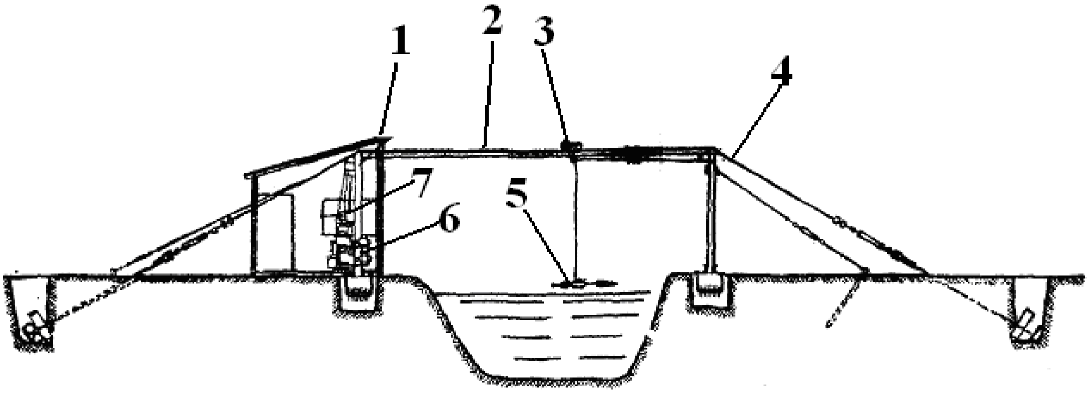


Figure5.4 – GR-64M device: 1, 4 - supports; 2 - cable; 3 - carriage; 5 - current meter; 6 - crane; 7 - electric motor

Hydrometric device GR-70 (Fig. 5.5) is similar to GR-64, but equipped with a manual drive of a cargo crane. The device is powered by a 12 V battery.

Gauging cable cars are arranged on mountain rivers with high currents and high banks. They can be arranged on one or two driving cables fixed on the shores. The gauging cable car is moved across the river using a crane or by hand. The design of some gauging cable cars allows them to move in horizontal and vertical directions. Determine the distance of the verticals from the initial point using a marked cable with a diameter of 2-3 mm.

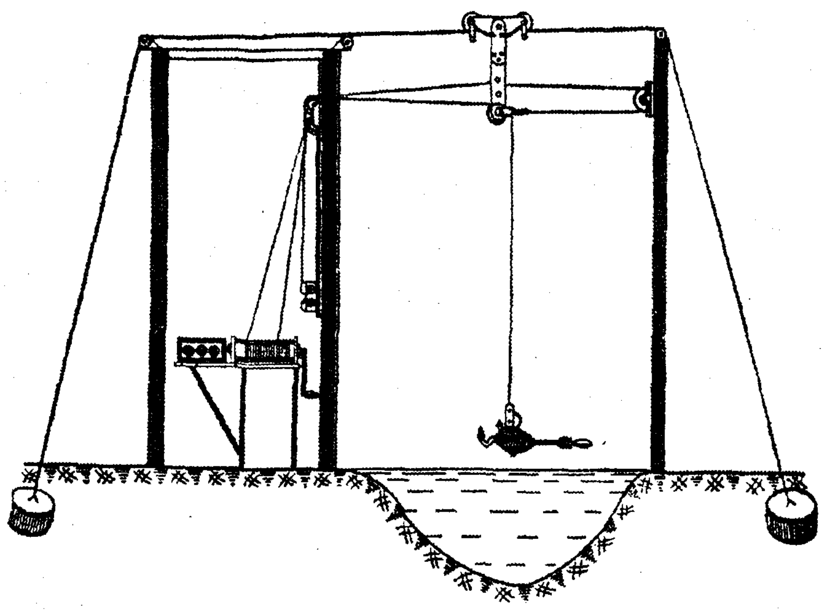


Figure5.5 – Remote hydrometric device GR-70

Pontoons are used on large rivers with significant current and depth. A pontoon is made from two boats, connecting them with a wooden deck. So that the boats do not affect the surface speed, the distance between them should be at least 1.5-2.0 m.

On large rivers, during spring floods, a **cutters** is used to velocity's measure. In winter, when the river is covered with ice, measurements of the distance from the initial point and vertical velocities are carried out from the ice. On rivers up to 200 m wide, water discharge measurements are performed from boats and ferries, which are equipped with a cable and a crane for moving them. To determine the locations of the verticals, a marked cable is used, which is stretched along the cross line.

5.3 Determination of water discharge with the help of hydrometric current meters

When measuring the flow velocity with a hydrometric current meter, it is necessary to draw velocity verticals on the profile of the discharge section line, the number of which depends on the method of measuring water discharges, the width of the river and the configuration of the bottom. In general, it is necessary that the coastal verticals should be as close as possible to the water cut, one should be in the deepest part of the channel, the rest with the correct (trough) shape of the channel is distributed evenly across the width of the river. In the case of sharp breaks in the profile of the channel, the velocity verticals are plotted in the places of the profile breaks.

When placing the verticals, it is important that the segments between them pass equal shares of the total discharge, so the velocity verticals should be equidistant from each other (Table 5.1).

Table 5.1 – Dependence of the distances between the velocity verticals on the width of the river

The width of the river, m	The distances between the velocity verticals, m	The width of the river, m	The distances between the velocity verticals, m
< 20	0.5-2.0	100-200	10
20-30	2.0	200-300	20
30-40	3.0	300-500	30
40-60	4.0	500-800	40
60-80	6.0	> 800	50
80-100	8.0		

When implementing the "velocity-area" method in a discharge section line, depths (on sounding verticals) and current velocities (on velocity verticals) are simultaneously determined.

According to sounding data, the area of the water sections in individual segments of the water section is calculated, according to the velocity data, the average velocity on the verticals is calculated, then the partial water discharges, the sum of which will give the full water discharge in section line.

When measuring water discharge, it is mandatory to water level observations during the entire time of water discharge measurements. With a stable channel - at least four times: at the beginning and at the end of sounding, before the beginning and at the end of current velocity measurements. If the water level changes during the measurement of water discharge by more than 10 cm, then the water level is measured an additional 3-4 times. At the same time, the time of water level measurements and the time of determining the velocity on each vertical are fixed. This must be done to reliably determine the calculated water level, which will later correspond to the measured water discharge. Also, when measuring water discharges, the longitudinal slope of the water surface is determined by slope water measuring gauges or leveling of water cut stakes.

When measuring water discharges, the following methods are used: detailed, basic, shortened and accelerating:

- **the detailed method** (5 measuring points on each velocity vertical) is used to study the features of the flow velocity field and on newly opened discharge section lines in the first 2-3 years of operation. The distance between the velocity verticals is assigned uniformly along the width of the river (Table 5.1). If there are sharp breaks in the bottom profile, velocity verticals should be assigned in these breaks as well. Near the floodplain, where the current is calmer, verticals are placed less often, and closer to the line of maximum velocity, velocity verticals are placed through one sounding vertical.

- **the basic method** (2 measuring points on each velocity vertical) involves measuring water discharges with a minimum number of velocity verticals (at least five), provided that the results of water discharge measurements by the basic method will differ from the water discharge measured by the detailed method, no more than by ±3%. The number of velocity verticals and their placement on the discharge section line is carried out on the basis of an analysis of 20-30 water discharges, measured in a detailed method in different seasons of the year under different conditions.

- **the shortened method** involves determining the water discharge at one or two points on the vertical when the channel is free and at two or three points when there is ice or when the channel is overgrown. The number and placement of velocity verticals and velocity measurement points on them is determined on the basis of a thorough analysis of the data obtained as a result of water discharge measurements in a detailed and basic methods. The application of the shortened method is advisable on rivers with a stable channel, when frequent and fast measurements of water discharge are necessary in case of unstable water movement.

Velocity verticals are fixed on the deck of bridges, with marks on a stretched cable or serifs with a theodolite from the shore or a sextant from the ship (Fig. 5.6 a, b, c). The places of the verticals on the wide floodplain are fixed with poles, on which the numbers of the verticals are written.

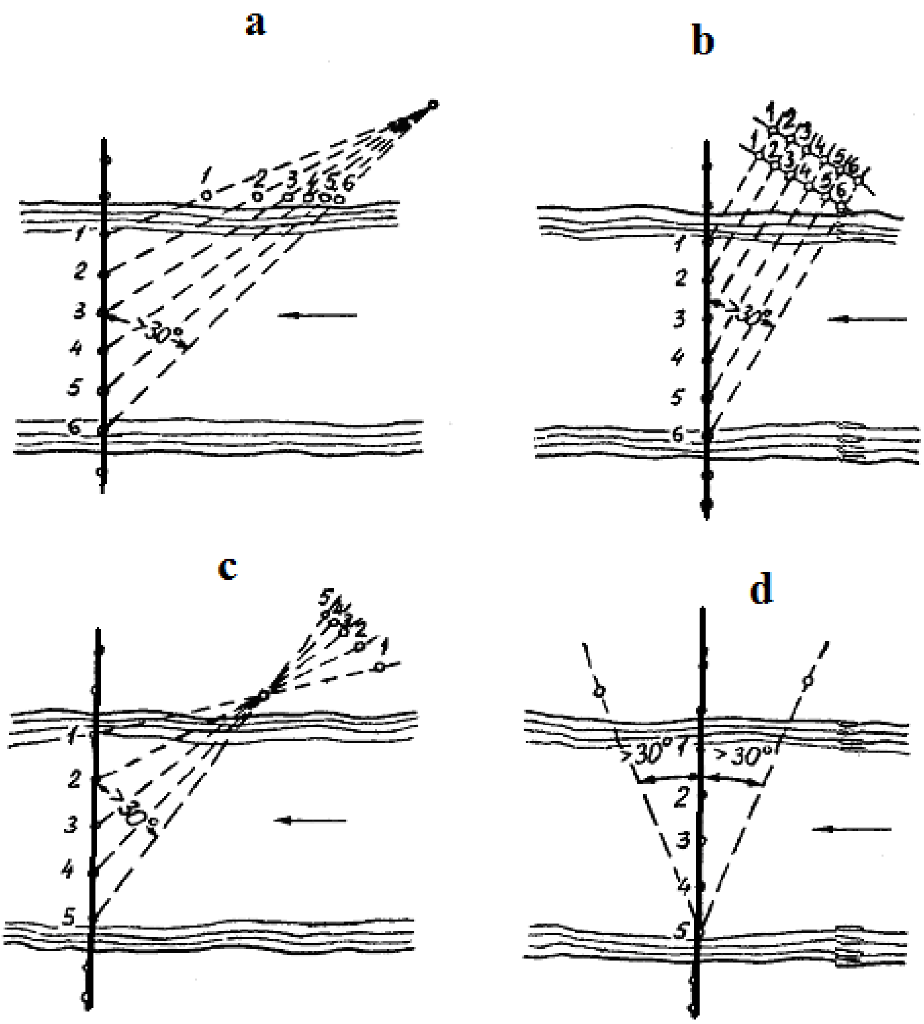


Figure5.6 – Scheme of oblique and fan-shaped section lines for fixing velocity verticals on wide rivers

Measurement of water discharge with a hydrometric current meter on rivers and canals is carried out in two methods - point and integration, and the results of water discharge measurement are recorded in the KG-3M(n) field book (or KG-3 for the detailed method, KG-4 for the basic method).

The main method of measuring water flow with a hydrometric current meter on rivers and canals is the **point method**, which, depending on the number of velocity verticals, velocity measurement points on the vertical and the time of velocity measurement at the point, is divided into options - detailed, basic, shortened and accelerated. The algorithm of actions for measuring and calculating water discharge with hydrometric current meters is considered in laboratory work № 6.

Calculation formula for total water discharge:

$$Q = kv_1w_1 + \frac{v_1 + v_2}{2}w_2 + ... + \frac{v_{n-1} + v_n}{2}w_{n-1} + k\ v_nw_n, \tag{5.1}$$

where $v_1, v_2...v_n$ - are average velocity on verticals;

$w_1, w_2...w_n$ – the areas of water sections between velocity verticals;

k - the coastal coefficient, which is intwading roduced for coastal sections and depends on the nature of the coast.

Schematization of the cross line into segments is shown (Fig. 5.7-5.8).

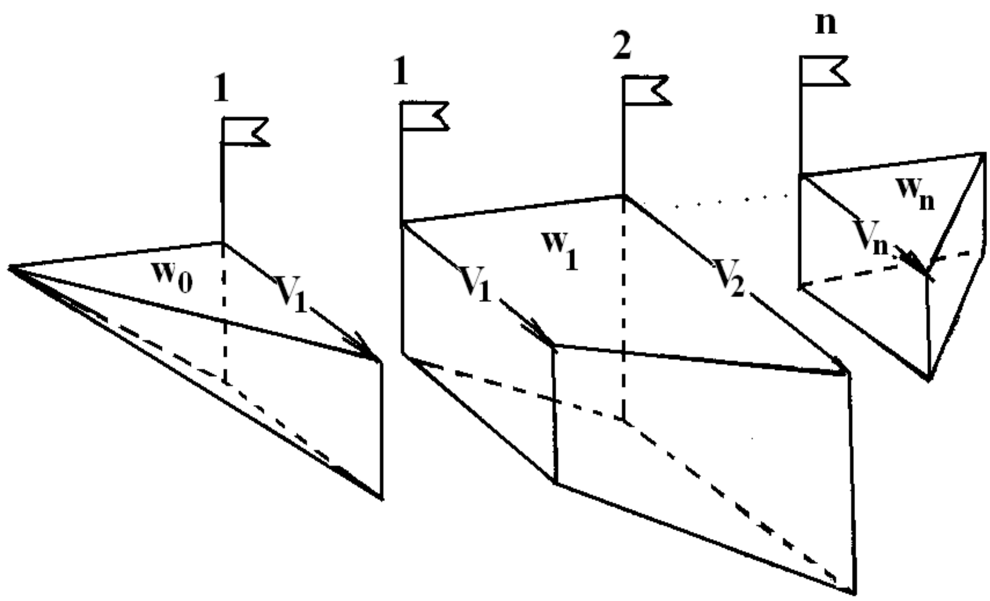


Figure5.7 – Scheme for calculating water discharges using an analytical method

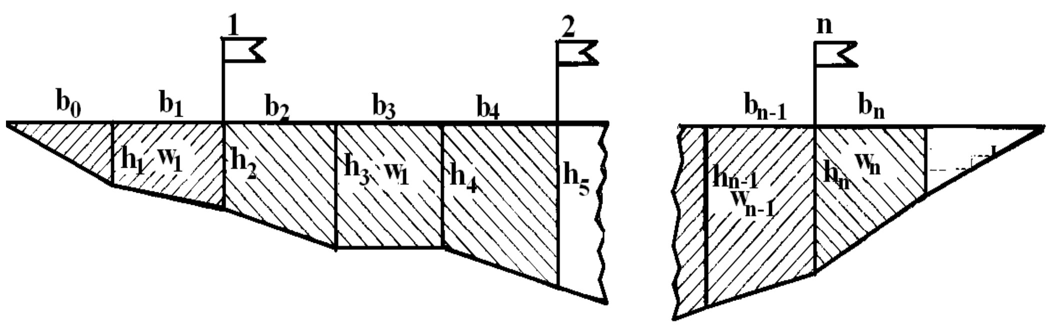


Figure5.8 – Scheme for calculating the partial areas of the living section

5.4 Determination of water discharge with the help of hydrometric floats

Bottom floats are used for measurements at low current velocities (up to 0.20 m/s), when current meter measurements are not reliable enough, and it is also good to use them to determine the limits of the dead space. The procedure for performing depth measurements, operations to determine the area of water sections and the appointment of velocity verticals is the same as when measuring with a current meter. Flow velocities are measured at the same points as with the main method of determining water flow with a current meter. Speeds are measured from the boat, on which three section lines are fixed from three horizontal staffs: upper, middle and lower. The staffs are placed at a distance of 1 m from each other and fastened with a rigid frame (scheme in Figure 5.9).

The velocity at a point is calculated by dividing the length of the base - the distance between the section lines by the average duration of the float's movement. Water discharge is calculated analytically, similarly to water discharge measured by a current meter.

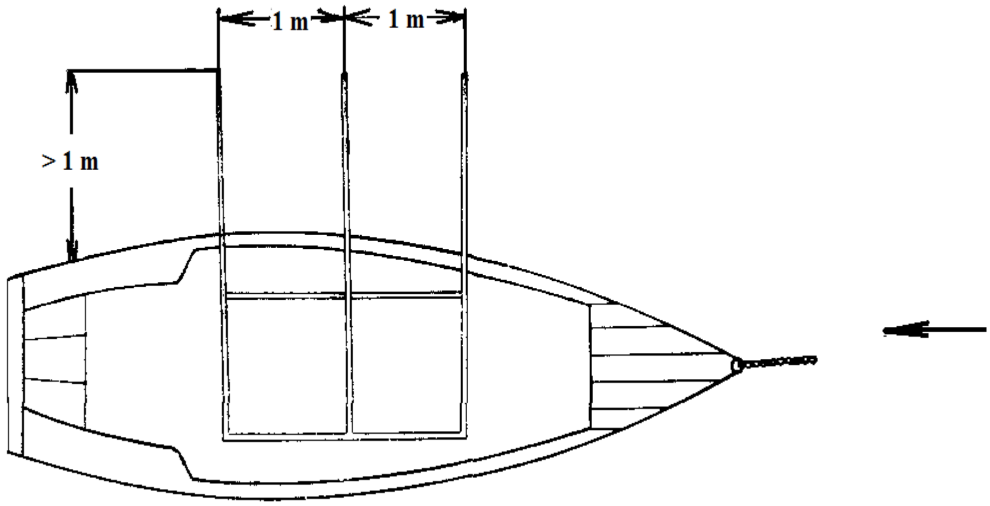


Figure5.9 – Scheme of boat equipment for measuring velocity by bottom floats

Surface floats give approximate results, so they are used in reconnaissance surveys of rivers, at low current velocities and other conditions. They are not used during ice flow, ice covered and wind velocity of more than 6 m/s. A straight section of the river with uniform depths, width and longitudinal slope of the water surface is chosen for work. The length of the site is usually taken to be three to five times the width of the river. On the shore, a basis line is laid parallel to the main direction of the current, and three section lines are fixed perpendicular to it: upper, middle, and lower (scheme in Figure 5.10). The distance between the extreme section lines is determined with the condition that the duration of the movement of the floats between them is not less than 20 seconds. If it is not possible to run floats across the width of the river, for example, on rivers with a fast current, where the floats are carried to the middle of the stream, the water discharges is determined by the greatest surface velocity.

The middle section line serves as the discharge section line, and the upper and lower section lines are placed parallel to it at equal distances. 10 m above the upper section line, a starting section line is assigned, from which floats are launched when measuring the current velocity so that when approaching the upper section line, each float picks up the velocity of the current in which it moves. All section lines are fixed on both banks with pegs.

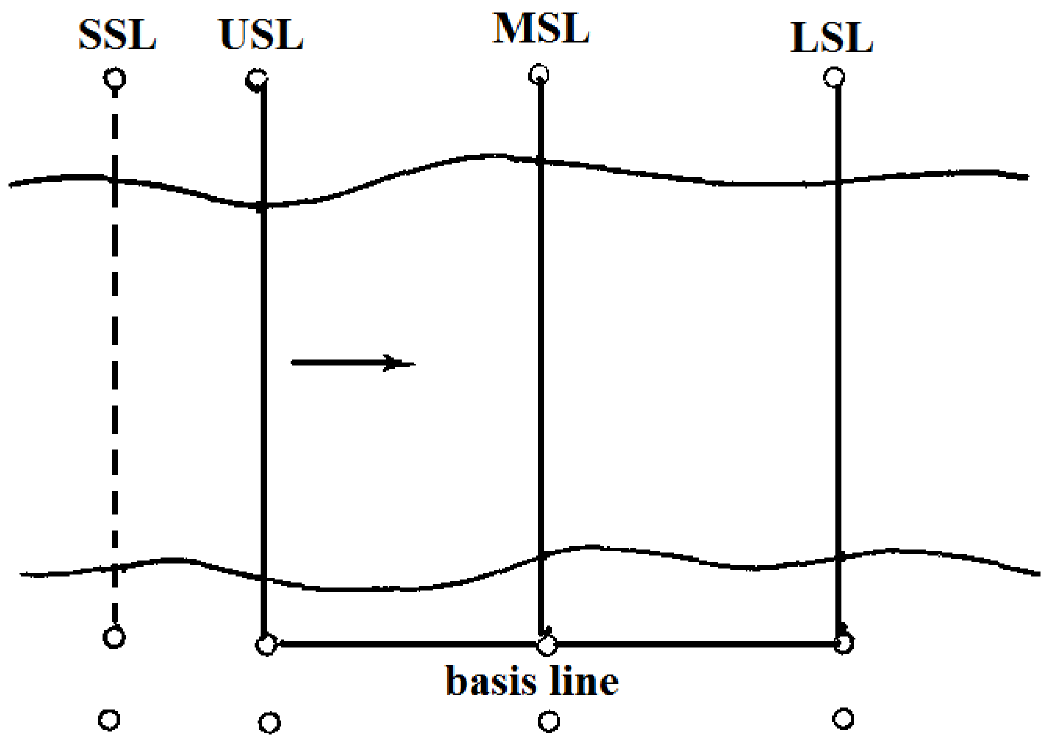


Figure5.10 – Scheme of the location of the stream lines for water discharge measurements (SSL – starting section line; USL – upper section line; MSL – middle section line; LSL – lower section line)

In the KG-7M(n) book, a graph of float velocities (Fig. 5.11) is built, which is used in calculations. Detailed measurement and calculation of water discharge by surface floats is considered in laboratory work № 5.

As a result, a fictitious water discharge is obtained, which is converted into a real water discharge:

$$Q_a = K \bullet Q_f, \tag{5.2}$$

where K - the transition coefficient from fictitious to actual water discharge.

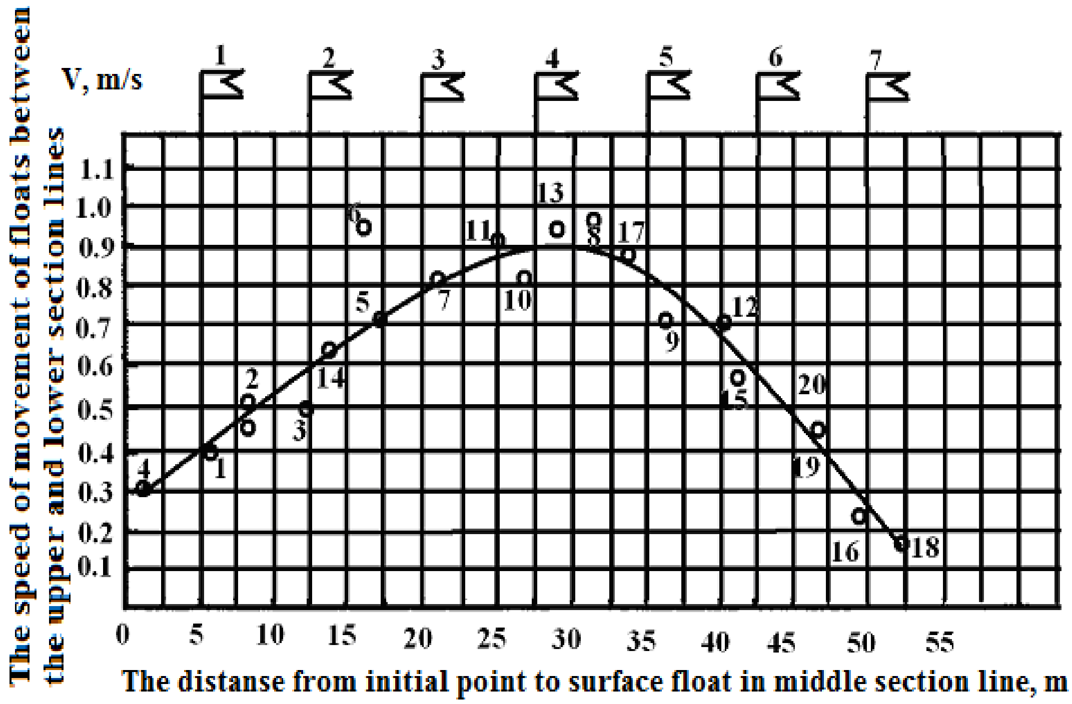


Figure5.11 – The curve of distribution the movement speeds of surface floats along the width of the river

5.5 Questions for self-control

1. Basic methods of water discharges determining.
2. Mathematical implementation of the "speed - area" model.
3. Requirements for the placement of a discharge section line for water discharge measuring.
4. Methods of determining the true direction of the discharge section line.
5. Equipment of discharge section line, fastening of velocity verticals.
6. Calculation of water discharges measured by hydrometric current meters.
7. Calculation of water discharges measured by surface floats.

6 STUDY OF SOLID RUNOFF AND BOTTOM SEDIMENTS

6.1 Main information about the sediments in natural waters

River waters always contain a certain amount of solid particles (sediments) and dissolved substances. Solid particles of mineral and organic origin that are transported by water are called **sediments**.

The total amount of solid particles and dissolved solids carried by the river during a certain time period is called **solid flow**.

Sediments are formed due to erosion. Dissolved solids in the water are present as a result of groundwater entering the river, dissolution of those rocks that lie in the river basin, anthropogenic processes. The study of sediment flow is of great importance and consists in establishing the dependence of sediment discharge on the hydraulic characteristics of the flow.

Sediments in the water stream are divided into **suspended sediments**, which are in a suspended state in the water column, and **bed load**, which move in the bottom layer. Such a division of sediments is conditional, because with a change in the current velocity, sediments can go from a raised state to a bottom state and vice versa, but methodologically, such a division is justified, because the measurement of suspended sediments and bed loads is carried out by different methods.

Sediment discharge is the amount of sediment carried by water through the cross-section of the river per unit of time.

Sediment flow (P, kg) is the amount of sediment carried by water through the cross-section during a certain period of time (day, month, year).

Sediment discharges are measured in weight units per second (kg/s). Usually, during hydrometric measurements, **the discharge of suspended sediments (R, kg/s), the discharge of bed load (G, kg/s)** and **the discharge of dissolved solids (S, kg/s)** are measured separately.

The determination of the specified discharges is based on taking into account such characteristics as water turbidity, elementary discharges of bed loads and mineralization of water.

The turbidity of water at certain points is determined by the amount of sediments per unit volume and is expressed by the dependence:

$$\rho = \frac{P_s}{A}, \tag{6.1}$$

where P_s – mass of sediments in the sample, g;

A – volume of water sample, m^3;

ρ – water turbidity, g/m^3.

The elementary discharge of bed load is the amount of bed loads that moves through a unit of length of the wetted perimeter of the watercourse in one second:

$$q = \frac{100P_b}{tl}, \tag{6.2}$$

where P_b - weight of bed load in the sample, g;

t – time of taking of water sample, s;

l - width of the device inlet, cm;

q - elemental discharge of bed load, g/(m/s).

Themineralization of water (α, g/m^3) is determined by the ratio of the dry residue in the water sample taken to the sample volume:

$$\alpha = \frac{P_{dr}}{V}, \tag{6.3}$$

where P_{dr} - weight of dry residue, g;

V - volume of water sample, m^3.

The study of solid flow makes it possible to estimate the annual flow of suspended sediments, bed loads and dissolved solids and its intra-annual distribution, the granulometric composition of suspended sediments, bed loads and the salt composition of water. Such information is quite important for the rational use of water bodies.

The distribution of sediments in the live section of the flow is affected by their large-scaleness, there are two characteristics of this - geometrical size of particles and fall diameter.

The fall diameter Z (mm/s) is the speed of free full-scale fall of particles in a non-fluffy water medium.

The classification of sediments by the fall diameter is given in Table 6.1.

Correspondence between particle size and fall diameter is given in Table 6.2 for a water temperature of 15° C. Such a relationship allows performing a mechanical analysis of the smallest sediment particles. When using this table in conditions of a different temperature, corrections are intwading roduced.

The moving characteristics of the particles are related to the characteristics of the particles (size, shape, density) and the features of the water flow (velocity field) in which they move.

Suspended sediments are transported by the water flow due to the turbulent mode of water moving (the presence of a vertical component of the velocity). If the vertical component of the velocity is greater than the fall diameter of the particles, they can rise high. The distribution of suspended sediments along the live bed is consistent with the velocity field, this pattern is broken near the bottom. Pits are formed in areas with high current velocities (bars) due to mass lifting of particles from the bottom, in calmer areas (pools) particles accumulate (sediment).

For spring floods and floods, the greatest turbidity is characteristic due to intensive washing of soil from the slopes, and for low-water period with mainly underground feeding, it is the smallest; suspended sediments form up to 95% of the solid flow on plain rivers.

Table 6.1 - Division of river sediments by size of particles (mm)

The group of fractions	Fractions						
	Clay	Mud	Dust	Sand	Gravel	Pebble	Boulders
Small	<0,001	0,001-0,005	0,01-0,05	0,1-0,2	1-2	10-20	100-200
Middle	-	-	-	0,2-0,5	2-5	20-50	200-500
Large	-	0,005-0,01	0,05-0,10	0,5-1,0	5-10	50-100	500-1000

Table 6.2 - Values of fall diameter and geometric dimensions of sediment particles

Diameter of particles, mm	Fall diameter, mm/s	Diameter of particles, mm	Fall diameter, mm/s
0,001	0,0008	1,2	128
0,005	0,02	1,5	154
0,01	0,08	1,8	177
0,05	1,95	2,0	192
0,1	6,10	2,2	204
0,2	17,4	2,5	227
0,5	55,5	3,0	242
1,0	110		

Bed loads move in the bottom layer of the flow by rolling and sliding. Less often, the jumping-like behavior of particle movement (saltation) is noted. The movement of particles begins when the critical flow velocity is reached. In the bottom layer, the movement of sediments is difficult due to great turbulence.

Bands (sand mounds) of various sizes are formed on the plain rivers with a sandy bottom. The transformation of bands is unstable and depends on the water regime of the river and the velocities in the bottom layer. The movement of bands is similar to the movement of waves on water (Fig. 6.1). On mounting rivers with a stony bottom composed of coarse gravel, pebbles or boulders, the mode of rolling is haptic, and for smaller fractions - saltation, while the bottom bands are not formed.

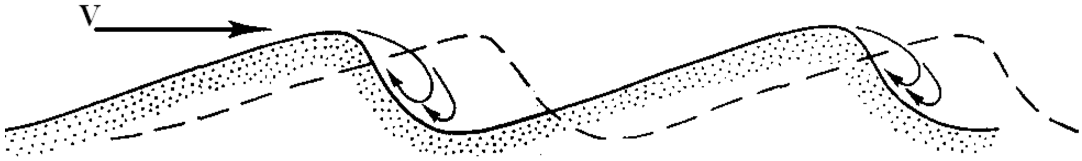


Figure6.1 – Scheme of movement of bottom bands

6.2 Measurement of quantitative characteristics of suspended sediments

An indicator of the content of suspended sediments in water is its turbidity, which is determined by selecting water samples with samplers (instant, gradual filling) or measured photometrically.

Samplers of instantaneous filling allow to determine instantaneous values of turbidity, which is important in experimental work. At the same time, several separate samples are taken at each point. This type includes **Zhukovsky sampler, Molchanov sampler.**

In hydrometry, samplers of gradual filling are widely used, which give more accurate values of turbidity: bottle-sampler on a wading rod (GR-16M), bottle-sampler on weight (GR-15M), vacuum sampler (GR-61M).

The bottle-sampler on the wading rod GR-16 is used on plain rivers, it consists of a bottle with a capacity of 1 dm^3 in a metal frame, sealed on the wading rod at an angle of 25° to the horizontal. The head of the bottle is closed by a metal head with air outlet and water intake tubes, which are oppositely oriented. Nozzles are screwed onto the ends of the pipes, the diameter of which depends on the current velocity. The tilted position of the sampler improves the conditions for water to enter it and ensures its operation at depths from 0.5 to 2.5 m and current velocity up to 1.5-2.5 m/s. The device allows taking water samples for turbidity by point and integration methods. To take a water sample, the device on the wading rod is immersed in water so that the water intake tube is against the current, and it is held at the point until the bottle is filled to 90-95% of its volume. The sample taken from the sampler is poured into another bottle and sent to the laboratory to determine the amount of suspended sediment. Before pouring the sample from the sampler, its volume is determined, for which the upper part of the bottle-sampler is divided by 40-20 ml and the numbers are written.

The bottle-sampler on the weight GR-15M consists of a fish-shaped weight on which a bottle with appropriate tubes and nozzles is placed, as in the GR-16. The weight provides stability in the flow, which allows the sampler to be used both independently from the winch and as part of remote hydrometric devices. GR-15M sampler can have weights 15, 50, 75 kg, which are stored at the corresponding current velocity of up to 1 m/s, from 1 to 3 m/s and more than 3 m/s. Samplers weighing 15 kg should be used on plain rivers with velocity's up to 1 m/s and depths up to 10 m, samplers weighing 50 kg - on rivers with velocity's up to 2-3 m/s and depths over 10 m, samplers weighing up to 75 kg - on mountain rivers with a velocity's of more than 3.0 m/s. The weight of 50 and 75 kg makes it possible to simultaneously attach a hydrometric current meter for measuring the velocity of water flow. During operation, the sampler is attached to the cable and lowered to the required depth with a crane.

Bottle-samplers are intended for both point and integration measurements of turbidity on verticals. At the same time, the volume of the sample taken should be between 800 and 950 ml, which guarantees the representativeness of the samples taken.

The GR-61 vacuum sampler is designed for spot and integration sampling in mountain and large rivers with depths of up to 20 m and velocity's of up to 2.5 m/s. The altitude limit for the use of the sampler is no higher than 2000 m above sea level (vacuum chamber displacement above the water up to 3-4 m). The principle of operation is the forced formation of a vacuum in the sampler chamber, under the action of which water from the reservoir is sucked into the chamber through a hose. The sampler consists of: a vacuum chamber with a capacity of 3 l, a pump and a water suction nozzle. The vacuum camera has four valves, a vacuum gauge and an inspection slot with a scale. A set of nozzles is attached to the device for adjusting the sample flow rate to the camera depending on the current velocity. When working with a sampler, the water suction nozzle is placed at the point of sampling, the initial vacuum is created with the pump (depending on the current, the length of the hose and the height of the vacuum chamber above the water surface - determined from the table attached to the device), the sample is sampled and drained. The accuracy of the operation is ensured by a tight connection of the hoses, a good condition of the pump, a possible underestimation of turbidity due to the lack of absorption of large sediment particles that jump past the nozzles.

The OTT sediments sampler (OTT company) is used in foreign practice, it contains a set of 6 bottles with a capacity of 2 dm^3 each, the filling of which is carried out from the water intake nozzle (uncorking and capping of the bottles) from the electric remote control. Measurements can be point or integration, depth 0.2 - 20 m, current velocity 0.3 - 3 m/s.

To determine turbidity, a photometric method is used, which is based on the phenomenon of light attenuation in cloudy water due to its scattering or reflection from sediment particles. Such devices have the common name of **phototurbidimeters**, they record changes in electric current that occurs in a photocell under the action of a light flux in a water surroundings with sediments.

Radioactive isotopes are used in scientific research to measure sediment discharges. For this purpose, a gamma ray source and detector are placed in the river. When gamma rays pass through a layer of water with sediments, their radiation intensity decreases depending on the amount of solid substances (the dependence of radiation intensity on the amount of sediments is set in advance).

The photoelectric method is also used, recording the reduction of the light beam depending on the amount of sediments. To do this, a sensor is placed in the river, which records the weakening of the light beam in the water under the influence of sediments. The oscilloscope records the intensity of the light beam on the photocell of the sensor. The dependence of the concentration of suspended sediments on the amount of reduction of the light beam is set in advance.

The discharges of suspended sediments is measured simultaneously with the measurement of water discharges (the same cross-sections and velocity verticals) by: water sampling (by different methods); determination of sediment content in water; calculation of turbidity values.

When examining suspended sediments, the following types of water samples are taken:

1) turbidity samples to calculate sediments discharges;

2) control single samples to establish the relationship between the turbidity of a single sample and the average turbidity of the river;

3) samples for determining the of suspended sediments size.

The first samples are made at points where current velocities are measured (or at velocity verticals using the integration method).

Control samples are taken to calculate the flow of sediments in the same place of the living area in which individual water samples for turbidity are taken.

On plain rivers at the initial stage of sediment flow study, the number of discharge measurements per year should be at least 20-25, with the most complete coverage of multi-water phases of the hydrological regime. On mountain rivers, such measurements should be brought up to 30-40. Water samples are taken by the following methods: point, total, integration.

The point method - samples are taken at separate points on velocity verticals, varieties: detailed (surface, 0.2h, 0.6h, 0.8h, bottom); the basic (0.2h, 0.8h), shortened (0.6h). If observed plant growing of water body, the sampling is carried out in points of 0.15h; 0.5h; 0.85h or at the point 0.5h (at shallow depths). It is used when the average turbidity is greater than 100 g/m^3, it is accurate and heavy, so it is used in the first year of observations to support the transition to less time-consuming methods of measurements. Each sample is processed separately and further used in calculations. The results are recorded in the KG-5 book.

The total method is used for turbidity up to 50 g/m^3 and consists in combining samples with a volume of 1 dm^3, which are taken at the points 0.2h and 0.8h into one sample for further processing and obtaining the average turbidity on the vertical. If the turbidity is less than 20 g/m^3, it is possible to combine samples from all live cross-section. The volume of point samples should be the same, and the total volume due to low turbidity should be at least

10 dm^3. If sampling was performed by a one-point method and the total volume is less than 10 dm^3, then two samples should be taken at the sampling points instead of one.

The integrated method provides the sampling on each velocity vertical by means of a smooth full-scale movement of the sampler from the surface to the bottom and in the opposite direction. It is used for rapid changes in the water level in order to shorten the measurings time. The result of integrated sampling is the average vertical turbidity. The integration method is used at depths from 1 m to a depth that guarantees incomplete filling of the samplers capacity when it is pulled out of the water.

Mandatory conditions for the integration method should be:

- constancy of the velocity of vertical movement of the sampler;
- incomplete filling of the sampler capacity.

The results of the total and integration methods are recorded in the KG-6 book. Regardless of the methods of sampling, their volume is determined depending on the turbidity of the flow (Table 6.3) in order to ensure proper accuracy (the weight of sediments on the filter should be at least 0.1 g).

A control unit sample of water for turbidity is performed at each measurement of the suspended sediments discharges. This is done in a permanent place of selection of single samples of water using the same tools and means. In the case of noticeable changes in turbidity during the period of water discharges measurement, two turbidity control samples should be performed: at the beginning and at the end of the water discharge measurement. The volume of control samples is determined by the amount of turbidity (Table 6.3). Control unit samples provide the determination of the relationship between the average turbidity of the water in the river and the turbidity of the unit sample and the possibility of calculating the daily suspended sediments discharges. Data on such samples are recorded in the KG-10 book.

Table 6.3 - Dependence of sample volume on turbidity

Amount of turbidity, g/m^3	The samples volume, dm^3
>100	≥ 1
5-100	2
20-50	5
<20	10

The samples for determining the size of suspended sediments are carried out during measurements of water discharges and suspended sediments discharges on all velocity verticals separately from the samples performed for measurements of suspended sediment discharges. If the turbidity is greater than

1000 g/m^3 and its smooth change in width, the number of velocity verticals can be doubled.

The tools and means of selecting samples for the size are the same as above for measuring the of sediments discharges, but unlike the latter, the samples are combined into one total sample along the entire cross section of the stream.

As a rule, tests for determining the size of suspended sediments are carried out in the main phases of the hydrological regime – spring floods, floods, low-water period - at least 4 samples per year.

Calculation of the suspended sediments discharges is carried out analytically or graphically.

The first method has gained more practical application, the second gives more accurate results and is used in the detailed method of measurements. To calculate the suspended sediments discharges, the data of the water discharges measurements and the turbidity values, which are determined based on the results of the analysis of water samples with sediments that are taken into account during the water discharge measurements, are necessary. To calculate the turbidity of the samples, the data of their laboratory testing are used, the turbidity is recorded according to formula 6.1.

The analytical method is implemented by the method of water sample selection.

The point method of selecting turbidity samples is usually associated with the calculation of the average unit discharge of suspended sediments for each velocity vertical. The formulas for determining vertical unit discharge are the same as for determining average velocity's:

- for an open watercourse:

$$\alpha_{mean} = 0.1(\alpha_{sur} + 3\alpha_{0.2} + 3\alpha_{0.6} + 2\alpha_{0.8} + \alpha_{bt}), \tag{6.4}$$

$$\alpha_{mean} = 0.5(\alpha_{0.2} + \alpha_{0.8}), \tag{6.5}$$

$$\alpha_{mean} = \alpha_{0.6}; \tag{6.6}$$

– for a plant growing of watercourse:

$$\alpha_{mean} = \frac{(\alpha_{0.15} + \alpha_{0.5} + \alpha_{0.85})}{3}, \tag{6.7}$$

$$\alpha_{mean} = \alpha_{0.5} \tag{6.8}$$

The subscripts near α indicate the relative depth of the point.

The discharge of suspended sediments is stored according to the formula:

$$R = 0.001(K\alpha_1 w_0 + \frac{\alpha_1 + \alpha_2}{2} w_1 + ... + \frac{\alpha_{n-1} + \alpha_n}{2} w_{n-1} + K_n \alpha_n w_n), \quad (6.9)$$

where $\alpha_1, \alpha_2 ... \alpha_n$ - are the average unit discharges of suspended sediments on velocity verticals, g/(s•m^2);

K - a coefficient that depends on the characteristics of the distribution of velocities near the streams (it is the one that is taken when calculating the water discharge);

w_0, $w_1 ... w_n$ - partial areas of the living cross-section segments, which are determined as well as after calculations of water discharges.

When turbidity samples are selected by total or integration methods along separate verticals, the turbidities of these samples correspond to the average turbidity on the vertical.

The suspended sediments discharges in this case is determined from the expression:

$$R = 0.001(\rho_1 q_0 + \frac{\rho_1 + \rho_2}{2} q_1 + ... + \frac{\rho_{n-1} + \rho_n}{2} q_{n-1} + \rho_n q_n), \quad (6.10)$$

where ρ_1, $\rho_2, ... \rho_n$ - average turbidity on velocity verticals, g/m^3;

q_0, q_n - partial water discharges in coastal sections, m^3/s;

q_1, $q_2, ... q_{n-1}$ - partial water discharges between adjacent verticals, m^3/s (partial water discharges is calculated by calculating the water discharges).

Calculations of the average turbidity of the river are performed according to the formula, which is given in a graphical way.

If the turbidity of the stream is small and it is necessary to pour together water samples from all verticals in the total or integration method, the flow of suspended sediments is stored according to the formula:

$$R = 0,001 \rho_{mean} Q, \quad (6.11)$$

where ρ_{mean}- turbidity of the total sample, g/m^3;

Q - water discharge, m^3/s.

6.3 Measurement of quantitative characteristics of bed loads

The flow of bed loads in plain rivers is no more than 10% of the total amount of sediments. But there is much more bed load in mountain rivers (about 50%).

To measure various characteristics of bed loads, sampling of sediments from the river and their laboratory processing is carried out consistently.

Sampling of sediments is carried out with devices called bottom samplers. The bottom samplers is placed on the bottom and kept for a certain period of time. The bottom samplers catches sediments on the section of the bottom of the cross-section, which in width is equal to the width of the inlet part of the device. Then, after lifting the device, determine the volume, mass of the sample and its granulometric composition.

Taking into account the size of sediment fractions, the bottom samplers are divided into two groups – bottom samplers for small bed loads (sand, gravel) and bottom samplers for large bed loads (gravel, pebbles).

Determining the bed loads discharges with bottom samplers of the first group on the plain rivers gives significant errors. The best results in these conditions are provided by the means of determining the flow of bed loads by the volume of loads in separators and reservoirs and by the displacement of elements of bottom bands.

On mountain rivers with large fractions of bed loads (pebbles, boulders) and high water current velocities, the effect of the device on the transport of sediments is insignificant, which makes it possible to use grid samplers for sample selection, despite the fact that they also need improvement.

The "Don" bottom sampler is used in watercourses with sand and gravel sediments up to 1 cm in size. The weight of the device is 30 kg, it consists of two main parts - a trap and a casing. In the trap is placed a trap with holes for trapping sediments. The exposure time of the device is up to 10 minutes.

Mesh boxes or bags are the main part of bottom samplers for the selection of large fractions on mountain rivers.

Shamov bottom sampler consists of a body, a net box, a rudder and a device for lowering and raising. The device is used with a crane, the current velocity should not exceed 2 m/s.

The GGI bottom grid sampler consists of a 20x20 cm metal frame and a wire grid attached to it. The device is installed on the bottom using a wading rod. The device is not used when the current is more than 2 m/s, there are difficulties in using it on mountain rivers, there is no uniform exposure time at a point, sediments are not completely caught.

The Pi-29 bottom net sampler is designed for the selection of moving particles with a diameter of 5 to 100 mm (there are two nets) from a wading rod up to 6 m long at a current velocity of up to 4 m/s. The bottom sampler consists of a net trap and a crane mounted on a wading rod. The trap - mesh bag and frame - is the working part of the bottom sampler that catches sediment.

Solovyov recorder - records the number of bed loads based on the impact of loose particles on a sensitive photocell. The device consists of a special wading rod, a piezoelectric transducer and a pulse analyzer and can work in remote mode on six channels, representing the number of particles that fall on the wading rod in the appropriate intervals of mass (with a mass from 0.00155 to 0.765 kg and a full velocity 2 m/s). By multiplying the area of the photocell by the impact force of the particles, the device immediately calculates the elementary bed loads discharge.

Measurements of bed load discharges are combined with measurements of water discharges and suspended sediments discharges. Bed load samples are taken on all velocity verticals of the discharge section line. To take samples of bed loads, the bottom sampler is lowered to the bottom and kept there for such a time that at least 50 g of bed loads get into the device (up to 10 minutes).

On each vertical, samples are taken at least three times and necessarily with the same holding time of the bottom sampler to prevent errors. The calculated value is taken as the average value of all measurements.

The bed loads from the catcher are transferred first into a basin, and then into a measuring cylinder (beaker) to determine the volume of the sample. The bed loads sample volume is measured 5-10 minutes after compaction. Then the bed loads samples are air-dried, poured into a separate jar or bag and sent to the laboratory to determine the weight and size of the bed loads.

If bed loads samples consist of large fractions (pebbles, gravel), then the sample volume is not determined.

Calculation of the discharge of bed loads is carried out graphically and analytically. Regardless of the applied method of calculation, first, for each velocity vertical, where samples were taken, the value of the elementary discharge of bed loads is determined according to the formula:

$$g_{bl} = \frac{100P_{bl}}{tl}, \tag{6.12}$$

where P_{bl} - is the weight of bad loads in the sample, g;

t - duration of exposure of the bottom sampler at the point of observation, s;

l - the width of the entrance hole of the bottom sampler, sm.

The total discharge of bed loads is calculated according to the formula:

$$G_{bl} = 0.001\left(\frac{g_1}{2}b_0 + \frac{g_1+g_2}{2}b_1 + \ldots + \frac{g_{n-1}+g_n}{2}b_{n-1} + \frac{g_n}{2}b_n\right), \tag{6.13}$$

where $g_1, g_2, \ldots g_n$ - elementary discharges of bed loads on the corresponding verticals, g/m;

$b_1, b_2 \ldots b_n$- distance between velocity verticals, m;

b_0, b_n is the distance between extreme verticals and water cuts, m.

The graphic method of calculating the discharge of bed loads consists in the fact that the elementary discharges of bed loads calculated by the formula is applied to the drawing of a live section of the river from above from the water surface and based on the obtained points, a plot of the distribution of elementary discharges of bed loads is built along the width of the river.

The area of the plot, determined by the planimeter, is quantitatively equal to the value of the total discharge of bed loads.

6.4 Measurement of quantitative characteristics of bottom sediments

During hydrological, hydrochemical and hydrobiological studies, as well as when studying the deformation of the banks of streams, canals, reservoirs and their siltation, it is necessary to know the composition of bottom sediments.

Bottom sediments in rivers are temporarily non-fluffy sediments that participate in the process of washing and accumulation in the late phases of the regime and lie on the bottom of the river in a layer of a certain thickness. Bottom sediments in lakes and reservoirs participate in the accumulation process and have smaller sediment fractions compared to river sediments.

Bottom sediments play an important role in the formation of water quality, sorption and desorption processes of chemical substances present in water take place intensively on them; in particular, bottom sediments are good indicators of contamination of natural waters with heavy metal compounds.

According to their origin, bottom sediments are divided into mineral (silt, clay, sand, gravel, pebbles) and organic (sapropel), which are part of lake sediments. To study the structure and composition of bottom sediments, bottom soil samples are taken in the corresponding section of the river or reservoir. On hydrometric surveys, samples of bottom sediments are taken simultaneously with samples of suspended sediments and bed loads on all velocity verticals. The study of bottom sediments in reservoirs is mainly carried out according to a special program that provides for the terms and number of sampling. On the stationary hydrological network, samples are carried out on the main discharge section line in the main phases of the water body regime. In hydrotechnical research, the place of sample selection is determined by the specific place of research, everything depends on the set goal. The selected samples should sufficiently characterize the variability of sediment density along the width of the stream. Therefore, at late points, from 5 to 10 samples can be played at the same time. The exception is special studies of bottom sediments, which require a more detailed study of them. The selected samples are sent to the laboratory to determine the granulometric composition (mass of fractions) and, if necessary, their mineral or organic composition.

Devices for sampling bottom sediments are divided into devices for sampling with disturbance and without disturbance of the soil structure. The bottom sediment sampler GR-86, wading rod bottom grab GR-91, bottom grab DCH-0.025 belong to the first group. The bag dredge GR-69 and coring tubes of various designs belong to the second group.

The DCH-0.025 bottom grab is used for the selection of soil samples in a wide range of mechanical composition - from dusty-muddy to gravelly-pebbly.

The numerical part of the model index corresponds to the area of the bottom in m^2, which is captured by the columns of the bottom lifter. Opened and lowered columns are closed with the help of a special tool. This happens after the sample hits the bottom and before the start of ascent. After lifting the dipper to the surface, the sample is removed from it, and the device is washed inside. The weight of the device is 13.2 kg.

The GR-91 wading rod bottom grab is designed for removing muddy and sandy-gravel soils in watercourses with depths of up to 2 m and current velocity of up to 2 m/s, and in stagnant bodies of water - even to greater depths, which is determined by the possibility of lowering the device on the wading rod. The volume of the bucket is 300 cm^3. The device works from a wading rod.

The bottom sediment sampler GR-86is placed in the weight and can work at depths of up to 30 m using cranes and remote devices GR-64 and GR-70. Designed for sampling weakly bound muddy and sandy-gravel soils from the bottom of rivers and canals at a current velocity of up to 2.00 m/s. The volume of the picker bucket is 300 cm^3, the weight of the picker is 43.5 kg.

The dredge is the simplest tool for bottom soil or benthos sampling, consisting of a metal frame and a bag for the collected soil. The metal frame has pointed ends that scrape the soil and bring it into the bag. The dradge is dropped on a cable from the boat and dragged along the boat for some time, then the device is raised, and the sample is removed.

The bag dredge GR-69 is used on reservoirs with muddy, sandy and gravel bottoms. The device is lowered on a wading rod or pole, depth up to 6 m, current up to 1 m/s. The device consists of a measuring cup for sample selection, a weight for its preservation (ensures that the cup is turned over), and a spring for pushing out the sample. The volume of the selection cup is 175 cm^3, the weight of the sample is 3.8 kg.

The Apollov bag dredge is designed for taking samples on sandy and other loose soils along the course of the vessel at great depths. The device consists of a tube with a stabilizer at one end and a sample cup at the other. The device with the cable is thrown, under its own weight it crashes into the soil, when it is lifted, the glass turns over and ensures the integrity of the sample.

The coring tubes are used to taking soil samples from great depths (up to 50 m). They have a length of 1.0 and 1.5 m, a capacity of 1800 and 2700 cm^3, a mass of 13.5 and 19 kg. The tubes are lowered on the cable when the crane is idle, which, under the action of its own weight and falling speed, ensures their entry into the ground. Work with tubes is carried out from the ship.

The ultrasonic method, which allows automatic recording of stratigraphic structure of bottom sediments on the tape, is promising in the research of bottom sediments.

On mountain rivers with a boulder-pebble watercourse, studies of the granulometric composition of bottom sediments are performed to some extent by the photographic method or the method of measurements. To do this, a 5-7 m section is cut out in typical conditional formations (circular sections, islands, deposits, side sections) in the gauge area. When photographing, the specified layout, with decimeter squares, is used.

6.5 The laboratory analysis of sediments and bottom sediments samples

After the selection of samples of deposits and bottom sediments, their initial processing is carried out at the gauge, and later - final processing in the laboratory. When processing samples at the water measuring gauge, the following works are carried out: separation of sediments from water samples (settling, filtering); drying and sending the selected sediments to the laboratory; division of bottom sediments into fractions.

To isolate suspended sediments from water samples, use: automatic filtering; filtering with preliminary settling of sediments; filtering under pressure; settling of sediments in the tube.

Separation of sediments from water samples to determine their size is carried out only by settling.

Automatic filtering is used when the water sample volume is up to 1 dm^3. The bottle with the sample is turned over and installed above the funnel with the filter (Fig. 6.2). A bottle for filtered water is placed under the watering can. The laboratory prepares, numbers and weighs paper filters with a diameter of 11-13 cm, which are sent to the water measuring gauge in advance. With automatic filtering, special cabinets are used, which are also designed for drying filters with sediments and storing equipment and materials needed during filtering. After filtering, the filter with sediments is dried in a watering can in the air, and then it is removed from the watering can and dried in a box, in which the opposite walls are closed only with gauze. The dried filters are stacked with sediments inside, each one is packed in a separate parchment envelope, on which the filter number is written, and sent to a stationary laboratory.

Filtration with preliminary settling of sediments is used for samples with a volume of more than 1 dm^3, they are poured into three-liter bottles or glass jars with a diameter of 10 cm. A label with the number of the sample is pasted on the vessel, then it is placed for settling in a darkened place. The duration of settling depends on the height of the water layer in the vessel, the temperature of the water and the size of the sediment particles. After settling, the clarified water is drained from the vessel using a siphon, and the rest of the sample is poured into a bottle of smaller volume and put on filtration, if the sample was taken to determine turbidity. If the sample was taken to determine the sediment size, the bottle with the sample is sent to the laboratory. Before that, the bottle is tightly closed with a cork and poured from above with paraffin or wax. For preservation, pour a few drops of 10 percent formalin solution into the bottle.

Filtering under pressure is carried out for samples with a volume of up to 6 dm^3 using **the Kuprin filter device GR-60**, which consists of a cylinder with a volume of 1 dm^3, a watering can with a mesh, a pressure gauge, a pump and a rubber hose. Before filtering, the cylinder is opened, a paper filter is placed on the mesh of the watering can, and the cylinder is closed. A sample of water is poured into the cylinder and closed, air is supplied with a pump, under the pressure of which the sample is rapidly filtered. The pressure in the cylinder should not exceed 3 atm. The filtered water flows from the watering can into a clean jar. After the end of filtering, the remaining sediments on the filter are washed from the inner walls of the cylinder. Then the filter is removed, dried, sent to the laboratory.

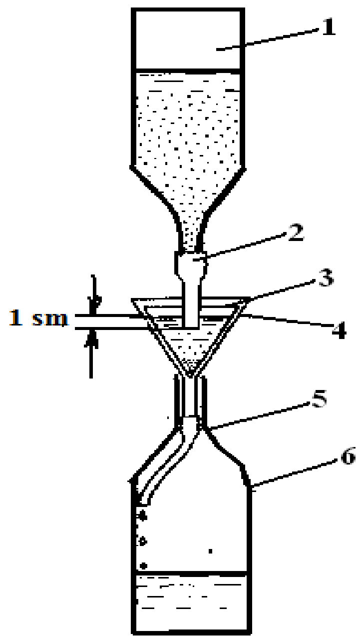


Figure6.2 – Automatic filtering: 1) a bottle with a water sample; 2.5) rubber tip; 3) paper filter; 4) funnel; 6) a bottle for filtered water

The sediments settling in the tube is based on the presence of a relationship between the height of the layer of sediments that settled in the tube during the day and the average value of the turbidity of the sample. The use of this method significantly reduces the volume of work on drying and weighing filters. To do this, each sample taken for turbidity in the premises of the gauge is placed in a machine for sediments settling in a glass tube for 24 hours. A bottle with a cork is fixed on the machine with the neck down, as during automatic filtering, and deposits settle in the tube (Fig. 6.3, a). After a day, the sediments layer is measured with an accuracy of 1 mm. The turbidity of the sample is determined by the graph of the relationship between the sediments layer and turbidity (Fig. 6.3, b).

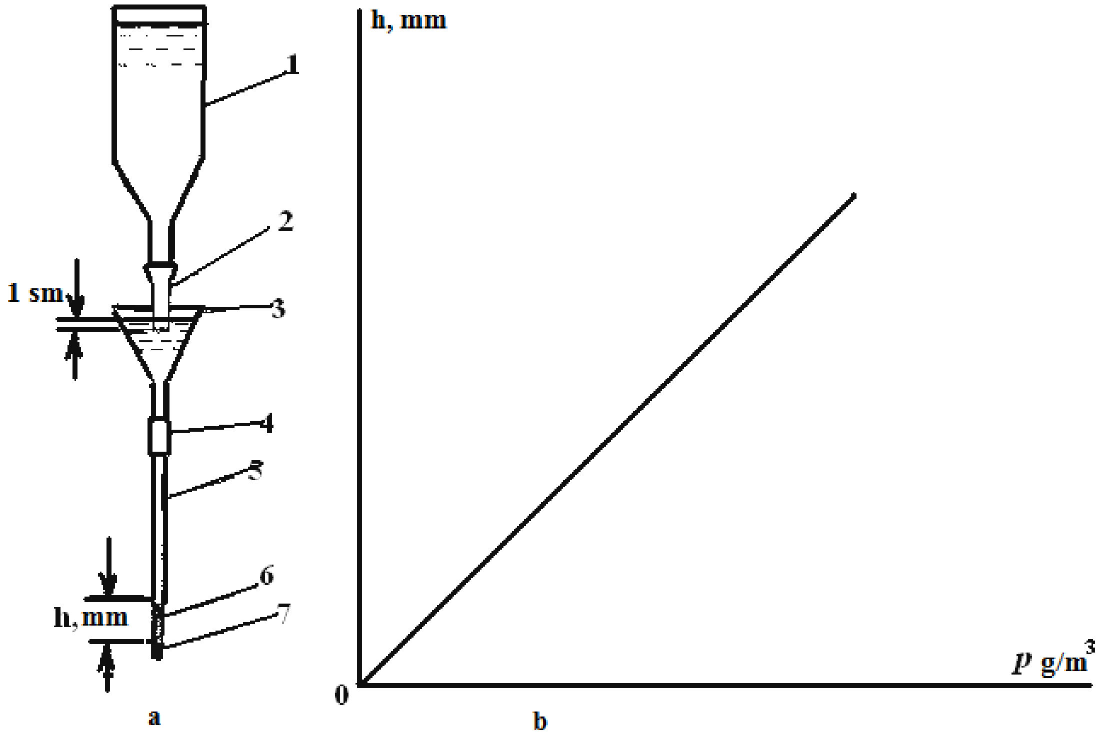


Figure6.3 – Method of daily sediments settling in tubes: a) device for sediments settling (1 – bottle with a cork; 2,4,5 – tubes; 3 – funnel; 6 – layer of sediments, 7 – cork); b) graph of the relationship between the sediments layer and turbidity

Separation of bottom sediments into fractions is carried out by sieving a sample of bottom sediments through mesh's with openings of 10, 20, 50 and 100 mm. As a result, each sample will be divided into the following fractions: larger than 100 mm, 100-50, 50-20, 20-10 and smaller than 10 mm. The largest fractions in the bottom sample are determined by direct measurement. If there are no mesh's on the gauge, the diameter of the soil particles is determined with a caliper or by measuring each particle with a measuring tape (roulette) (in three different directions). The average diameter (mm) is calculated using the expression:

$$d = \frac{A}{3.14}, \qquad (6.14)$$

where A - the average length of a circle in three dimensions.

Calipers with a diameter of 10, 20, 50, 100 mm are made of wire in the form of circles attached to a handle. The soil particles of the sample are divided into fractions according to the caliber and weighed. The determined weight of the fractions is shown as a percentage of the weight of the entire soil sample.

The following works are performed in the stationary laboratory: weighing clean filters; determination of the amount of sediments in the sample; separation of suspended sediments and bottom sediments by particle size; determination of hygroscopic moisture, volumetric weight of bottom sediments; determination of chemical composition (content of organics, heavy metals).

The laboratory must provide water measuring gauges with clean weighted filters, these are circles with a diameter of 11-13 cm made of special ashless paper. Before sending to the water measuring gauge, the filters are numbered with a simple pencil and weighed. For weighing, each filter is placed in a separate already weighed bag and placed in a thermostat for 2-3 hours, where it is kept with the lids open at a temperature of 105-110°. After 2-3 hours, the boxes in the thermostat are closed with lids and transferred to a desiccator for 30-40 minutes to cool to room temperature. Cooled bags with filters are weighed on analytical scales with an accuracy of 0.0001 g. The weight of the filter is determined by the difference between the weight of the bag with the filter and the weight of the bag itself and recorded in a logbook. After weighing, the clean filter is placed in an envelope made of parchment paper and sent to the water measuring gauge.

Filters with sediments sent from the water measuring gauge are dried in a thermostat at a temperature of 105-110° for 5 hours. Then it is cooled in a desiccator and weighed on an analytical balance with an accuracy of 0.0001 g. The weight of sediments in the sample is determined by the difference between the weight of the bag with a filter with sediment and the weight of an empty bag and a clean filter. The weight of the clean filter is found in the logbook by its number.

Methods of determining the size of sediments and bottom sediments are based on mechanical and hydraulic principles. The mechanical principle includes methods of: direct measurement of parts; sieving of particles through screens and mesh’s. The hydraulic principle includes methods: fractionometric; pipette

6.6 Questions for self-control

1. The main elements of solid flow.
2. Features of movement of suspended sediments and bed loads in the stream.
3. Fall diameter and geometric sediment size.
4. The procedure for measuring and calculating discharges of sediments and bed loads.
5. Devices for the study of suspended sediments and bed loads.
6. Research of bottom sediments.
7. Primary processing of sediment samples at the gauge.
8. Processing sediment samples in laboratories.

7 SPECIAL METHODS OF OBSERVATIONS

7.1 General information

Hydrochemical monitoring of the state of water bodies is carried out by specialists of hydrochemical laboratories of the Ukrainian Hydrometeorological Center, hydrology departments of the HMO, hydrological stations and gauges in the presence of a specialist hydrochemist. Observations are carried out on a stationary or expedition basis.

Hydrochemical work is carried out at the water body, in the chemical laboratory of the station and in regional departments of UHMC. To obtain guaranteed accurate indicators of water quality, it is recommended to perform all research in laboratory conditions, with the exception of determining the main physical and chemical indicators of water, which must be immediately analyzed in the field (temperature, color, transparency, taste, smell of water, pH indicator, content of dissolved gases - oxygen, carbon dioxide, hydrogen sulfide, etc.).

Water temperature affects the speed of physicochemical and hydrobiological processes, the solubility of gases in water.

Observations of water temperature are carried out at all hydrological gauges as part of standard water measuring observations every day at 8:00 a.m. and 8:00 p.m., also during expedition research, when water samples are taken for chemical analysis.

The place of temperature measurement is designated in the section-line or nearby, at a flowing place with a depth of 0.3 m, away from the influence of abnormal factors (spring waters, sewage discharges), or its located in the point there is a water sampling are taken for chemical analysis. The temperature can be measured on the surface or at depth, the thermometer is kept at the measurement point for at least 5 minutes.

To measure water temperature, use (Fig. 7.1): a water thermometer in a frame (error 0.1 °C), microthermometers (error 0.01 °C), electric thermometers (error 0.1 °C), mercury thermometers. In addition to measuring the temperature near the surface, they also measure the temperature at different depths, using thermometers built into samplers for this purpose, the temperature is taken with an accuracy of 0.1 °C.

The water turbidity is due to the presence in it of finely dispersed and colloidal substances of inorganic and organic origin - silt, silicic acid, iron and aluminum hydroxides, organic colloids, microorganisms, plankton. During hydrochemical studies, turbidity is determined by the methods of turbidimetry or nephelometry by comparing, respectively, the light absorption or light scattering of the sample with standard SiO_2 suspensions (photocalorimeters, nephelometers are used, calibration graphs are built). Turbidity is determined within 1 day after sampling, the sample must be stored in the dark, for conservation add 1-2 cm^3 of chloroform per 1 dm^3 of water.

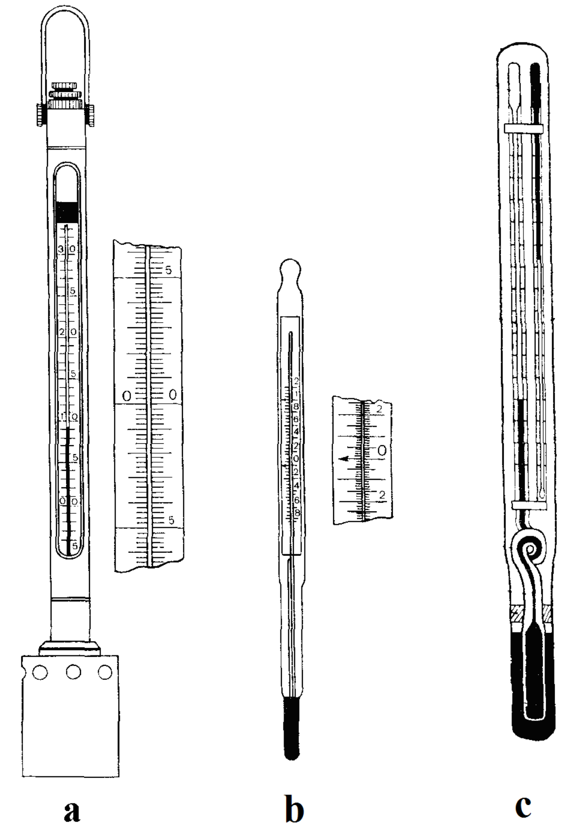


Figure7.1 – Thermometers: a) water thermometer in a frame; b) microthermometer; c) deep-sea inverted thermometer

Water transparency is determined by its color and turbidity. The measure of transparency is the height of the water column, through which you can still see the white color or read a 3.5 mm typeface. The transparency of the water in the field is determined using the Secchi disk (Fig. 7.2) - a white metal circle with a diameter of 300 mm with a weight, through the center of which a bushing with a measuring cable marked with marks passes. Transparency is determined from the shadow side of the boat by slowly lowering the disc into the water and fixing the depth of immersion, which corresponds to the disappearance of the disk's visibility, on a measuring cable. Transparency is redefined when the disk is lifted. To do this, after the first determination of transparency, the disk is lowered another 1-2 m and after 10-15 seconds the measuring cable is slowly selected until the disk appears. The depth is determined when the disk disappears and appears with an accuracy of 0.1 m. The difference in determination after two measurements should not exceed 0.5 m. Otherwise, the observations are repeated.

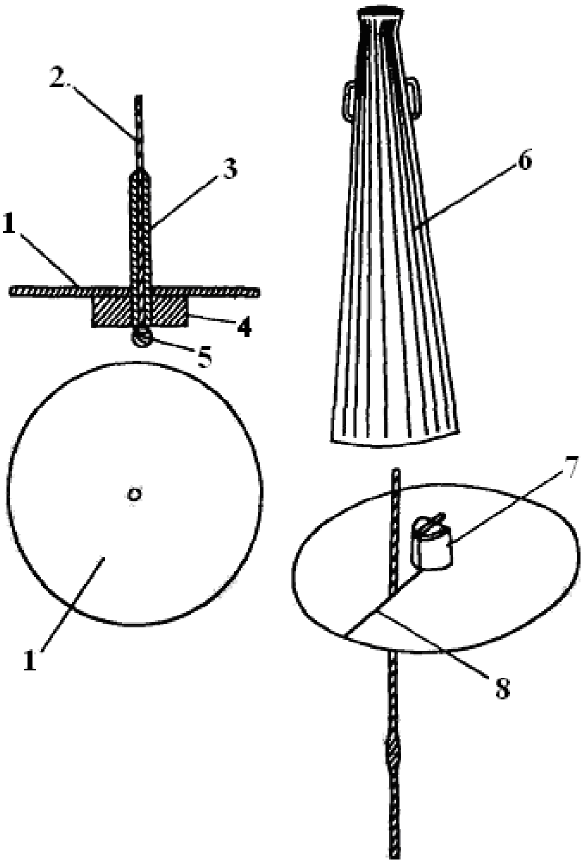


Figure7.2 – Secchi disk for determining water transparency: 1 - disc; 2 - cable; 3 - brass tube; 4 - weight; 5 - node; 6 - tube; 7 - weight; 8 - slot

The color of surface waters is related to the presence of colored humic substances and iron (III) compounds in them. In many cases, the color of water is also caused by the content of microorganisms, silt particles, and colloidal metal sulfides in it. The color is determined in filtered or centrifuged water. The water sample is not preserved, and its color is determined within 2-3 hours after sampling. The color of water is determined according to the standard water color scale, which consists of 21 tubes with numbers. Each test tube is filled with a colored solution, the color range of all solutions represents a gradual transition between the main colors of water in reservoirs - blue, green, brown. The scale is provided with a certificate indicating the time of inspection. In two or three years, colored solutions can become colorless. That is why it is necessary to have two scales when working: one is a working scale, the other is a standard. The reference scale must be protected from exposure to light. Observations of water color are carried out simultaneously with measurements of its transparency. To determine the color of water, a test tube with water is viewed against the background of white paper and the closest color is selected according to the water color scale.

The taste and smell of natural waters are mainly determined in places of their possible industrial and agricultural pollution. The taste is determined only for water that is used for drinking. There are four main categories of taste: salty, sweet, bitter, sour. There are also tastes (alkaline, metallic, etc.) and intensities of taste (no taste, weak, strong). In the records, certain tastes are noted: bitter-salty, salty, iron, etc.; if there is no specific taste, note "No taste". The taste of water is determined by the temperature of the water at the time of its sampling. The intensity of the taste in points varies from 1 (no taste) to 5 (very strong).

There are different types of smell, in particular: spicy, cucumber, violet, chemical, chlorine, herbal, etc. The intensity of the smell in points varies from 1 (no smell) to 5 (very strong).

The pH indicator characterizes the presence of hydrogen ions and hydroxyl ions in water. At pH<7, water has an acidic reaction, >7 – alkaline, and 7 – neutral. In unpolluted natural waters, the pH ranges from 4.5 to 8.3, in the summer period, with intensive photosynthesis of aquatic vegetation, the acidity of the environment changes and the pH rises, while the destruction of organic residues in the water decreases the pH. Acidity is also affected by the content of humic substances and salts that hydrolyze. Also, in polluted waters, certain pollutants also affect the pH of the water.

The pH indicator can be determined potentiometrically (if the water sample has high turbidity and color) or colorimetrically.

Portable pH meters are used for potentiometric determination: pH-150M, pH-47M, etc.

The pH indicator can also be set using **a colorimetric scale** - a set of indicators, 19 reference tubes filled with a solution with a previously known pH value and 2 empty tubes for a water sample. In each reference tube, the solution has its own color. One empty test tube is filled with water breakdown; while stirring, a little bit of the indicator solution is added there and they wait for the color of the sample to change. Then the colors of the sample and the standards of the scale are compared with each other and thus the pH is found. In case of failure, a second empty test tube and another indicator are used to re-find the pH of the sample. The method is less accurate than potentiometry.

There are many methods for determining the **oxygen** content in water, in monitoring practice, titrimetric iodometric (Winkler method) and electrochemical methods are used.

Carbon dioxide CO_2 is contained in natural waters in molecular form and carbonic acid dissociation pwading roducts $H_2CO_3 \rightarrow H^+ + CO_3^{2-}$ in concentrations of 0-4 mg/dm^3 depending on the season. In spring and summer, as a result of photosynthesis and respiration of aquatic organisms, its content is minimal, in winter it is maximal due to the decomposition of organic remains and a decrease in the intensity of hydrobiological processes. At high concentrations of CO_2, water becomes aggressive to concrete due to increased acidity.

To determine the content of CO_2 in water, two methods are used - calculation of the content of CO_2 in water based on the pH value and the concentration of HCO_3^- ions or direct titration with soda. The first method is more reliable and does not depend on the presence of humic acids and salts in the water, the second method is used only for slightly polluted and slightly mineralized waters (up to 1 g/dm^3) with pH <8. If the water sample has high turbidity, CO_2 is not determined.

Carbonate ions CO_3^{2-} are determined by titrating the sample with a solution of hydrochloric acid.

Among the methods for determining small concentrations of **hydrogen sulfide** and sulfides in natural waters, the most sensitive, simple, and specific are photometric. It is also possible to more accurately determine the content of hydrogen sulfide and sulfides by titrating the sample with sodium thiosulfate, iodine, and starch.

The **electrical conductivity of surface waters** is related to the presence of salt components (main ions) in them - Na^+, K^+, Ca^{2+}, Mg^{2+}, HCO_3^-, Cl^-, SO_4^{2-}. The presence of organic matter, iron ions, aluminum, ammonium, nitrates, nitrites, phosphates is not taken into account by electrical conductivity due to their insignificant content. Electrical conductivity is not equal to the amount of mineralization, but only indirectly characterizes its variability. In the laboratory, a water sample is poured into a cylinder, the electwading rodes of the conductometer are immersed in it, an electric current is passed through the solution, and the electrical resistance is measured, which is then converted into specific electrical conductivity ǽ.

7.2 Questions for self-control

1. Determination of water temperature.
2. Determination of water turbidity.
3. Determination of water transparency.
4. Determining the color of water.
5. Determining the taste and smell of water.
6. Determination of pH of water.
7. Determining the taste and smell of water
8. Determination of dissolved gases in water.
9. Determination of electrical conductivity of water.

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Навчальне електронне видання

ЯРОВ Ярослав Сергійович

МЕТОДИ ТА ЗАСОБИ ГІДРОМЕТЕОРОЛОГІЧНИХ ВИМІРЮВАНЬ
(гідрологічні вимірювання)

Конспект лекцій

(англійською мовою)

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