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Arctic Hydrology: History of Shaping, Development and Prospects

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Abstract. The article provides the history of the shaping, development and prospects of scientific division *arctic hydrology* of the State Scientific Centre of the Russian Federation «Arctic and Antarctic Research Institute» other scientific institutes and academic centers of Soviet Union and Russia. The history is divided to 6 stages: description of the lower reaches and mouths of the main rivers, the organization of polar stations in the Arctic (1930-1953); providing Arctic navigation with icing hydrological forecasts on the North Sea route and projects development for the fundamental improvement of navigable conditions in estuarine bars and river ledges (1953-1964); arctic hydrology's contribution in the International Hydrological Decade (1965-1974); hydrological researching to assess the effects of hydropower construction and spatial redistribution of Siberian rivers water resources (1975-1990); arctic hydrology as an abiotic component of Arctic aquatic ecosystems (1991 – 2008); elaboration of the system-wide integrated water management projects development for surface water bodies monitoring of the Arctic (2009 – 2020). Structural and functional analysis of the field studies and engineering, researching and methodological working on division of the arctic hydrology shows, firstly, the contribution of arctic hydrology to hydrological science in general; secondly, their interdependence from states historical stages; thirdly, the contribution of Soviet and Russian experts to the AMAP, IAH, UN and etc. Further development of *arctic hydrology* will undoubtedly be associated with the pooling of knowledge of social and natural sciences concerning water resources to meet the interests of society.

1. Introduction

Historical retrospective of the shaping and development of the scientific direction *arctic hydrology* prospects [1], as regional part of the general hydrology on aqua-territorial region of the arctic physico-geographical complex [2] within competence of "Nature protection. Hydrosphere. Classification of water bodies" [3] is based on the historical structural and functional research method. *Arctic hydrology* includes surface water bodies of the Russian Arctic, comprising estuary areas of large-medium rivers, covering lower rivers and their estuarine swells (lips, bays, limans, lagoons, etc.) – as constituent parts of the water fund and the aqua-territorial complex of coastal zones located in internal surface waters of the Russian Federation. Water-basin principle and hydrographical zoning, which are the basis for the development of a state monitoring modern system of rivers and water resources estuarine regions and the management under water-resources, Water and Land codes and Environmental legislation in the Russian Arctic. Taking into account the boundaries of the Arctic Monitoring and Assessment



Programme (AMAP), monitoring and management systems enable to represent the contribution of *arctic hydrology* to modern information and communication «system of systems» and to reveal its practical significance in the social and economic scientific divisions.

2. Literature review

The history of the general hydrology scientific development in Russia and its final design as an independent science can be studied on the works of the general hydrology founders, as well as the materials of hydrological conventions initiated by leading institutions in Soviet times. Hydrological congresses held at Leningrad showed the expansion of regional hydrology development features: the First Hydrological Congress (7-14.05.1924), held under the Interdepartmental Hydrological Commission of the Russian Hydrological Institute initiative (now called the State Hydrological Institute); the Second All-Union Hydrological Convention (20-27.06.1928), the Third All-Union Hydrological Convention (7-17.10.1957), which was exclusively devoted to problems of the hydrology of the land.

Arctic hydrology's development closely connecting with history of State Hydrological Institute (V. Glushko leading 1919-1930) [5]. The sectorial division of the Hydrological Department of the All-Union Arctic Institute (AAI) was established in 1930 under the initiative of V. Vizé. Later the sectorial division of the Hydrological Department of AAI has become the headquarters of the general hydrology since the beginning of the International Hydrological Decade (1965-1974) and was renamed as a Department of rivers estuaries and Water resources with laboratory structure since 1976.

The main sources describing the development of the direction of *arctic hydrology* can be divided into the following 6 groups: description of the lower reaches and mouths of the main rivers, the organization of polar stations in the Arctic [6], [7], [8]; providing Arctic navigation with icing hydrological forecasts on North Sea route and projects development for the fundamental improvement of navigable conditions in estuarine bars and ledges of Siberian rivers [9], [10], [11]; contribution of arctic hydrology in the International Hydrological Decade [12]; hydrological researching to assess the effects of hydropower construction and spatial redistribution of Siberian rivers water resources [13], [14]; arctic hydrology as an abiotic component of arctic aquatic ecosystems [15]; elaboration of the system-wide integrated water management projects development for surface water bodies monitoring of the Arctic (2009 – 2020) [16].

3. Results and discussion

History of shaping and development of the scientific direction *arctic hydrology*, which showing their prospect in contemporary researching in Polar regions Arctic and Antarctic is devoted article.

The relevance of *arctic hydrology* basics study is related to applied tasks, which are faced by the state – integrated infrastructure establishment; the environmental monitoring system improvement, considering the implementation of advanced technologies available; enhancement of international scientific and technological cooperation, cooperation in the global climate change division, nature conservation and efficient development of natural resources under environmental standards [14].

3.1. First stage. Description of the lower reaches and mouths of the main rivers, the organization of polar stations in the Arctic (1930-1953)

The shaping of the scientific direction on *arctic hydrology and water resources* date back to the All-Russian Arctic Institute (AAI) foundation in 1930. The River Hydrology Sector as well as the Sector of the Sea within Hydrological Research Department of AAI was set up under the initiative of V. Vizé. The staff of the River Hydrology Sector was formed by specialists from the State Hydrological Institute due to its reorganization (hydraulics, hydrological technicians of waterways and ports, hydrological physicists, etc.). Since 1932 under the General Governance of the North Sea Route objective has been hydrological expeditions organization and carrying out the study of the lower reaches and lower estuaries of large Siberian rivers, which enter the Arctic seas, to obtain hydrological navigation and polar stations in these areas. Throughout seven years, from 1932 to 1940, the bottoms

and lower reaches of all the main rivers that drain the Arctic seas from Ob to Kolyma rivers in the East were surveyed. This includes the primary sea and river ports construction and expansion as well as hydrological stations and posts opening in the estuarine regions of the Siberian rivers.

AAI's tasks of the Arctic rivers hydrology were formulated by L.K. Davydov, a Senior Hydrologist, in 1936. These were drawing up an aquatic inventory of the Arctic territories, studying the hydrological regime and the processes of water bodies, composing a monographic description of river objects to exploit their potential resources. In 1938, the Kurey Ice-technic Expedition to Yenisey and Kureyka rivers was launched under the leadership of V.S. Antonov et al.

At the same time, including the Second World War years, assessments of river waters inflow and their impact on the "ice and water" regime at the rivers estuaries, Arctic coastal areas and others were conducted (V.S. Antonov, B.D. Zaikov, M.I. Zotin, etc.). The purpose was to provide scientific and operational navigational forecasts and warnings on North Sea route, in the rivers lower reaches and estuaries of the Laptev Sea and the East Siberian Sea (K.N. Balashov, V.I. Ulitin and N.G. Maslaev). After the Second World War, the division of river hydrology continued expeditionary research on the hydrological navigation aids compilation, developed hydrological stations and posts, developed long-term icing forecasting techniques, primary for the scientific and operational navigation of the estuaries of the Siberian rivers approaching the Northern seaports. Back then, the department was led by A.P. Burdykina and I.Z. Samburenko.

3.2. Second stage. Providing navigation with icing hydrological forecasts on the North Sea route and projects development for the fundamental improvement of navigable conditions at estuarine bars and Siberian Rivers ledges (1953-1964)

A fundamental focus change in the river department (Division 3, the Head was V. Antonov), which was transformed into a Department of the Hydrology of rivers estuaries, began in 1953, followed the subordination of General Governance of the Northern Sea route to the unified Ministry of Maritime and River Navy. At that time, the main tasks were to ensure navigation in ice conditions and to improve the dimensions on inland waterways at the Siberian rivers reaches. The event determining this change was the successful vessels rescue frozen on the waterways of the Lena river basin in the autumn of 1952 (V. Antonov, I. Peschansky, M.Fedorov, A. Burdykina). Under the direction of V.S. Antonov, the division developed a plan of activities to rescue the Lena fleet. It was led by the A-144 expedition, which included the Ictech Laboratory (supervised by I. Peschansky, V. Lavrov) and the A-66 Aerotech Laboratory (A. Gaudis and N. Shakirov). Long-term forecasts of 1-2 months were issued, which made it possible for vessels to be assigned crews for ships to be released promptly on ice-covered routes. These vessels got moved rapidly to the estuaries of small rivers during the period of the ice drift, before the flood falls, and exposed the ships. The Headquarters carried out the operations directly from the aircraft and at the same time, aerological surveillance was carried out. These resources were used to observe the autopsy of the Bykovskaya duct and then to determine the morphometry of the navigable ducts after the ice drift. Besides hydrometric surveys were carried out at the Bykovskaya duct's permeating beams to develop projects for the fundamental improvement of navigational conditions. The Yakutsk Hydrometeorology services supported the rescue of the fleet. This experience was well received and contributed to the expansion of the Department of estuaries hydrology. Besides, exploratory river exploration has become a distinct form of expeditionary, scientific and operational activities of the Institute on inland waterways (expeditions A-113 and A-114 in the river reaches and estuaries of all Arctic rivers).

Between 1954 and 1964, hydrological vessels expeditions have been working on engineering research programs to develop the radical improvement projects of navigation restrictions of Siberian rivers and reaches, involving physical modeling, numerical methods and estuarine process calculations (V. Antonov, M. Fedorov, V. Ivanov, A. Piskun). These activities were accomplished in addition to traditional methods of forecasting and warnings on water routes. Surveying, initiated by the Irtysh Basin Authority in the 1960s in the Ob delta and related to the selection of a rational option and the introduction of specific activities to open a deep path from the Ob Lip through the Yamsal Bar deeper

into the Ob-Irtysh basin, was confirmed by AARI's precautionary calculations with a fundamental interference with nature [18].

The synthesis experience in engineering and hydrological calculations [19,20] was presented at the Third All-Union Hydrological Convention (7–17 October 1957) and was also taken into account in the elaboration of the Union-wide and departmental regulations.

3.3. Third stage. Distribution of arctic hydrology to the International Hydrological Decade (1965-1974)

The International Hydrological Decade (IHD), proclaimed at the 13th session of the General UNESCO Conference in November 1964 with 96 participating countries, was a significant event that identified hydrology as a distinct scientific division with a far-reaching perspective in the science's development [21]. The years of IHD in AARI can be divided into two periods: 1965 to 1971 and 1971 to 1974. At the beginning of IHD (1965-1971), the division's of Hydrology of Estuarine rivers activities were mainly directed towards hydrological studies of Arctic water bodies within the AARI's framework of the IHD program and summarizing the scientific and expeditionary research on estuarine areas in the post-war period under the supervision of V. Antonov, N. Doronin, V. Ivanov, Z. Solovyeva, N.Maslaev, N. Komov, I.Osipov, etc. At this stage, several monographs and scientific summaries were published in AARI scientific publications and other journals. As a result, guidelines for hydrological research and calculating elements of a hydrological regime in the coastal zone of the seas and the estuaries of rivers in engineering studies have been developed [22]. Since 1971, Prof. V. Antonov dedicated himself to organizing and conducting expertise and postgraduate hydrological studies for the rest of his life.

In the second half of IHD (1971 - 1974), the results of the first phase were implemented in integrated projects carried out by the Institute for seas and estuarine regions of the Arctic Ocean (AO) under the scientific supervision of an academician A. Treshnikov, a Director of AARI. Since 1971, V. Ivanov has taken over the Department of Hydrology of Estuarine rivers leading with the assignment of responsibility for the IHD's AARI projects completion. Consequences of the AARI's head unit activities were the following: standardization of estuary zoning; basic principles of hydrological-morphological zoning of rivers estuaries in the Arctic; «Water of the land» section execution in the Arctic Atlas, which included the studied run-off maps, average annual and intra-annual flow distribution over the catchment area of the Arctic Ocean (N. Doronina, V. Ivanov); "the Arctic" section monography preparation for publication [23] and Atlas of «World Water Balance and Water Resources of the Earth» [24] with the following organizations - State Hydrological Institute (A. Sokolov, K. Voskresensky, N. Alyushinskaya, O. Drozdov), State Geophysical observatory (V. Sharova, L. Zubenok), Leningrad Institute of Water Transport (K. Grishanin, V.Makaveyev, V.Lyakhnitsky).

The research on the World Water Balance and Arctic Water Resources carried out at the Institute in the period of IHD led to the reorganization of the Department of the Hydrology of River Estuary into a Department of the Hydrology of Estuaries and Water resources with a laboratory structure in 1976.

At the Fourth All-Union Hydrological Convention, held in 1973, *the estuarine of large rivers* were recognized for the first time as *a separate object of study*, together with lakes and reservoirs [25]. Besides, the work carried out at the Institute during the IHD period contributed to the reorganization of the Department of Hydrology of Estuarine rivers into the Department of Hydrology of Estuarine rivers and Water Resources with a laboratory-group structure. Thus the estuarine areas of Russian rivers, including the Arctic region, have been strengthened; at the same time, a new direction in the estuarine hydrology of rivers was established – *water resources*.

3.4. Fourth stage. Hydrological researching to assess the effects of hydropower construction and spatial redistribution of Siberian rivers water resources (1975-1990)

Since 1976, the direction of the Department of Hydrology of Estuarine rivers and Water Resources, the main unit of the institute, has been fully subordinated to the tasks of hydro-technical construction

and territorial flow redistribution on the Arctic seas estuarine regions. Many departments of the Institute were involved in this work under the scientific supervision of A.F. Treshnikov and the responsible executor of V.V. Ivanov [26, 27]. To support this work, expeditions A-68, A-117, A-118, subsequently renamed as Ob-Yenisey estuary expedition, operated together. In 1986, at the Fifth All-Union Hydrological Convention, the *estuarine rivers regions* were finally recognized as separate *surface water bodies* [28] along with lakes and reservoirs due to water transport development on Siberian and the Far East rivers, transportation of combined navigation vessels of the «river-sea» type and extension of guaranteed navigation on large rivers.

A makeable event of this period was the USSR State award in 1981 to V. Ivanov, in a member of the Hydrographic Institute and the Hydrographic Society for the completion of the International Hydrological Decade's projects on the world water balance; another Award of the State Prize in the field of science and technology of the USSR went to A. Balabaev and N.Komov for ice-scouting instrumentalities on Siberian rivers.

Throughout this period, the programs were co-organized by the Institute of Water Problems of Academy of Science (G.Voropaev, S. Vendrov, V. Debolsky), the Leningrad Polytechnic Institute (M. Mikhalev), Moscow State University (V. Mikhailov), the Leningrad Meteorological Institute (Yu. Doronin), State Institute of Oceanography (S. Baidin), Hydrographical Institute (V.Vuglinsky) [29], [30], [31], [32], [33], [34].

The international activity of the *arctic hydrology* division was strengthened in 1985 due to participation in the Arctic Monitoring Assessment Program (AMAP), in the National Committee of the International Association for Hydrological Research (IAHR).

3.5. Fifth stage. Arctic hydrology as an abiotic component of Arctic aquatic ecosystems (1991 – 2008)

Since 1991, *arctic hydrology* has been supplemented by a new direction – *Ecology* when implementing a scientific and technical program, in which many other subdivisions of the institute have taken part with their research subjects (geography, medicine, oceanology, etc.). In the period of the AARI performance until 1992, the scientific activities of the Department of Hydrology of Estuarine rivers and Water Resources under the leadership of V. Ivanov were expanded to a scientific generalization of Siberian rivers estuarine regions study and development of icing and hydrological long-term forecasting methods, calculation and modeling for navigation purposes (V.Antonov, Z. Solovyeva, A. Piskun, T. Vinogradova, M.Tretyakov etc.) [35].

In 1999 – 2000, the department undertook a competitive project «Integrated studies of anthropogenic and natural changes of ecological systems abiotic components of sea-river estuaries in Russia» (leading by V. Ivanov) with the participation of State Institute of Oceanography on southern seas estuarine regions (V.Brysgalo, Z. Solovyeva, V. Makeev, O. Medkova, etc.). In 2005, due to operational activities reorganization, the Ice and Hydrological Forecasting Laboratory was transferred to the Informational Centre of Ice hydrometeorology of AARI together with the responsibility for issuing operational forecasts regarding the estuarine regions of rivers opening and freezing. Until 2008, the department worked on realization of the state scientific and technical target programs of Roshydromet - «Integrated oceans and seas investigation» et al. (V. Ivanov, V. Zamyatin, A. Piskun, A. Bozhkov, V. Zimichev, M.Tretyakov, etc.). Since 2000, the department has been carrying out expeditionary activities to study surface water objects in the Svalbard and North Zemlya archipelagos.

Projects co-executors were the Leningrad Polytechnic Institute (M. Mikhalev), State Chemical Institute (A.Nikanorov, V. Bryzgalo), Zoological Institute (V. Khlebovich).

3.6. Six stage. Elaboration of the system-wide integrated water management projects development for surface water bodies monitoring of the Arctic (2009 – 2020)

Since 2007, the current focus research of Department of Hydrology of Estuarine rivers and Water Resources, as well as Roshydromet regarding hydrology, is determined by the Government of Russian Federation resolutions and orders of Roshydromet after the introduction of the new Water Code of the

Russian Federation (2006) and based on it Water Strategy on 2009-2020, approved by the Government of Russian Federation in 2008. Since 2011, the department is headed by M.V. Tretyakov [36,37].

The Department of Hydrology of Estuarine rivers and Water Resources of AARI is moving on to the complex system development of water management projects for monitoring water bodies based on the water-basin principle, hydrographic zoning of estuarine regions and rivers regions.

In 2012-2014, the department performed scientific activities within the Federal target programs (FCP) framework of «Water management complex development of the Russian Federation in 2012-2020», «Improvement of methods and technologies of hydrological forecasts formation at the bottom and reaches of large rivers in the Russian Arctic zone», «System projects design of hydrological network development and modernization for river basins of the Russian Federation», «Modern and prospective assessment of water resources and water supply in the Russian Federation», «Methods development for accounting and predicting the characteristics of the terrestrial water bodies hydrological regime, under consideration of climate change and anthropogenic load, for the hydrological justification of the design, construction and operation of the country's water management complex and reduction of negative and harmful effects of waters» (M.Tretyakov, V.Ivanov, A.Piskun, R.Terekhova, E.Rumyantseva, O.Golovanov, O.Muzhdaba, etc.).

Since the times of division establishment of the AARI since the 1940s has been conducting a postgraduate study in the competitions of «hydrology and water resources» and «oceanography», including specialization in the study of arctic rivers estuarine regions. More than 20 postgraduate students from various institutions in Leningrad have graduated from these studies over the years and continued their work in AARI, Murmansk Branch, Arctic Hydrometeorological Service and other institutes. The staff of the department has been carrying out pedagogical work since the establishment of the AARI postgraduate study of hydrology and water resources (heads of V.Antonov, V.Ivanov) and conducted courses on hydrosphere, hydrology and water resources at Saint Petersburg State University (SPBU), State Polar Academy (SPA), and Russian State Hydrometeorological University (RSHU).

As a result of the activity of the Department of Hydrology estuarine rivers and Water resources in AARI, the direction for the study of patterns formation and assessment of water resources in the Arctic and the scientific school «Arctic hydrology» was formed. The area of division activity from the foundation to the current date covers the estuarine region of the large and medium rivers located in the terrestrial waters of the Russian Arctic within the Arctic zone of the Russian Federation, as shown at Fig. 1.

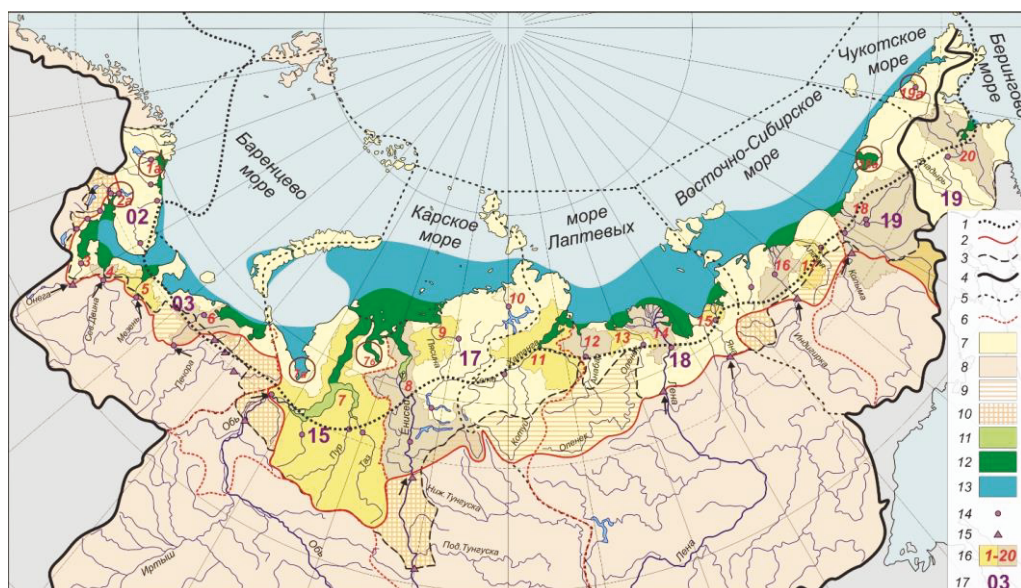


Figure 1. Estuarine regions of large and medium rivers located inland waters of the Russian Arctic (RFA) [38]

Borders are as follows:

1 – physical geographical (1985); 2 – water resource (1990) (aquatic ecological (2007), hydrographic (2016)) of the Russian Arctic; 3 – administrative territories of the Arctic zone of the Russian Federation (2014); 4 – reservoir basin of the Arctic Ocean; 5 – sea basin catchments; 6 – catchments of water basins.

Reservoir basins are as follows:

7 – rivers of the Russian Federation Arctic zone within boundaries of administrative territories; 8 – rivers outside the Arctic zone of the Russian Federation; 9 – Arctic rivers within the water resource (hydrographic) boundary of the Russian Arctic zone; 10 – rivers of the Arctic beyond the water resource (hydrographic) boundary of the Russian Arctic zone.

Zones are as follows:

11 – year-round freshwater; 12 – freshwater at maximum flow and saline at minimum flow; 13 – distribution of river waters in the seas.

Main-stream stations are as follows:

14 – closing main-stream hydrometrical station on main rivers;

15 – frontier main-stream hydrometrical station on the water resource (hydrographic) boundary of the Russian Arctic zone;

16 – the estuarine area number of large and medium (the number with index in the circle) rivers (1 – Kolsko-Tulomskaya; 2a – Kandalakshskaya; 3 – Onezhskaya; 4 – North Dvina; 5 – Mezen and Kuloya; 6 – Pechorskaya; 7 – Obsko-Tasovskaya; 7a – Baidaratskaya; 7b – Gydanskaya; 8 – Yeniseyskaya; 9 – Pyasinskaya; 10 – Nizne-Taimyrskaya; 11 – Khatangskaya; 12 – Anabarskaya; 13 – Olenekskaya; 14 – Lenskaya; 15 – Yanskaya; 16 – Indigirskaya; 17 – Alazeyskaya; 18 – Kolymskaya; 18a – Chaunskaya; 19a – Amguyemskaya; – 20 – Anadyrskaya).

17 – water basin district number by Water code (02 - Barents-Belomorsky; 03 - Dvinsko-Pechorsky; 15 - Nizhneobsky; 17 - Yeniseisky; 18 - Lensky; 19 - Anadyro-Kolymsky).

4. Conclusion

Prospects of *arctic hydrology* in the coming years relate to scientific research development on the methods and technologies design for operational hydrological forecasts, research of the water balance and water resources, the surface waters monitoring in the Arctic, including estuarine areas of large rivers and water bodies in scientific inpatient facilities of AARI and their changes under the influence of natural and anthropogenic factors [39,40], including the development and improvement of methods and technologies for their diagnosis, calculation and forecasting, as well as continuing to participate in international expert work [41,42]. The next tasks of *arctic hydrology* will undoubtedly be the fulfillment of state monitoring of the Arctic water resources, their protection and rational use, combining knowledge of social and natural sciences concerning water resources to satisfy the interests of society.

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