# ACTUAL PROBLEMS OF REGULATION OF THE HIGH FLOW DURING THE CONTROL OF WATER RESOURCES OF RESERVOIRS OF HYDROELECTRIC POWER STATION

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The high flow of the reservoir is determined by admission of possible floods. Analytic maximal discharges of the inflow in the reservoir are defined by statistic parameters of the high flow that are determined during the period of observation before the beginning of the exploitation of the waterworks facility [1].

The largest waterworks facilities in Russia have been constructed on the rivers of Siberia and the Far East in 70-s – 80-s. That is why it is very important to know how parameters of the high flow have been changed and possible values of the high flow, taking into account a long period of its exploitation. This corresponds to the decision of the Third All-Russian Conference of Hydropower Engineers that took place on September 11, 2007, about realization of such work on all operative hydroelectric power stations aiming the trouble-free admitting of maximal discharges of floods, as well as the federal law of the safety of hydraulic engineering structures.

The flow observations at the operative hydroelectric power stations of Siberia and the Far East (Sayano-Shushenskaya hydroelectric power station on the Yenisei, Kolymskaya power station on the Kolyma, Vilyuiskaya power station on the Vilyui and Bureyskaya power station on the Bureya) were carried out. The parameters of the high flow for the period of time before starting the first unit, the operation period and for the whole observation period (natural and restored) were calculated at the department of land hydrology of the Russian State Hydrometeorological University in 2007. The parameters of the high flow at the Bureyskaya hydroelectric power station were calculated for the period before the technical project ratification, the period during 1983 – 2001 and the whole observation period. The parameters of the hydroelectric power stations are given in Table 1.

Research materials were provided by the department of hydrology of Lenhydroproject. Calculation of the high flood discharges for Sayano-Shushenskaya power station during its operations from 1979 to 2006 was performed at the department of land hydrology of Russian State Hydrometeorological University.

Table 1. Power Station Characteristics

| Power Station | River | Average long-term volume, $km^3$ | Available storage, $km^3$ | Flowregulation type | First unit launch |
|---|---|---|---|---|---|
| Kolymskaya | Kolyma | 13,9 | 7,24 | long-tem | 1981 |
| Sayano-Shushenskaya | Yenisei | 46,7 | 15,3 | annual | 1978 |
| Vilyuiskaya | Vilyui | 20,5 | 22,4 | long-tem | 1967 |
| Bureyskaya | Bureya | 27,3 | 10,7 | annual | 2003 |

The results of statistical analysis of the data on the high flow in Kolymskaya, Sayano-Shushenskaya and Vilyuiskaya power stations and the maximal water discharges during the spring high-water period in Bureyskaya waterworks facility are presented in Table 2.

Table 2. Results of statistical analysis of data on the high flow

| Power Station | Period | Statistical parameters | | | $Q_{0.01\%}$ | Change, $Q_{max}$ | |
|---|---|---|---|---|---|---|---|
| | | $Q_{max}$ | $C_v$ | $C_s/C_v$ | | Max | Min |
| Kolymskaya | 1934-1980 | 3630 | 0,49 | 3,0 | 21100 | 8500 | 1110 |
| | 1981-2000 | 3950 | 0,36 | 3,0 | 16500 | 6180 | 1870 |
| | 1934-2000 | 3730 | 0,44 | 3,0 | 18300 | 8500 | 1110 |
| Sayano-Shushenskaya | 1908-1978 | 6940 | 0,29 | 4,0 | 23600 | 13700 | 3860 |
| | 1979-2006 | 5680 | 0,30 | 4,0 | 22200 | 9000 | 3000 |
| | 1908-2006 | 6620 | 0,30 | 3,0 | 20800 | 13700 | 3000 |
| Vilyuiskaya | 1926-1966 | 6600 | 0,31 | 2,0 | 18700 | 12600 | 3740 |
| | 1967-2002 | 8700 | 0,28 | 4,0 | 30400 | 16800 | 6950 |
| | 1926-2002 | 7570 | 0,32 | 3,0 | 24980 | 16800 | 3740 |
| Bureyskaya | 1937-1982 | 7920 | 0,32 | 3,0 | 27700 | 14900 | 2660 |
| | 1983-2001 | 6930 | 0,24 | 2,0 | 16600 | 9840 | 4070 |
| | 1937-2001 | 7630 | 0,30 | 3,0 | 24900 | 14900 | 2660 |

The analysis of the table's data shows that the high flow on points of observation of Sayano-Sushenskaya hydroelectric power station during the period of exploitation (1979 – 2006) reduced on 18% relative to the norm, staying close to it during the whole monitoring period (1908 – 2006). On Kolymskaya power station the maximal flood flow increase a little relative to the norm, staying close to it during the whole period. While the maximal flood flow in Bureyskaya power station decreased to a certain degree from 1983 to 2001, on the whole the maximal flood flow in 1937 – 2001 was close to the norm.

As for Vilyuiskaya power station, results there are not so good. The maximal flood flow during the exploitation period (1967 – 2002) increase almost on 30% relative to the norm. The mean discharge for the whole period (1926 – 2002) reached 8700 m3/s, which exceeds the norm for the period of 1926 – 1966 by 2100 $m^3/s$. During this period was also exceeded the historical maximum of 1890. Such a sudden increasing of the flow caused growing of the maximal flood flow with possibility of exceeding 0,01%

with guarantee correction 18700 $m^3$/s into the project, up to 21600 $m^3$/s taking into account the runoff in last years.

The calculations show that in order to manage the high flow exceeding the high flow used for project design, which has the probability of 0.01% with a guarantee correction and without exceeding the set full supply level of 249.0 m it is necessary to decrease the reservoir storage from the level of 241.2 m to the level of 239.0 m, i.e. by 2.2 m or by 4 km3. It is impossible to do the pre-flood storage decrease of the reservoir in April when the Vilyui is covered with ice.

An increase in reservoir discharges up to 1500 – 1600 $m^3$/s can result in an artificial ice drift leading to a winter flood. The least dangerous means to handle the problem is to decrease the affluent level – 246.0 m and the pre-flood reservoir level – 241.2 m by 2.0 m. The final solution of this problem requires additional research. A longer observation period is needed to confirm the assumption on the trends in changes of the maximal high flow. As research by V. A. Lobanov and A. V. Rozhdestvensky show that the longer the observation series are, the higher the probability of extreme events is [2].

The second problem along with the hydrological one is the problem of electrical drain during the period of floods. The useful value of the reservoir or its season part is filled with inflow excesses over discharges of the total plant output. The control scheme is developed starting from this same as opening levels of spillway are determined.

However, as it was in 2006 and 2007 Zeyskaya hydroelectric power station, because of absence of a power-consuming consumer and impossibility of thermal stations discharge, during the exploitation of the waterworks facility the demands of a hydroelectric power station in the period of floods reduce up to 50-60% reduction of the total capacity of a hydroelectric power station. This results in fast infill of the reservoir up to control opening levels with following filling of tail-bay objects.

One can think that it is possible to increase the discharge of the hydroelectric power station from 700 – 800 $m^3$/s to 1300 $m^3$/s, which is prescribed by the rules, by the spillway. However technically the opening of the spillway is only possible after the destruction of the ice-cover of the river, i.e. in the early June.

Data of filling of Zeyskaya reservoir and aggregate reservoir discharges (real and estimated in compliance with Operation Regulations) is given in Table 3.

Table 3. Reservoir filling and aggregate reservoir discharges of Zeyskaya reservoir

| Period, date, t | Characteristics | | | | |
|---|---|---|---|---|---|
| | $Q_{inflow}$ | $Q_{real}$ | $Q_{est}$ | $Z_{real}$ | $Z_{est}$ |
| summer 2006 | | | | | |
| V | 1840 | 767 | 990 | 311,68 | 311,68 |
| VI | 1812 | 714 | 700 | 312,78 | 312,78 |
| VII | 1724 | 688 | 700 | 313,85 | 313,85 |
| VIII | 2747 | 858 | 1145 | 315,03 | 315,03 |
| IX 1-10 | 2640 | 2314 | 1300 | 317,06 | 317,06 |
| IX 11 | 2800 | 2791 | 1300 | 317,41 | 317,41 |
| IX 12-30 | 1809 | 2220 | 1300 | 317,42 | 317,42 |
| X | 556,9 | 1349 | 1300 | 317,11 | 317,11 |
| XI | 79,2 | - | - | 316,20 | 316,20 |
| summer 2007 | | | | | |
| V | 1964 | 736 | 736 | 312,24 | 312,24 |
| VI | 2676 | 1300 | 1300 | 313,63 | 313,63 |
| VII 1-18 | 5050 | 1470 | 1300 | 315,50 | 315,50 |
| VII 19 | 15200 | 2713 | 1300 | 317,70 | 317,70 |
| VII 20-24 | 8360 | 4173 | 1300 | 318,10 | 318,10 |
| VII 25 | 3500 | 4844 | 3500 | 318,70 | 318,70 |
| VII 26-31 | 3137 | 4669 | 3080 | 318,60 | 318,60 |

Table abbreviations. Qinflow – average inflow during t, $m^3$/s, Qreal и Qest – real and estimated aggregate reservoir discharges, $m_3$/s, Zreal и Zest – the levels of the reservoir at the beginning of t, real and estimated, respectively, m.

In 2006, the overflow spillway was opened on September 1 at the reservoir level of 317.06 m, and it was closed on October 24 at the level of 316.36 m. In 2007, the overflow spillway was in fact opened on June 1 at the reservoir level of 313.63 m, and according to the estimates – on July 25 at the level of 317.6 m.

The analysis of Table 3 shows that it was possible to avoid the tail-bay objects flooding in summers of 2006 and 2007 if the decrease of storage had been carried out

to 310 m level by May 1 and if the reservoir had been filled
with inflow excesses over discharges of the total output equal to 1300 $m^3/s$, versus real 700 – 800 $m^3/s$.

Safety of hydraulic structures and tail-bay objects needs more precise definition of the high flow parameters during the waterworks facility exploitation and also more precise definition of the control scheme taking into account current electrical drain.

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**NOAH, THE RIGHT INFORMATION AT THE RIGHT TIME AT THE RIGHT PLACE**

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**BACKGROUND**

Along the North West European rivers many organizations are responsible for water management issues. In general, high water management consists of different stages, with different actions and responsibilities involved. In all Western European countries, the same type of hierarchical structure for water management exists. Appointed authorities for water management, such as water boards or municipalities, are in charge during times of normal water levels. They are responsible for day-to-day maintenance of flood defences, for planning and preparation of flood scenarios and measures. During a period of rising water levels, these authorities remain primarily responsible. At the critical level the local authorities take over (part of) the responsibility.

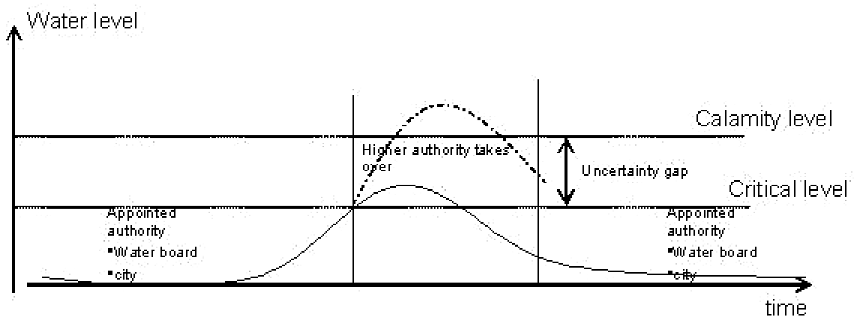


Figure 1: responsibilities during high water event

Decisions whether or not to take action during flood events are made on the basis of the available information. This means that such information has to be as reliable as possible and tailored for the separate fields of flood defence management and emergency management.

Recent flood events and high water periods in different North West European river catchments (e.g. Rhine, Elbe, Scheldt, Maas) and in Central and Eastern Europe

(Switzerland, Austria, Hungary, Romania and Bulgaria) have emphasized that it is very important that measures and actions are taken at the right place and at the right moment. The "von Kirchbach-report" on the floods of the Elbe in 2002 shows that information was available but did not get to the right place, or not in a useful form. We also learned that a large amount of information is exchanged, both within and between organizations and with the general public and media. As a result of stress and complexity during emergency situations, this information flow is often uncontrolled, not on time or unreliable, thus raising feelings of uncertainty at decision maker level and with the threatened public.

Decisions are made based on information on actual or forecast water levels and the status of the flood defences. Unreliable information means that actions may be taken unnecessarily, resulting in avoidable risks and damages. Although an actual disaster may not occur, the impact and costs can still be considerable, not to mention the 'blame game' between the involved governmental organizations after the event and, very important, the loss of trust of the general public in their water managers.

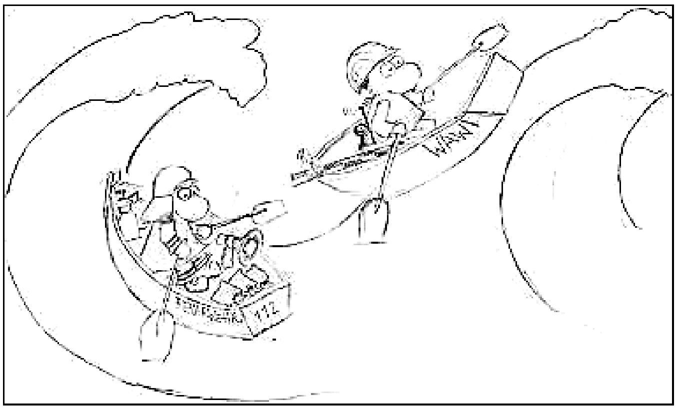

figure 2: separated organizations

**NOAH**

Information transfer is identified as a key factor in modern and dynamic water management. And the human factor in operational flood management constitutes a significant risk regarding effective information transfer. It is acknowledged that the use of automated tools for operational flood management such as forecasting and warning, but also for action monitoring, communication and post event evaluation can reduce this risk. By using computers for what they are good at (storing information, handling predefined procedures), humans can focus on what they are better at: dealing with unexpected developments and making decisions based on incomparable criteria and data. Therefore, automation of information management can lead to a significant increase of safety and reduction of damage and personal risks caused by flooding.

Within the EU-Interreg funded project NOAH, partners from the Netherlands, Germany and Ireland joined forces to develop and implement such an automated tool and to increase public awareness of the advantages and dangers of water in the neighborhood. The main objective of the project is to cope with information demands and to make information available in a fast and unambiguous way during high water events. The project addresses the information and communication issues encountered in actual high water situations and will bridge the uncertainty gap between early warning systems and emergency plans.

Information management will be supported by development and application of a new, innovative and generic information system called FLIWAS (FLood Information and Warning System), designed for use in a multi actor environment. FLIWAS will be available and accessible for all key players, focused on short notice dynamic actions and reduction of uncertainties in flood management.

The second key objective of the NOAH-project is the development of Flood Partnerships between governmental organisations, general public and other relevant parties involved. The goal of these partnerships is to involve all parties on the issues of high water management and by doing so to create awareness of the profits and disadvantages of water in the neighbourhood. By making available and using additional information on flood risks, the required and desired protection level of inhabitants and companies in high-risk areas can be determined and communicated. The much needed awareness of the risk of flooding will be created and/or increased.

**Development of FLIWAS**

The concept of FLIWAS was developed in close cooperation with the end users. During workshop sessions users from the project regions were invited to state their wishes and demands. This resulted in a joint development of the overall functional design for FLIWAS. FLIWAS builds upon existing flood forecasting systems, geo-info, alert plans, flood risk maps and disaster scenarios. Basic design principles were derived from systems already under construction in Germany (Hochwasser-informationssystem zur Gefahrenabwehr and HoWISS) and the Netherlands (Geautomatiseerd Draaiboek Hoogwater). After an intensive coordination effort with other ongoing projects, NOAH was able to incorporate other initiatives as well, such as the Dutch High Water Information System (HIS), which is and was being developed by Rijkswaterstaat/DWW (part of the Dutch Ministry of Transport and Public Works). Close cooperation with the VIKING program (Province of Gelderland

and Nord-Rhein Westphalia) ensures that the communication to the emergency management organizations (police, fire-brigades) is optimized.

All relevant information of these building blocks are bundled and made available through an internet-oriented GIS based application. This are structured in such a way that decision makers, water managers and emergency services professionals as well as the public will receive all relevant information, optimized for their needs, accessible at their level. The modular design of the information system enables the user to install only the needed functionality. FLIWAS will be based on

Some specific functionality of FLIWAS:

- Monitoring the high water situation on the river using available measurement information and forecasts. This information will be used to initialize actions to protect areas from flooding.
- High Water Protection (for structures and embankments). Setting up scenarios and action plans for structures and embankments to protect areas and towns against flooding. Initializing and monitoring actions based on warning stages and direct communication to all involved staff.
- 2D flood modeling. Real time calculation of flood scenarios in endangered areas. In NOAH a prototype area along the upper Rhine River is modeled (figure 3). As a result, flood maps and scenarios of the upper Rhine River between Iffezheim and Mannheim are available. The experience gained during the building of this real time-model can be used in other regions.

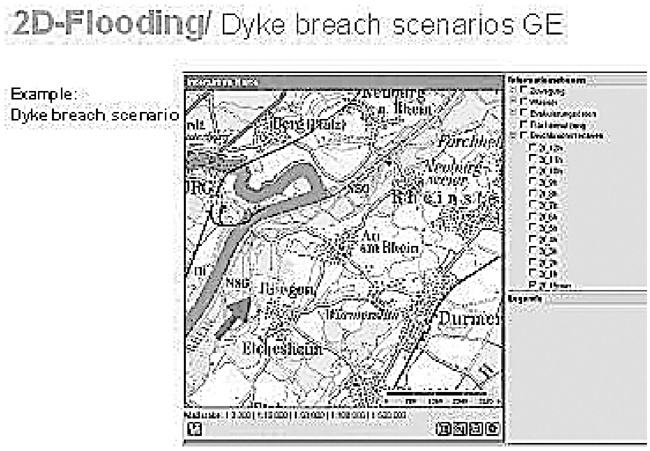


Figure 3: flood scenarario

- Evacuation. Designing of evacuation plans in advance and assisting during the execution during emergency situations, using results of the 2D-flood model, data of geographic maps, population distribution and infrastructure. A decision about evacuation can be taken based on signals from the High Water Protection-model.

General features of the system are its ability to communicate automatically with key staff, its ‘watchdog’ function to manage execution of actions and its logging module. FLIWAS is multi-lingual (English, Dutch, German) and represents the state-of-the–art in management and decision support systems for operational flood management. It will enable water managers in crisis situations to decide on the basis of real time and reliable data, thus reducing the uncertainty gap. This will help solving the question of responsibilities, which rises during emergency situations.

A first version of FLIWAS has been delivered in Autumn 2007. A second release with additional functionality will be delivered in Spring 2008.

**Use of FLIWAS**

FLIWAS is a generic system. The input to FLIWAS customizes the system to the organization that uses it. FLIWAS enables organizations to implement their own contingency plans and basic data on one hand and to structure the information and initiate actions during events on the other hand. In management mode FLIWAS will be used to import contingency plans and data, to test contingency plans and to evaluate previous events. Appointed users will define high water stages or threshold levels, determine actions needed for those stages and link actions to responsible persons. The way actions are initiated and communicated (e.g. by phone, fax, e-mail or sms) is also determined.

During the high water season or during a high water event the system is switched to operational mode. Information such as telemetry data and forecasts of water levels or rainfall are used to determine the phase in which a monitored object is, related to threshold values set by the administrator of the system. If a threshold is exceeded, the system will inform the user and suggest going to the next stage. If the user decides to accept this advice, the system will initialize actions predefined for this stage. The system will then monitor progress and log the actions on completion. Each user has restricted rights and will only have access to the functionality and information that is relevant to him/her. As the system allows data import during high water events, it will always display the latest status of the situation on the ground. Ad hoc actions may be imported too. For decision makers this kind of reliable information is very important; it helps them to decide on the actual safety situation. In

its operational mode FLIWAS runs on one or more web servers. On client PCs and palmtops FLIWAS is accessed through a graphical user interface, using a web browser. For the communication between web server and clients the Internet or an intranet is used. If this infrastructure is not available because of the emergency situation, FLIWAS must still be operational. To enable stand-alone operation the data (geo-data, emergency plans and evacuation scenarios and operational data) can be mirrored to a local system. If the communication fails FLIWAS can still be used in off line mode on the local system. As soon as the network becomes available again the data of the local system and the web server are synchronized and the system will switch to on-line mode.

**First experiences with FLIWAS**

Although the final release of FLIWAS is still under construction, the project partners have already started implementation with first releases. Existing contingency plans have been evaluated and have been strongly improved during the process. Also basic (geo) data is gathered and fed in databases that will be used to feed FLIWAS.

In 2007 a first operational version of FLIWAS was implemented at municipalities and district offices in Baden Wьrttemberg. In October 2007 FLIWAS was submitted to a significant test for the first time, in the framework of a staff exercise. The purpose of the exercise was to test a number of the functions developed in FLIWAS, i.e. "alarm- and deployment plans" and the "presentation of large-scale flood projections following a dike breach", as well as the "communication possibilities" between the institutions in charge.

Participants in the exercise in Baden-Wьrttemberg included the Ministries of Internal Affairs and the Environment, the Karlsruhe Government Presidium, the Districts of Karlsruhe, Rastatt and Rhein-Neckar-Kreis and the urban districts of Karlsruhe, Mannheim and Heideberg, as well as nine municipalities. All together 120 persons co-operated in the exercise. In addition, some 25 representatives of the project participants and of institutions from Rheinland-Pfalz and Sachsen were able to follow the exercise live, as it was presented on a large screen in the Karlsruhe government presidium. The exercise was based on an extraordinary flood scenario in the project area between Rastatt und Mannheim of several days' duration, in the course of which dikes along the Rhine broke at two places and large parts of the Rhine flats were flooded. This resulted in the evacuation of around 50,000 people and the close-down of large industrial companies, including two refineries.

The exercise took several days, to allow the alarm- and deployment plans of the fire brigade to be concluded. On the actual day of the exercise the focus was on the presentation of flood projections and the issue of communication. In the latter framework, some 2000 e-mail messages were exchanged in the course of the 4-hour exercise.Apart from typical testing setbacks the deployment of FLIWAS essentially functioned well. Only in the area of communication a real need for improvement has been identified. Such optimisations will be implemented in new releases, so that the FLIWAS Basis version can be introduced throughout Baden-Wьrttemberg from the middle of 2008.During Spring 2008 exercises in both the Netherlands and Germany will be held. Actual results on these exercises will be available during the conference.

Public awareness and involvement. Another important issue the project addresses is the increasing demand of the general public for reliable and unambiguous information. From recent high water situations (e.g. the Elbe flood) it is known that the public was informed by several authorities and the media in a diffuse way, leading to uncertainty and unwanted actions such as unnecessary evacuations. Within the project, instruments are developed and implemented to inform and actively involve the general public on high water issues. In NOAH, the concept of High Water Partnerships is applied. In High Water Partnerships all relevant stakeholders in a community, such as the city council, entrepreneurs, NGOs and the public are brought together. The idea is that in this setting the interests of all parties are identified and looked after and that information transfer is simplified. By providing and using additional information on flood risks the required and desired protection level of inhabitants and companies in high-risk areas can be determined and communicated. If they receive more information and are more knowledgeable, people living in flood-prone areas can be expected to take on a higher level of responsibility for their situation. For instance, they may change the interior of their house in a way that reduces the impact and costs of flooding (e.g. stone floor covering instead of carpet or wood) or they can take precautions to keep the water out. By establishing flood partnerships in areas adjoining the Rhine the required and much needed awareness of the risk of high water and flooding will be created or increased. This meets ICPR demands to increase the sense of responsibility of people living in endangered areas. High Water Partnerships will also become important information channels to introduce the information system FLIWAS and make it accessible to a larger public. In Baden Wuerttemberg, the first High Water Partnership was established in the city of Au am Rhein on November 11, 2004, and a score of others has followed. At the moment, Baden Wuerttemberg has been subdivided in a total of 15 High Water Partnerships, covering the whole state.

**Project progress**

The ultimate objective of the project is to increase flood awareness and to create a common interest for information transfer on high water related issues along a river. Therefore project partners are very actively involving other water management organizations by sharing project results on websites (www.fliwas.eu), by reporting project progress in the NOAH newsletter and by presentations on seminars and in written journals.

The project received very positive feedback from the field. For instance, the Hochwassernot¬gemein-schaft Rhein, representing all North Rhine Westphalia cities along the Rhine, joined the project as an observer. It also became apparent that further development of the system to support coastal zone flood management is feasible and desirable, especially after recent flood events in the north of England, Ireland and the Baltic Region. The NOAH project has been rewarded with additional funding to expand the project and broaden the installed base of FLIWAS to Ireland and other organisations in the Netherlands and Germany.

Another success is the approval of the CADSES INTERREG IIIb project MOSES involving nine partners from Slovakia, Hungary, Germany, Romania and Ukraine. At the moment, implementation of FLIWAS is considered for Slovakia.

The need for such a strategic project as NOAH is underlined by the outcome of the European Council meeting on the 14th of October 2004, in which the Council agreed that Member States should develop and implement flood risk management plans and flood risk maps for river basins and coastal areas. The resulting Flood Directive has been approved by the European Commission on June 27 2006. NOAH, MOSES and FLIWAS fit perfectly within this development.

In the Netherlands, a Taskforce Management Flooding (TMO) has been established and is working to prepare the Netherlands to major flooding events. TMO has adopted FLIWAS as a major communication tool to be used in a nationwide exercise which will be held in November 2008. With regard to speeding up implementation of FLIWAS, instruments are created to support (future) users of FLIWAS, such as training courses, e-learning and implementation tools.

**CONCLUSIONS**

The NOAH project with development of the high water management system FLIWAS acts upon the widely spread urge to improve information transfer and communication during flooding events. Key feature is that FLIWAS enables organizations to implement their own contingency plans and basic data on one hand and to structure the information and initiate actions during events on the other hand.

First results with exercises based on the use of FLIWAS are very promising. The project is well underway and fits also perfectly in recent EU developments regarding the Flood Directive.

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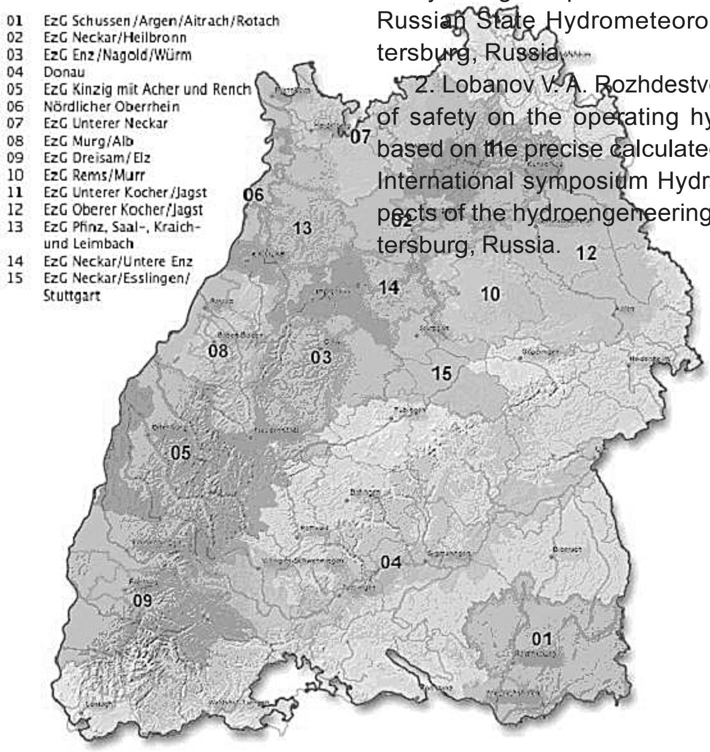


Figure 4: High Water Partnerships in Baden Wuerttemberg, Germany

## SATELLITE SEGMENT ARCHITECTURE AND ITS PLACE IN THE WATER BODIES MONITORING AND MANAGEMENT SYSTEM

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Resolution on state monitoring of water bodies (hereinafter – monitoring) was adopted by the Regulation of the RF Government #219, dated April 10, 2007. Special attention in this resolution is paid to the methods of monitoring in terms of using unified information and technical assets, providing for compatibility of its data with those of other environmental monitoring types.

Modern programs of Earth remote sensing from space provide a large variety of parameters of data received in terms of spatial resolution (data with the resolution from 0.5 m to hundreds of meters per pixel) and in time (from several images per day to several images per year). Possibilities of contemporary data reception equipment, processing centers and of data archiving systems enable to create a system of continuous water bodies monitoring, ensuring regular different time and spatial resolution updates. Summary data on currently operating satellite platforms and on basic characteristics of the received data are shown in Tables 1 and 2. The tables illustrate that the range of data acquired is very big and both highly detailed images and wide FOV data can be used for different purposes of water bodies monitoring to get integral estimates of the water bodies and river basins condition. By now domestic and foreign scientists have accumu- lated a large experience of operating with remote sensing data, received from different satellite platforms. Satellite data differ in many parameters and can be used to resolve a vari- ety of tasks. Basic differences are in orbital parameters of satellites and onboard instrument characteristics. These factors define the possibilities of satellite platforms with respect to transfer of data of certain spatial and temporal resolution.

## STATE AND PROSPECTS OF HYDROLOGIC MODELING FOR RIVER BASINS OF RUSSIA BASED ON ECOMAG

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Experience of hydrologic design for the Volga basin, preliminary results of hydrologic modeling in the Yenisei and Lena basins, as well as prospects to use process system ECOMAG for modeling main river basins of Russia are on the tapis.

Process system ECOMAG (ECOlogical Model for Applied Geophysics) includes mathematical model ECOMAG, special-purpose geographic information system (GIS), bases of real-time hydrometeorological data, and information on microdescription of terrain, as well as control program.

ECOMAG is a version of spatial extended model of hydrological cycle, flow generating process, transfer and transformation of the pollutants in river basins. Hydrologic part of the model describes main processes of land hydrological cycle: infiltration, evaporation, thermal and water regime of soils, snow cover formation and melting, formation of surface, subsurface, ground, and river flow. Geochemical part of the model describes surface accumulation of pollutants, their precipitation dissolving, and penetration in to soil, interaction with soil solution and solid body, transfer of pollutants by surface, subsurface, ground and river flow.

Model dimensional patterning of the river basin is carried out on the basis of electronic map of the region using GIS-procedure based on ArcView.

Databases contain information on soil properties, land use, vegetation, pollutants, and hydrometeorological information on anthropogenic load for land.

Control program enables to constitute a link between GIS and database information, to configure required version of design, to calculate model, to display calculation data on a computer monitor screen in the form of graphic charts, schematic maps, including base material, designed hydrologic map, and maps of river basin and channel net pollution.

Process system ECOMAG is designed for wide range of hydrologic and environment-oriented applied problems of diagnostics and forecasting. Since 2001, ECOMAG has been used by Federal water resource agency for modeling and scenario design of hydrologic characteristics in the Volga basin to calculate lateral inflow to Volga-and-Kama reservoir cascades. The system was evaluated and started to use in solving various scientific applied problems on the rivers of Sweden, Norway, and France. Main results and selection of model parameters in different spatial scales, as well as possibility to use the system for hydrologic modeling throughout the country are being discussed.

## STRATEGY OF THE WATER DISTRIBUTION AT THE TEREK DELTA AS A WAY FOR OPTIMUM MANAGEMENT OF REGIONAL WATER RESOURCES

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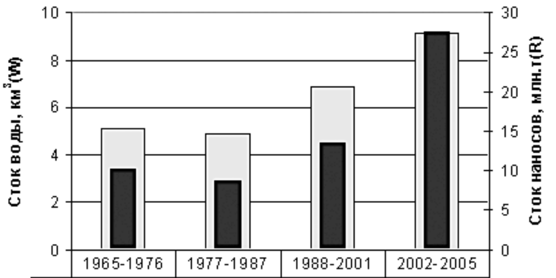
### INTRODUCTION

According to experts WMO the steady tendency of increase of material losses and vulnerability of a society because of increasing influence of the dangerous natural phenomena now is marked. Flooding are one of most frequently repeating natural acts, they quite often surpass all other extreme situations in the area of inundated territories and damage for population. In 2002 and 2005, catastrophic floods, largest for last 50 years occurred in the River Terek catchment basin. They caused flooding of vast areas in the river delta and inflicted a huge damage to the environment and economy of the region. In high waters vast areas were flooded; dwelling houses, bridges, and other constructions were destroyed; several-kilometer segments of protective levees and dams were washed away; ten thousand hectares of agricultural grounds were inundated, the settlements located in zones of flooding have suffered [1, 2].

Researches which SOI spend together with DagHMC since 2002 in Terek delta, testify, that the reason of these catastrophic flooding are modern features of development of hydro-morphological processes in delta of Terek and the tendency of climatic changes in the extensive territory including Terek catchment basin [3, 4]. At the present stage in Terek delta there were conditions for existence of constant threat of flooding during high waters period. And, prominent feature of this process is joint active action of the natural and anthropogenic factors directed on increase of probability of flooding.

### RESEARCH METHODS

Modern changes of hydrological conditions in Terek delta occur against the background of global climatic changes. The general warming and wetting leads recent years to increase water runoff and activization of erosion and washout on the Terek catchment basin located on northern slopes of the Great Caucasus, causing thereby essential increase in water discharges and sediment load arriving to the Terek delta top (Fig. 1) [4].




| | 1965-1976 | 1977-1987 | 1988-2001 | 2002-2005 |
|---|---|---|---|---|
| □ W | 5,13 | 4,87 | 6,89 | 9,09 |
| ■ R | 10,19 | 8,71 | 13,43 | 27,42 |

Figure 1. Annual mean water runoff (W) and sediment load (R) at the Terek delta top.

For research of tendencies of climatic parameters changes (air temperature and precipitations) at the Terek catchment basin data of meteorological supervision on stations of Federal Hydrometereology and Environmental Monitoring Service and net data CMAP (CPC Merged Analysis of Precipitation [5, 6]) are used.

The analysis of change of annual mean air temperatures during 1960-2006 is spent according to meteorological stations (MS), located at the Terek basin at different elevation (Fig. 2).

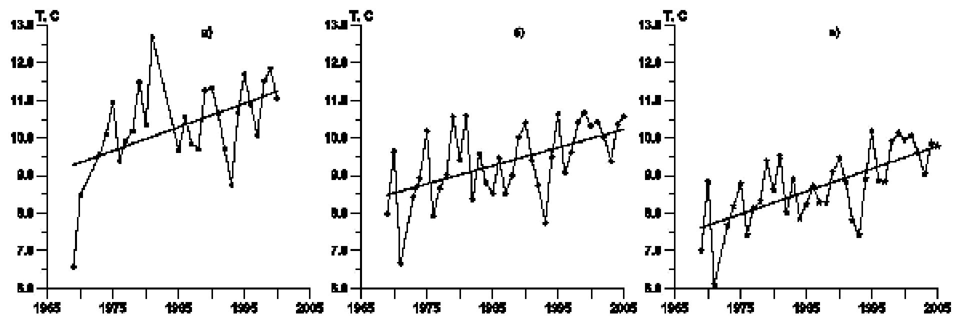


Figure 2. Annual mean air temperatures at the Terek catchment basin.
а – lowland (MS Mozdok), б – foothills (MS Min.Vody), в – hills (MS Vladikavkaz).

For the analysis of tendencies of wetting changes at the Terek basin are used average pentad precipitation data CMAP during the 1979-2006 received by merging seven kinds of individual input data sources [5, 6]. These input data sets include the gauge data (the GPCC gauge-based analyses over land and the atoll gauge data over ocean), 5 sets of different satellite estimates [6]. Precipitation fields generated by the NCEP/NCAR reanalysis are also utilized as an additional source. These data allow not only to reveal interannual and seasonal changes of precipitations in the Terek basin, but also to allocate the short-term heavy shower caused by passage of storm fronts. The analysis of average pentad precipitation data at the Terek basin has allowed indicating the periods of sharp increases of Terek water runoff, connected with increase of repeatability and duration of heavy showers (Fig. 3).

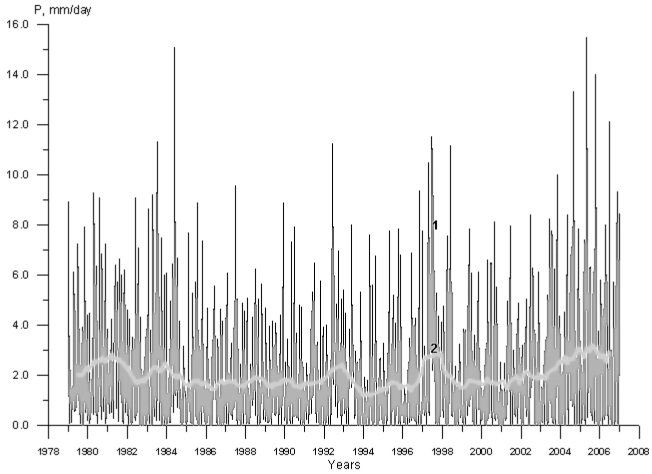



Figure 3. Average pentad precipitation data at the Terek basin (1) and annual running average (2).

Since 2002, the SOI in collaboration with DagHMC has been performing a program of complex monitoring the Terek delta [7], including operative remote sensing monitoring, supervision on a network of hydrological gauge stations, seasonal (May-October) specialised field surveys in the Terek delta. In 2002-2007 SOI together with DagHMC are spent 12 specialised seasonal expeditions for estimation of a modern condition of Terek delta water objects. Results of field works are a basis for working out of recommendations about carrying out of prime actions for unloading of main delta channel and decrease in threat of flooding of surrounding territories. In parallel with hydrological works are spent specialised field inspections for remote sensing data interpretation and an estimation of consequences of breaks of protective levees and dams. In frameworks of field inspections works on mapping of flooded territories and an estimation of the areas of flooding are performed.

**RESULTS**

The joint analysis of the data received by a network of Federal Hydrometereology and Environmental Monitoring Service in Terek catchment basin and the net data CMAP has shown, that on a background of the general tendency of increase of mid-annual air temperatures in region both in lowland, and in mountain its parts (Fig. 2) from the beginning of XXI-st cent. there is an increase of the annual sums of precipitations (Fig. 3), and is marked growth of repeatability and duration of the heavy showers causing short and powerful floods. The analysis of intraannual distribution has shown that the basic increase in precipitations occurs during the winter period at the expense of plentiful snowfalls, and also during the summer period at the expense of intensive showers. Thanks to it last years Terek water runoff in high waters period (May-September) has grown on 57 % on comparison with average long-term values. According to hydrological supervision DagHMC the average annual water discharge in top of the main delta channel for last 10 years has exceeded average long-term values in 1,5 times, and an annual sediment load - in 3 times. Water discharges average from the maximum values for last 5 years have grown on 17 % on comparison with average long-term values and have reached 1080 m3/s. In top of the main channel of delta in 2005 the average annual water discharge 364 m3/s has been fixed – the maximum value during supervision since 1965, the sediment load - 18,1 million ton - in 2 times has exceeded average long-term values.

For Terek and its main tributaries originating in a mountain part of a reservoir, intensive processes of washout and carrying out of a firm material are characteristic. In the conditions of raised wetting and climatic warming erosive processes on slopes become more active. It results to intensive washout, increase in carrying out and accumulation of sediments in delta. Deposition of sediments in the main channel of delta leads to constant increase of absolute bottom elevation marks and occurrence of threat of catastrophic breaks. In the conditions of excess of bottom elevation marks and bank elevation marks over surrounding territories its destruction at extreme water runoff inevitably leads to delta flooding, formation of a new channel and gradual dying off of an old channel.

The history of development of Terek delta in XVI-XX centuries [8, 9] shows that each 50-70 years the existing delta comes to a nonequilibrium condition which comes to the end with catastrophic break and radical change of a direction of a main delta channel. Last break which has occurred 1914, has begun development of modern delta. To the beginning of 1960th elevation marks of a bottom and water levels in the tideway of the main delta channel have reached critical points. The catastrophic flooding 1958 и1960 when it has been flooded by 125 thousand in hectares and 64 thousand in hectares accordingly [10] testified this fact. Channel breaks in 1967, 1970, 1977 and inundation of 30-50 thousand hectares of farmlands have shown that conditions to start formation of a new main channel in Terek delta have created.

In XX century in delta of Terek were carried out the numerous hydraulic engineering actions directed on decrease of high water danger. More than 200 km of protective levees and dams, a network of artificial canals and fishing reservoirs have been built. The most important action, which has rendered significant influence on hydrological regime, was construction of artificial cut-off (so called "Prorez") through Agrahansky Peninsula to Caspian Sea in 1977. As a result there was sharp incision of Terek river channel in a lower part of delta and concentration of water runoff in the main branch. In the great degree efficiency of the accepted measures was defined by low Caspian Sea level (-29.0 m abs.) during 1970th.

Within last 30 years which have passed from "Prorez" construction, natural and anthropogenic factors concurrent in Terek delta. A consequence of its simultaneous influence is the steady increase in high water danger.

On the one hand sediment load constantly grew (Fig. 1) on a background of Caspian Sea level sharp rise from -29,0 m abs. in 1977 up to -26,6 m abs. in 1995, that has caused the rise of river channel bottom marks in lower part of Terek delta. According to the data of field works of SOI, by 2004-2005 the Novy Terek channel bed elevations reached again their position observed in the 1970s, before "Prorez construction" (-25…-26 m abs.). Marks of a bottom of a channel and water levels in delta lower reaches on 0,5-1,5 m have exceeded the marks fixed in the early seventies (Tab. 1). Those years the critical condition of a channel has served as the basic argument for a conclusion of a drain of the river to Caspian sea on an artificial canal "Prorez" through Agrahansky peninsula.

On the other hand, last 30 years the height of protective levees along Novy Terek channel was constantly increased, that also stimulated the process of sedimentation and the rise of channel bottom elevations.

Table 1. Annual mean water level (H) and bottom elevation marks (Z) in the Terek delta.

| Years | gauge Alikazgan | | gauge Damba | |
|---|---|---|---|---|
| | H, m abs. | Z, m abs. | H, m abs. | Z, m abs. |
| 1976 | -23.73 | -25.22 | -25.48 | - |
| 1980 | -24.37 | -26.24 | -27.54 | -29.58 |
| 2004 | -22.23 | -24.82 | -25.24 | -27.68 |

The researches have been carried out by SOI in 2002-2007 in the framework of the program of complex monitoring have shown, that at the present stage there were conditions for existence of constant threat of flooding in Terek delta during high waters. It is necessary to emphasize, that threat is represented with high waters, levels and water discharges of 8-10 years back did not represent danger to surrounding territories. According to supervision and expedition works it is possible to conclude, that real threat of break of a channel in its up and middle stream arises in modern conditions with water discharges above 900 m3/s, P 25%.

The received results testify, that by present time the potential of the hydraulic engineering actions spent in the middle of XX century is practically settled, there are no preconditions for development of radical decisions which would allow to remove a sharpness of a problem of flooding protection of Terek delta for 30 years forward. Materials of previous researches in second half XX century and results of SOI works in the beginning of XXI century allow to assert, that in the developed conditions strategy of water runoff distribution in Terek delta can become the effective key tool of water resources management of this region.

The carried out researches have shown, that unloading of main delta channel by usage of a natural channel network and creation of new artificial reserve paths for dump of flood waters can become one of the most effective decisions of a problem of Terek delta inundation. In short-term and intermediate term prospect it is possible to provide decrease in risks of flooding of territories, carrying out operative redistribution of water runoff and sediment load on all delta.

On the basis of archival materials and SOI field surveys data the specialised calculations are carried out. Results have allowed to make the proved recommendations about designing of prime actions for unloading of main delta channel and decrease in threat of flooding of surrounding territories. For a substantiation of recommendations following kinds of works have been executed:

1. Calculations of slopes of delta surface for a choice of optimum directions of recommended reserve paths of dump of flood waters, and also calculation of slopes of water surface in low water conditions according to SOI field hydrometric and geodetic works.

2. Calculations of water discharges, hydraulic characteristics and potential throughput of constant and temporary branches and creeks which may be used for transit of high waters at various scenarios of development of inundation.

3. Calculations of the areas of constant and temporary reservoirs which may be used as reserve capacities in a high water period.

The analysis of results of complex monitoring program of Terek delta, modern maps of scale 1:25000, remote sensing data of the high resolution (5-10 m/pix) and results of specialised calculations has shown possibility of strategy of flood waters distribution over the delta territory with use of reserve paths. Designing of directions and throughput of reserve paths is necessary for spending taking into account available possibilities of an existing network of constant and temporary branches and reservoirs. Predesigns of throughput of offered reserve paths show that at their use there is a possibility of the admission to 50 % flood runoff that will allow to lower danger of occurrence of catastrophic breaks of protective levees and dams.

One of prime actions for unloading of main delta channel is realisation of dump of water on the left shore territory through system of artificial canals in Nizhnetersky lakes and further, with a water exit on existing waterways in Northern Agrakhal Gulf. Predesigns have shown that for today without additional actions for this direction can be dumped to 100 m3/s. For maintenance of the admission of considerable water runoff in this direction it is necessary to carry out reconstruction of existing water tracts, and also dredging works in system of natural and artificial channels and reservoirs. After realisation of these actions during the high water period there will be a possibility of tap to 50 % of the main channel water runoff (to 400-500 m3/s) in reserve path system of left shore and further in Northern Agrakhal Gulf. Below the Alikazgan bridge dump on the left shore in direction of Northern Agrakhal Gulf can be carried out in volume to 250 m3/s through the branching system of Kubjakinsky bank generated in last years.

The constant unloading on the right shore territory in volume of 150-200 $m^3/s$ can be provided on a way of 2005 year passage of flood waters - to channel Dzerzhinsky collector into Southern Agrakhal Gulf. Also at high water levels the system of temporary branches and creeks of the Batmaklinsky bank starts to work intensively, it takes away water about 250 $m^3/s$ on the right shore, into Southern Agrakhal Gulf. Dump of flood waters from Southern Agrakhal Gulf can simultaneously be carried out in two directions: to 200 $m^3/s$ on the south through fishing canal and the Juzbash-Sulaksky collector to Caspian sea, to 100 $m^3/s$ on the north through the First-Fourth canals into Terek.

After carrying out field interpretation inspections and analysis remote sensing data actual zones of inundation have been defined for various flood water discharges. These data will allow to plan further optimum modes of dump of high waters for the right and left shores and to minimise damages from harmful influence of waters.

The use of regulating capacities of the Northern and Southern Agrakhan Gulfs makes it possible to cut off the flood peaks; also, these conveyance capacities are very important for the Terek delta ecological state. Thus, during the flood-2005, the water outflow onto the right shore provided freshening the drain water in the Dzerzhinskii collector, cleaning the Southern Agrakhan Gulf, decreasing the salinity of its water and of the water in the fish-pass canal. Over 4--5 months, the discharge of clarified water from Southern Agrakhan Bay provided the Terek channel flushing (within the reach downstream of the gauge of Damba) and significant decrease in bed elevations on the fixed cross-sections in the Prorez' channel. The increase in water runoff into Northern Agrakhan Gulf is favorable for the reproduction of valuable species of fish in this region

**CONCLUSIONS**

Results of complex monitoring program of Terek delta which is spent since 2002 in SOI in collaboration with DagHMC, allow formulating following basic conclusions: To the beginning of XXI century owing to action of large-scale natural processes (climatic warming, increase of wetting in Terek basin, increase of Terek water runoff and sediment load, Caspian Sea level rise) the new condi- tions of hydro-morphological processes in Terek delta have developed [4]. The account of modern tendencies of development at carrying out of hydraulic engineering and reclamation works will allow raising efficiency of engineering actions considerably.

For the prevention and decrease in negative consequences from harmful influence of waters and maintenance of sustainable development of region realisation of the complex approach to water resources management of delta of Terek based on strategy of water runoff distribution is necessary. Realisation of actions for water redistribution gives the chance to start in the near future working out of "The Concept of operated development of Terek delta» which will allow lowering considerably damages from harmful influence of waters in case of their surplus and in case of a lack.

Realisation of strategy of water runoff and sediment load redistribution along with necessary hydraulic engineering actions will lead in the near future to increase of economic value of the lands in Terek delta both at the expense of steady decrease in inundation risk, and at the expense of adjustable increase in water security of the territories having the big economic value.

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# BUILDING GEOINFORMATION SYSTEM FOR WATER RESOURCE MANAGEMENT IN SUBJECTS OF RUSSIAN FEDERATION

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At the moment in Federal Agency of Water Resources the work on building of a full-scale multilevel decision support information system for water resource management is being held. The feature of water objects is their sufficient spread and distribution through the territory of Russian Federation. The presence of information on precise object placement, their topological and spatial relationships and interconnections takes strong impact on quality of administrative decisions that are made at territorial, basin and federal levels. For working out software solutions at a territorial level development of Geoinformation system (GIS) of Water Resource for territorial department is being held. GIS of Water Resource of Republic of Bashkortostan (GIS WR RB) was chosen as an example.

Purposes of development of GIS WR RB are: supplying staff with full and reliable spatial information (reference and analytical); decision support on water resource management at territory of Republic of Bashkortostan (RB); providing unified approaches to GIS design at different levels and working out unified technology for data exchange at three levels (federal, basin and territorial).

The paper contains detailed information on the system structure and structures of subsystems included in GIS WR RB.

One of the important aspect for working out the standard GIS decisions is building generalized data structure for all subsystems being built at territorial levels. Data model created for GIS WR RB is adjusted to one's of Rosvodresursyi GIS and it has some features peculiar to information used in work of territorial departments. Spatial database is based on vector map of RB of 1:200000 scale and of map of 1:1000000 scale of bordering federal subjects. It contains the following basic feature classes: "Geographical objects" (information on nature and antropogenic objects, placed at the territory (rivers, lakes, forestry, roads, pipelines etc.)), "Special layers" (underwater communications, agricultural grounds, places of permanent ice blocking, emergencies etc.), "Water objects" (square of drainage area, depth, width, flow velocity etc.), "Hydraulic structures" (dam characteristics, stream name, year of comission, capacity, exploiting organization etc.), "Executive organizations and their responsibility zones" (references on staff and organizations, realizing the control of water objects state or information users etc.), "Special territories and zones" (water object basin, area of water, zone of special sanitary control, water protection zone etc.), "References and documents" (references of water objects, hydraulic structures types, contaminants etc.), "Observation stations and monitoring" (Rosgidromet posts, data on hydrologic and hydrochemical monitoring etc.).

Spatial database sharing (including remote access mode) between experts is organized via special software ArcGIS Server 9.2 for Workgroup. Local area network users connect to geodatabase using special software ArcView 9.2 and ArcEditor 9.2. Users that do not have such software and also remote users of the system connect to database using browser via remote access subsystem.

On a base of available spatial information solution of the following standard tasks of territorial department staff was realized (as subsystems of GIS):

- modelling of emergency pollutant flood and spread in water objects and at risk of reaching water objects (calculation of pollutant spot passing through water object and on land, speed of its spread, square of pollution);
- modelling and forecasting of flood zones at building and destruction of hydraulic structures (calculation of flood zone square, bursting wave, determining of objects impacted by the water);
- emergency data processing (computer-aided emergency data processing in cartographic and atributive form, creating of outgoing documents and their sending to superior bodies);
- statistical data analysis, processing and interpretation (classification and visualization of information on water users, water usage, contaminants in water objects etc. in cartographic and atributive form).

The further GIS evolution supposes development of the following subsystems: subsystem for forecasting and estimation of flood zones at a subject of Russian Federation using digital electronic maps and space imagery, subsystem for snow blanket descent tracking during flood period, subsystem for preprocessing data of state water register and state water objects monitoring and hydrologic systems.

Implementation of GIS provides unified methodological and technological base for integration of different information systems, creates a corporate resource for decision making support at different levels, provides good quality of information and quick access to it for presentation and usage.

# CLIMATE CHANGE ADAPTATION FOR URBAN WATER SUPPLIES, DEMAND MANAGEMENT AS A STRATEGY: A CASE STUDY OF TWIN CITIES OF ISLAMABAD AND RAWALPINDI, PAKISTAN

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## 1. INTRODUCTION

The twin cities of Islamabad and Rawalpindi are being fed water supply from multiple sources i.e. surface water reservoir local basin (Simly dam & Rawal dam), water transfer from a near basin through Khanpur dam and harvesting the ground water potential). The existing demand is 200 MGD, whereas present level of water production is 128 MGD. This level of production itself is subject to variation (climate variability and drought spells). The potential is also under threat due to expected reduction in the rainfall-runoff to the reservoirs and depletion of groundwater due to increase in paved area, urbanization in watershed, change in land use, cutting of trees, pumping more than the safe field and climate change.

a Khanpur Dam
b. Simly Dam
c. Rawal Dam

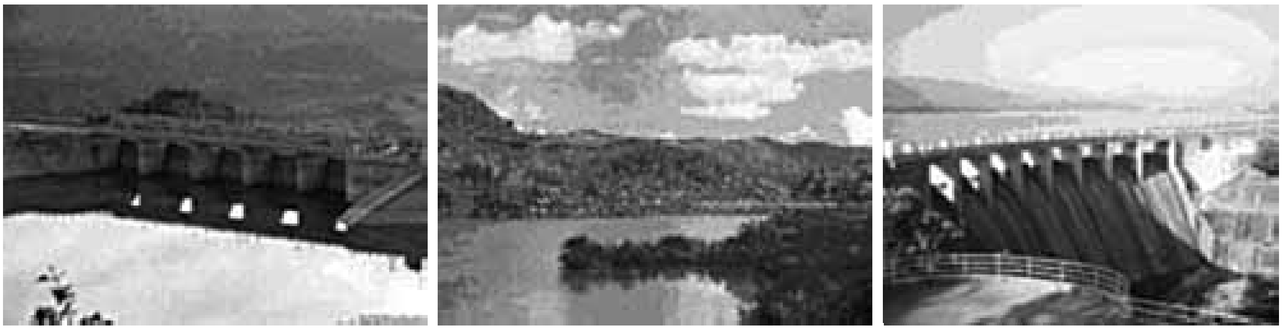

Figure 1. Dams used as a source of water supply for twin cities of Islamabad and Rawalpindi

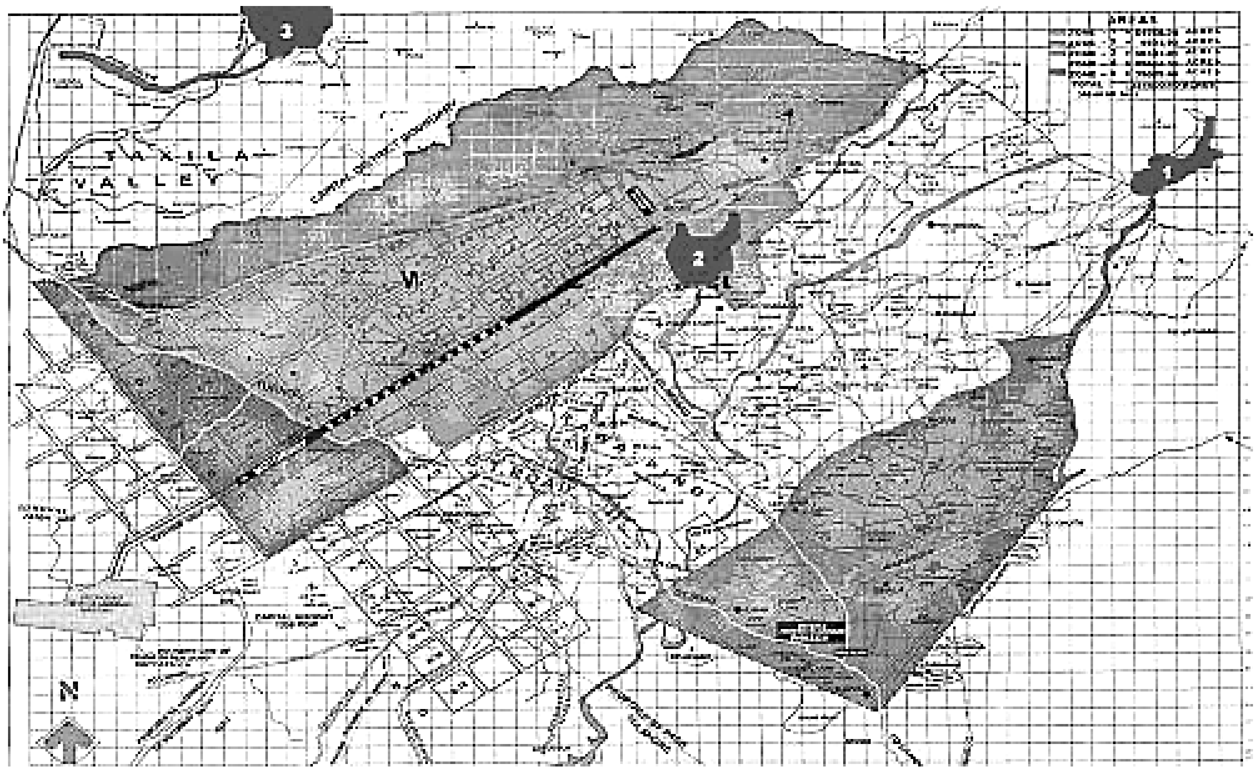


Figure 2. Simly, Rawal and Khanpur dam locations

## 2. TWIN CITIES AT A GLANCE

2.1 Rawalpindi

Rawalpindi city is situated in Potwar Plateau near Pakistan's capital city of Islamabad, in the province of Punjab. It is 275 km to the north-west of Lahore. The city is home to many industries and factories. Islamabad International Airport is located in Rawalpindi. It is the administrative seat of the Rawalpindi District. The projected population upto 2050 is 5.64 million and water demand @50 gpcd is 282 MGD.

Table1. Projected population and water demand upto year 2050 for Rawalpindi City

| Description | Calendar Years | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Growth rate | 3.5% | 3.5% | 3.5% | 3.5% | 3.5% | 3% | 3% | 2.5% | 2% |
| Years | 1998 | 2000 | 2005 | 2006 | 2010 | 2015 | 2020 | 2030 | 2050 |
| Projected population (million) | 1.58 | 1.73 | 2.04 | 2.11 | 2.40 | 2.77 | 3.20 | 4.01 | 5.64 |
| Water demand @ 50 gpcd (MGD) | 79 | 86.5 | 102 | 105.5 | 120 | 138.5 | 160 | 200.5 | 282 |

The reported [1] rate of extraction of ground water in Rawalpindi is 120 MGD. Year wise comparison of water table depletion matrix is shown in figure below, which is @ of 10 ft per year. The fluctuation of groundwater levels in Rawalpindi is shown in figure 3.

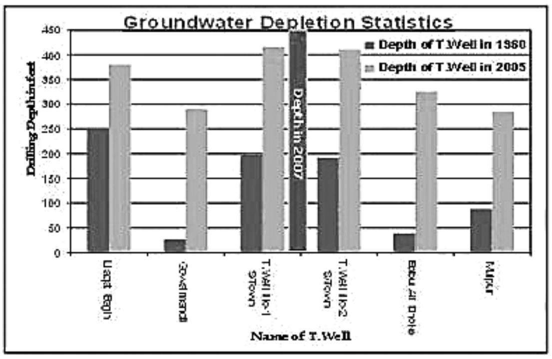


Figure 3. Groundwater Depletion in Rawalpindi, Pakistan

2.2 Islamabad

Pakistan's new Capital ISLAMABAD nestles against the backdrop of the Margalla Hills at the northern end of Pothowar Plateau. It offers a healthy climate, pollution free atmosphere, plenty of water and lush green area. It is a modern and carefully planned city with wide tree-lined streets, large houses elegant public buildings and well-organized markets/shopping centers. Jasmine & bougainvillea fill the parks and scenic viewpoints. The demand of Islamabad city is depicted in figure 4.

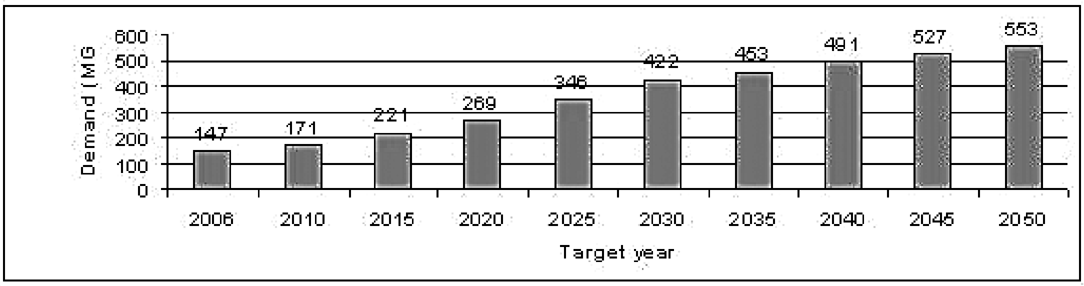


Figure 4. Demand Vs Water supply

### 3. NEED ASSESSMENT

The existing situation of water availability reveals that current system caters only for urban areas & developed areas and sources are entirely dependent on rainfall. It is due to climate variability that these sources are unreliable for sustained water supply.

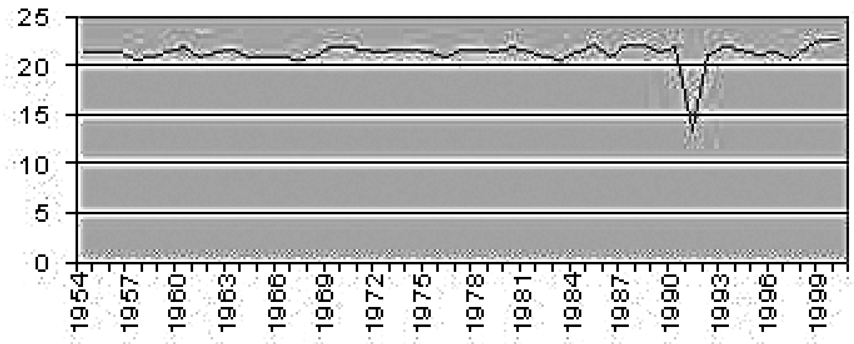

Figure 5: Annual Average temperature trend in Islamabad

Data source: Pakistan Meteorological Data

The forecasted water supply demands for twin cities for years 2010, 2020, 2030 and 2050 are 291 MGD, 429 MGD, 622.5 MGDD and 835 MGD respectively.

The table No. 1 shows that available water resources are inversely proportional to the water demand. Realizing this situation a project by the Capital Development Authority "Conduction of water from Indus River System (Tarbela lake) to the cities of Islamabad & Rawalpindi (Phase-I)" was proposed. The main objective of this project is to augment the present water supply potential to meet present and future demands up to the year 2050 with an additional transfer of water (300 MGD) at a distance of 54.7 km with a tunneling arrangement of 1.1 km for alignment of route. A reservoir (RCC) of 10 MG capacity is proposed near terminal point.

As Tarbela lake receives stream flows from Indus River. The variation in Indus flow is considerable. The climate change may significantly affect the average flow of Indus River and melting of glaciers is a future threat for the reduction in flow (upto 40%). The physical evidence of the shrinking of glaciers is presented in figure 6.

3.1 Climate Change Threats to Pakistan

Global Change Impact Studies Centre studies [2] highlighted some threats, including increased variability of monsoons, escalating risks of floods and droughts, severe water-stressed conditions in arid and semi-arid zones and food insecurity due to reduced agriculture productivity. Highlighting the vulnerability of Pakistan to this phenomenon that climate change will have a severe impact on agriculture, river flows and exacerbate food and energy shortages.

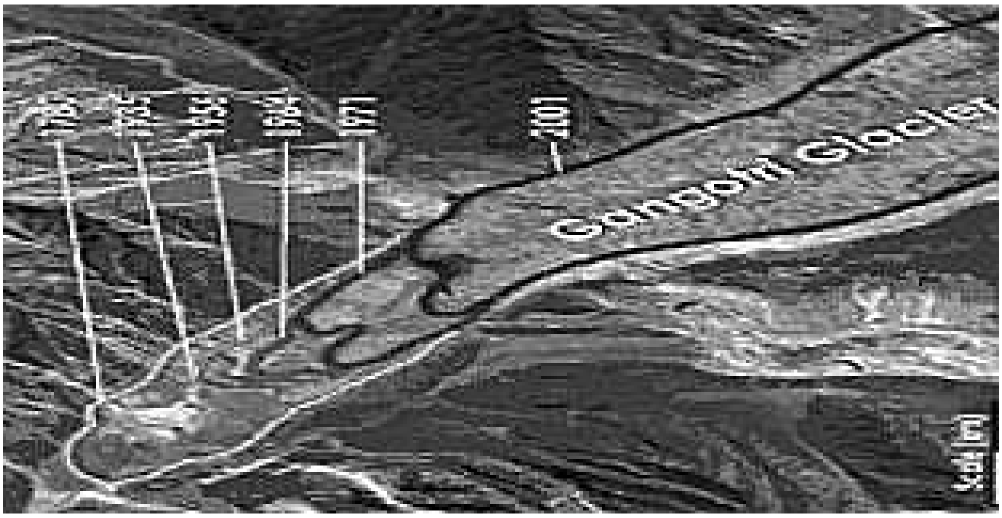


Figure 6. The continuous decrees in mass of Gangotri Glacier, Northern Areas of Pakistan

Source: Indus basin, Inventory of Glaciers and Glacial Lakes

3.2 Index of Drinking Water Adequacy (IDWA)

IDWA, an average of five component indicators on most relevant variables [4] and identify the ranking of the countries. The bar shows the IDWA value for Pakistan is only 39 as compare to the average size of above 50.

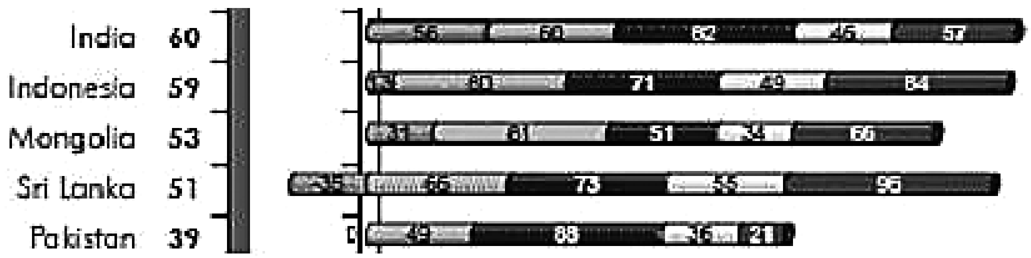


Figure 7. Ranking of Pakistan based on IDWA

Source: ADB report Pakistan water woes

3.3 Challenges

1) Water security in a dry climate and climate change scenario with and population growth is of paramount importance

2) Healthy water environments – as urbanization increases our waterways and wetland systems face increased risk from contaminants

3) Greenhouse emissions – with climate change firmly on the global and local political agenda, the energy costs of water supply options become increasingly important to utilities

4) Aging infrastructure – maintenance and management of aging water infrastructure.

**4. OPTIONS**

The under given chart shows the schematic strategic approach diagram indicating the stepwise follow up to cater the impact of climate change on water resources and its management accordingly.

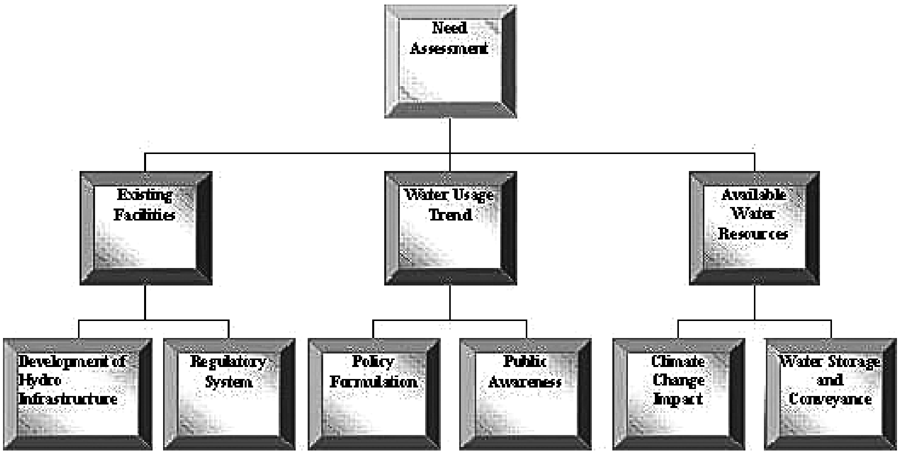


Figure 8. Methodology as a fallow up for the climate change impact on water resources

## 5. WATER SUPPLY DEMAND MANAGEMENT STRATEGY

The strategy to control the water utilization and management of water supply demand can be demonstrated as provided below:

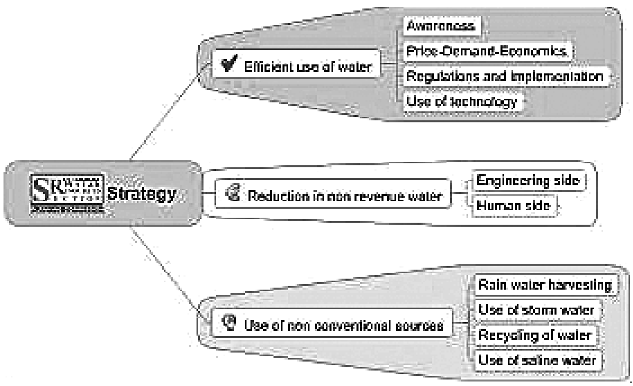


Figure 9: Water demand management strategy

## 6.ADAPTATIONS

6.1 Technology based

The technology based adaptations include the development of the small dams, lining of water distributaries, high efficiency distribution system and improvement in the water conservation system.

6.2 Policy adaptation

The increasing scarcity of water resources requires resources demand management through policy framework [5]. This approach gives the right to the water users to have the access to their need of water without harming the water resources. In another words it is a strategy of influencing demand to achieve efficient and sustainable use of a scarce resource.

Table2. Water supply demand management measures matrix

| Water Saving (%) | Level of Restriction | | | |
|---|---|---|---|---|
| | Normal | Moderate | High | Very High |
| 5 | Awareness | Metering system | Low tariff | N/A |
| 10 | Awareness | Metering system | Moderate tariff | Saving water |
| 25 | Awareness | Metering system | High tariff | Waste water Recycling |
| 50 | Awareness | Metering system | Very high tariff | Water use restriction |

6.3 Policy formulation

The optimized and efficient use of water can be en- forced through policy framework and this effort was in the form of policy by the (Pakistan Environment Protection Agency) PEPA was suggested [6]. The overall objectives of the policy are outlined below:

a. To provide a supportive policy and legal framework that facilitates access of all citizens to safe drinking water on a sustainable basis.

b. To provide guidelines that will allow consistency and conformity between the drinking water policy and the overall water sector policy, environmental policy, health policy and drinking water quality standards that will facili- tate the provision of safe water to all.

## STATE AND PROSPECTS OF HYDROLOGIC MODELING FOR RIVER BASINS OF RUSSIA BASED ON ECOMAG

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Experience of hydrologic design for the Volga basin, preliminary results of hydrologic modeling in the Yenisei and Lena basins, as well as prospects to use process system ECOMAG for modeling main river basins of Russia are on the tapis.

Process system ECOMAG (ECOlogical Model for Applied Geophysics) includes mathematical model ECOMAG, special-purpose geographic information system (GIS), bases of real-time hydrometeorological data, and information on microdescription of terrain, as well as control program.

ECOMAG is a version of spatial extended model of hydrological cycle, flow generating process, transfer and transformation of the pollutants in river basins. Hydrologic part of the model describes main processes of land hydrological cycle: infiltration, evaporation, thermal and water regime of soils, snow cover formation and melting, formation of surface, subsurface, ground, and river flow. Geochemical part of the model describes surface accumulation of pollutants, their precipitation dissolving, and penetration in to soil, interaction with soil solution and solid body, transfer of pollutants by surface, subsurface, ground and river flow.

Model dimensional patterning of the river basin is carried out on the basis of electronic map of the region using GIS-procedure based on ArcView.

Databases contain information on soil properties, land use, vegetation, pollutants, and hydrometeorological information on anthropogenic load for land.

Control program enables to constitute a link between GIS and database information, to configure required version of design, to calculate model, to display calculation data on a computer monitor screen in the form of graphic charts, schematic maps, including base material, designed hydrologic map, and maps of river basin and channel net pollution.

Process system ECOMAG is designed for wide range of hydrologic and environment-oriented applied problems of diagnostics and forecasting. Since 2001, ECOMAG has been used by Federal water resource agency for modeling and scenario design of hydrologic characteristics in the Volga basin to calculate lateral inflow to Volga-and-Kama reservoir cascades. The system was evaluated and started to use in solving various scientific applied problems on the rivers of Sweden, Norway, and France. Main results and selection of model parameters in different spatial scales, as well as possibility to use the system for hydrologic modeling throughout the country are being discussed.

*Oral presentations*

## MATHEMATICAL MODELS FOR FORECASTING THE PROCESS OF PROPAGATION OF CATASTROPHICAL FLOOD WAVES IN SYSTEMS OF OPEN RIVER CHANNELS

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### INTRODUCTION

Mathematical models, numerical methods for solving the hydraulic problems in open channels are considered.

The models take into account the real morphometric and hydra ulic chara

$$B\frac{\partial z}{\partial t}+\frac{\partial Q}{\partial x}=q$$

cteristics of river bodies, affect of flood- plains and meteorological factors (wind, atmospheric pressure). On the basis of the difference methods, the el- ements of the system theory and the system analysis ef- fective algorithms have been developed. Its have used to

calculate the unsteady flows both branching (tree-type) systems and arbitrary systems (with loops) of open channels. The problems of its using for the studying of the unsteady flows at a wind-induced surge, catastrophic spring-autumn flooding at rivers, the propagation of wives following rupture of a dam have been received.

**MATHEMATICAL MODELS**

The mathematic model describing unsteady wave processes of catastrophic floods is based on the Sent-Venant equations [1, 2]:

a) equation of continuity

, (1)

b) dynamic equation

$$\frac{\partial Q}{\partial t}+\frac{\partial}{\partial x}\left(\frac{Q^2}{\omega}\right)+g\omega\frac{\partial Z}{\partial x}=-g\omega\frac{Q|Q|}{K^2}-\frac{\omega}{\rho}\frac{\partial P_a}{\partial x}+\zeta\cdot BW_l|W|, \quad (2)$$

where is a time, is a coordinate of the cross section, B(h,x) is a top width of free surface, Z(x,t) is a free surface ordinate, Q(x,t) is a rate of discharge, q(x,t) is a lateral inflow per the unit length of the channel, (h,x) is a the cross section area of the channel, g is a acceleration of gravity, K(h,x) is a discharge modulus, $P_a(x,t)$ is a atmospheric pressure, $W_l(x,t)$ is a component of the wind velocity along the channel,|W(x,t)|is a modulus of the wind velocity, is a water pressure, is a wind stress coefficient. General unknown functions in the equations (1), (2) are Z(x,t) and Q(x,t).

The system of the open channels has presented as a dynamic system, including two types elements: open channels segments and nodes. It all together represent the terminations of these segments are segment place confluence or the upstream and downstream cross sections of the system open channels. At the upstream and downstream cross sections of the system the boundary conditions are prescribed in the form of functional relations:

$$Q(l,t)=f(t) \text{ or } Z(l,t)=f(t) \text{ or } Q(l,t)=f(h(t)), \quad (3)$$

here l is a coordinate of upstream or downstream sections.

For conjunction stream flow at the nodes the conjunction conditions are formulated. We will assume that m -th segment adjoins to the j -th node if the node is one of the end of this segment; $\gamma_j^+$ is a set of segment numbers right end of the segment; $\gamma_j^-$ is a set of segment numbers left end of the segment. Then conditions of balance of discharge are formulated as

$$\sum_{m\in\gamma_j^+} Q_m(l,t)=\sum_{m\in\gamma_j^-} Q_m(0,t)-\Omega_j^*\frac{dZ_j^*}{dt}-Q_j^*, \quad (4)$$

where $Q_m(l,t)$ and $Q_m(0,t)$ are the discharges at the right and left ends of the m -th segments; $\Omega_j^*=f_1(Z_j^*)$ is a water-surface area of the flood plain storage at the j - th node; $Q_j^*=f_2(t)$- is a local inflow (outflow) at the node. When there are no flood plain storage ($\Omega_j^*=0$) and local inflow (outflow) ($Q_j^*=0$) we are obtain the simple conjunction conditions.

we are obtain the simple conjunction conditions.

$$Z_m=Z_j^*-\xi_m Q_m\left|Q_m\right|, \quad (5)$$

where $\xi_m$ is a local resistance coefficient. When ($\xi_m=0$) equation (5) means equality of levels in adjoining sections.

Peculiarity of the unsteady processes at the catastrophic floods is the submergence of the flood plain areas, adjoining at the open channel segments. For this investigations the mathematical models taking into account the water exchange between flood plain and the open channel at the different water level of the floodplain submergence are developed. In dependce on the present situation the following models for the calculation flow in channels with flood plains are used:

- model taking into account the influence of the flood plain through the summery hydraulic characteristics of the channel and the flood plain [3,4];
- model which is based on separation of the channel flow, and the flood plain plays a role of the distributed storage volume [2, 5].

**NUMERICAL METHOD**

With the point of view of the system's theory and the system analysis open channels systems are relating to distributed and local parameter dynamic systems. The open channel system contains two types of the elements: the sections of the open channel with the floodplain and the nodes with the local storage volume and the local inflow (outflow). Distributed hydraulic parameters Z(x,t), Q(x,t)are used for describing the state of flow in the sections of open channels, and local parameters Z*(t), Q*(t), $\Omega^*$(t) for describing the flow in nodes. Difference approximation of the Sent-Venant's equations is used to find distributed parameters and boundary conditions and conjunction conditions for finding local parameters. For approximation of the Sent-Venant's equations we use absolutely stable implicit difference schemas which allow to calculate of unsteady processes with large time steps [1]. Thereat the steps of the difference network along and along are chosen independently and with necessary accuracy requirements. Peculiarity of the investigation problem of the processes in channel systems is necessity of calculation of distributed and local parameters simultaneously at all sections and all nodes. With the mathematical point of view this peculiarity demands to solve the algebraic equation's system of large dimension. By reason of it is necessary to develop economical methods to solve the linear equation's systems which take into account the matrix's structure of the difference equations [1, 6]. Thus for the case of branching (tree-type) systems the special method is developed. In the case of an arbitrary system (with loops) the algorithm of solution is divided into the following two stages. At the first stage at each segment the system of difference equations together with the conjunction conditions (5) and the balance conditions (4) is reduced to the system of linear equations only for water level at nodes $Z_j^*$. Then if the dimension of the received system is not so large the explicit method is used, otherwise it is used the iterative method to compute $Z_j^*$. At the second stage computed quantities' water level at nodes are used to calculate the discharges and the water levels at the each segment's length.

**RESULTS AND DISCUSSION**

Example 1. Storm surge at the Ob-Taz region

The calculation of the storm surge 1988 year (15–20 august) at the Ob-Taz region from p. Salehard and p. Nahodka to p. Tambey was carried out. Length of this calculation region was 1306 km (fig. 1a). As up boundaries of calculation region it were selected p. Salehard and p. Nahodka, in which the corresponding storm surge function of the discharge (in each ones) the rating discharge curve Q = Q(t) in the time of the surge was specified. The down boundary was selected the p. Tambey (sea boundary of the mouth region) at which the storm surge's stage-time curve was specified. At the surge calculation the considering region was divided on 5 sections of a difference length. For the illustration the defining role of meteorological factors (wind, atmospheric pressure) in the surge's forming and the rise of the extreme situation, besides the basis calculation the additional calculation without wind and atmospheric pressure was carried out.

Fig. 1b shows the results of the calculations of the storm surge with the account (dashed) and without (dot-dashed) meteorological factors in a comparison with the nature data (solid).

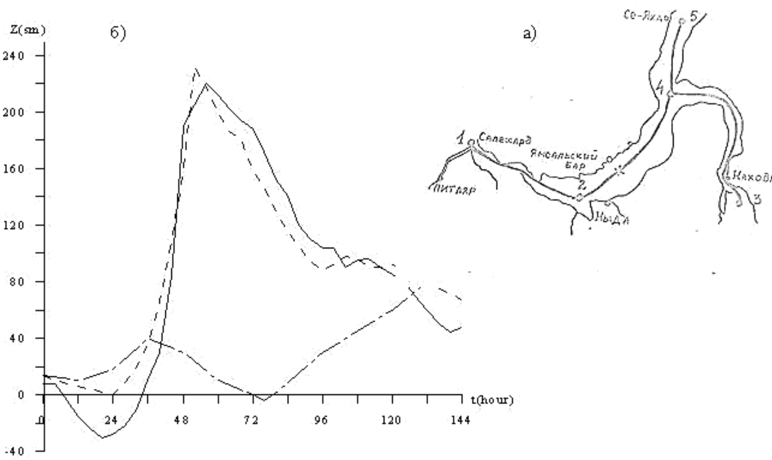


Figure 1. a) The Ob-Taz region's scheme; b) The water level at the storm surge 1988 year (15-20 august) at the Jamsalsky Bar. The solid is the nature lever, the dashed and the dot-dashed are the calculation water levels with and without account of meteorological factors respectively.

Example 2. Spring flooding at Enisey estuary

The mouth region of Enisey river from p. Selivaniha to p. Dikson with the length equal 1329 km was considered (fig. 2a). As the up boundary of this region it was selected the inflow's point N. Tunguska (near p. Selivaniha) where in a strong surge's absence the water level was defined by the water discharges in the river. As the down boundary region it was taken the sea border's Enisey estuary (p. Dikson). At the calculation the considering region was divided on 7 sections of a difference length. Boundary conditions were been: the rating discharge curve Q = Q(t) for the catastrophic flooding 1986 year in p. Selivaniha, the water levels Z = Z(t) in the flooding time in p. Dikson. This both conditions were specified from observations.

Fig. 2b shows the results of the calculations (dash) water levels at the punkts: Igarka, Karaul and Sopochnaja Karga in a comparison with the nature data (solid).

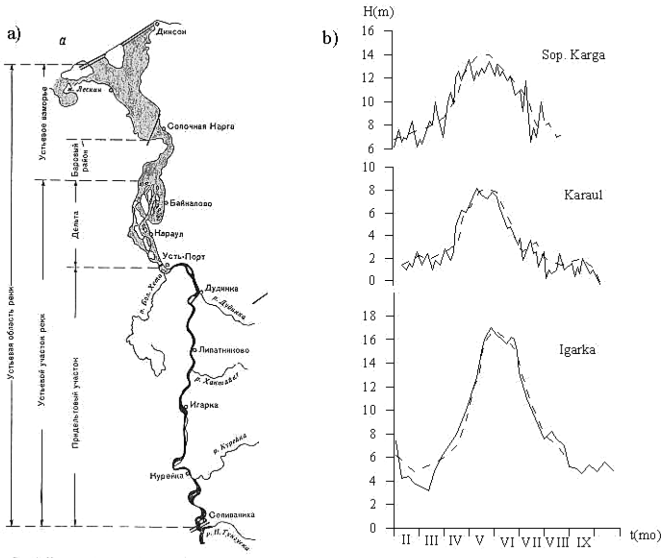


Figure 2. a) The calculated part of estuary r. Enisey scheme; b) The water levels of flooding 1986 year at Igarka, Karaul, Sop. Karga. The solid is the nature level, the dashed is the calculation level.

Example 3.Propagation of waves due to the rupture of a dam

The propagation of wave due to the dam's rupture of the Veselovsky water body was considered. This water body (the volume is equal near 1 billion cub. m, the water surface area is equal near 300 sq. km, the average depth is equal near 4.5 m) is the part of Ust-Manych water supply system. In the time of the full rupture of the dam (hypothetic example) the wave was propagated along Ust-Manych water body. This water body is tail bay of Veselovsky dam, which is transferring into the Manych river. At the 35 km from the dam the Manych river has the inflow (Podpolnaja river). Near their junction there are two bas bridges with connecting dike (fig. 3a).

Fig. 3b shows the results of the propagation of wave for different time moments beginning with 10 min to 10 daily from the dam rupture's moment.

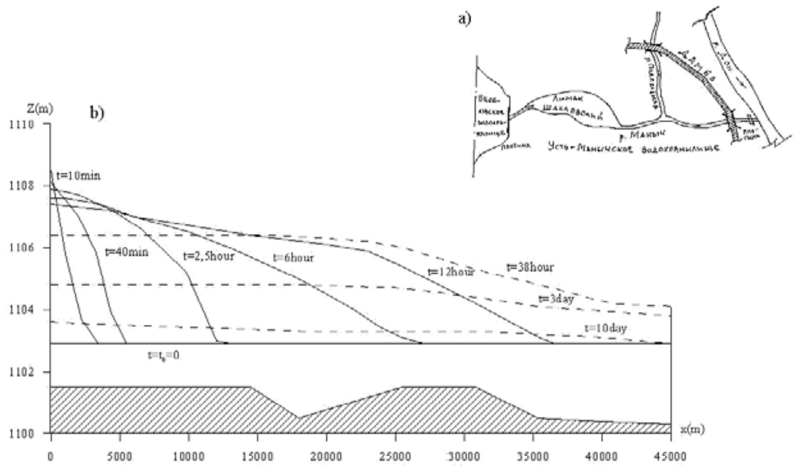


Figure 3. a) The calculated part Ust-Manych water supply system's scheme; b) The propagation of the flush wave at Ust-Manych water body at different time moments.

**CONCLUSION**

The mathematical models, the numerical methods and the complex computer program for solving the wide range of the unsteady problems in the open channels on hy- draulic substantiation of water supply project, the as- sessment of their possible negative environmental impact, development of the effective projective measures are developed. On the basis of this computer models the numerous research of unsteady processes (in particular, to calculate the propagation of the flood waves, release waves in the systems of the open channels) were carried out. The results of the computational experiments and their comparison with the nature data are shown the effi- ciency of application of this development for research of the unsteady processes essentially in the time of cata- strophic phenomena at the water objects.

The research is fulfilled with support within the Pro- gram of RAS Presidium 16.2 and Grant NSh-2260.2008.1.

# THE USE OF ARC VIEW TECHNOLOGIES AND SPECIALIZED DATABASES WITH NUMERICAL SIMULATION OF FLOODING OF NIZHNIY DON FLOOD PLANE

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The research on "Creating electronic model of flooding plane of Nizhniy Don with enabling different means on basis of Arc View Systems" was carried out by order of Administration of Rostovskaya region to make a system of operative control of floods on the territory of Nizhniy Don to prevent and minimize aftereffects. The model can also be used to evaluate the damages from floods and dam failure waves.

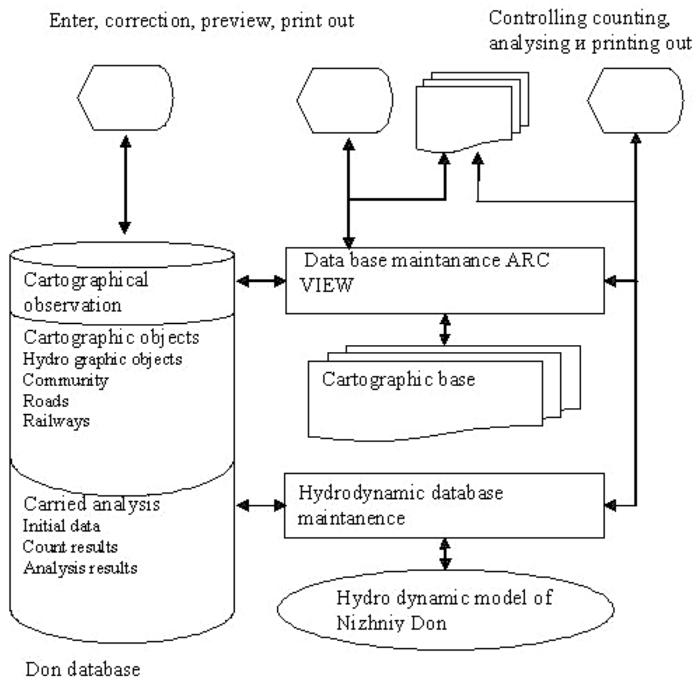
Flooding of Nizhniy Don plain between the Tsimliansky hydropower project and Taganrogskiy Gulf of Azov Sea can appear under different circumstances caused by both natural (high snowmelt flood, water fetch denivelation and their combination) and anthropogenic factors. The latter are terrorist actions that lead to Tsimliansk dam failure that creates the surplus of water, damaging constructions of Tsimliansky hydropower project that needs the emergency drawdown of reservoir for repairing, alarm discharging of polluted water of Tsimliansky reservoir. The flooding of populated areas can lead to economic damages and heavy casualties on the Rostovagglomeration territory.

Therefore making electronic model of flooding of Nizhniy Don flood plain using modern databases geoinformational technologies for operative forecast and monitoring of developing situation is a topical task.

Solving Nizhniy Don Problem has an integrated approach, including the problems of hydrology, computational hydraulics, hydraulics of constructions, hydraulic engineering, economic, energetic, water transport and other field of knowledge. The solution of this problem is highly developed now, but integration of separate tasks to the system with regard to such prolonged object the Don River valley downstream of the Tsimliansky dam is a complicated scientific and engineering task.

**INFORMATIONAL ANALYTIC COMPLEX NIZHNIY DON STRUCTURE**

According to the previous data mathematical basis of computer model of flooded areas were created. Detailed hydrological and other information about Nizhniy Don Basin has been collected, Informational analytic complex Nizhniy Don was worked out. The complex includes subsystems: graphic-informational and research and information (Picture 1)




Pic. 1. Informational Analytic Complex Nizhniy Don Structure

Graphic-Informational subsystem includes Don Database, PC maintenance, cartographical dummy and Arc View version 3.3

Research and information subsystem consists of digital hydrodynamic dummy of the plain and bed of Nizhniy Don, programs that provide research of flood water streams, building thematically graphic strata about water surface, deepness of high water, speed of streams and save the collected data in Don database.

The common element of both systems is don database. The base is built with MS SQL SERVER 2000. It keeps data both on hydrology and description to cartographic objects, results of the carried research of high water streams and summary data of objects that are in the flooded areas.

There is information kept about:

Areas of the region, water objects, level gages, community, water catchments plants, canal spillways, railways, roads, hydro technical constructions etc. All the objects are connected and depicted at the Arc View.

Looking through the information about the object in the base you see its location at the map, after you can select it and get extra data about it from database.

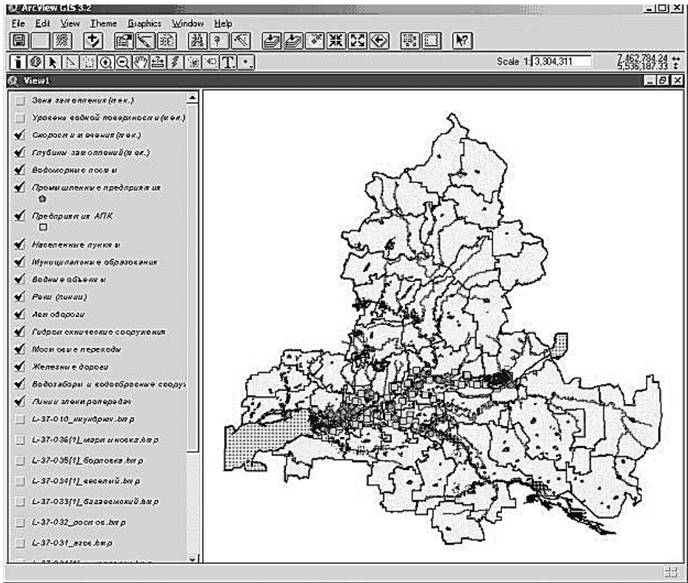
Cartographical dummy is posed by means of digital maps: vector M1:200000 of Rostov region and raster image M 1:100000 of Nizhniy Don Basin. You need to operate ARC VIEW 3.3 to work with them.

Computerized hydro dynamical model of the valley and bed of Nizhniy Don is built on the basis of digital model of the relief (DMR) of and Nizhniy Don Basin in accordance with Saint-Venant two-dimensional equations with use of triangular- rectangular hybrid computation mesh. The model was calibrated with data of high snow-melt floods (including the snow-melt flood of 1917 that had 0.5 % exceedance probability), database Don and computer model were arranged, and suggestions for monitoring of Nizhniy Don were elaborated.

**CREATION OF DIGITAL RELIEF MODEL WITH ARC VIEW**

The basic task of creating the model was to unify different topographical information into one system.

As data base certified topographical maps M 1:200 000 were chosen. The maps are made at Mercator projection on isogonal triangular on Krasovskiy ellipsoid (step of hights 20 metres, accuracy of planned location 60-140 metres. At that time they were only non-secret available maps. (Pictures 2,3)




Pic. 2. Rostov region map M 1:200 000 ArcView.

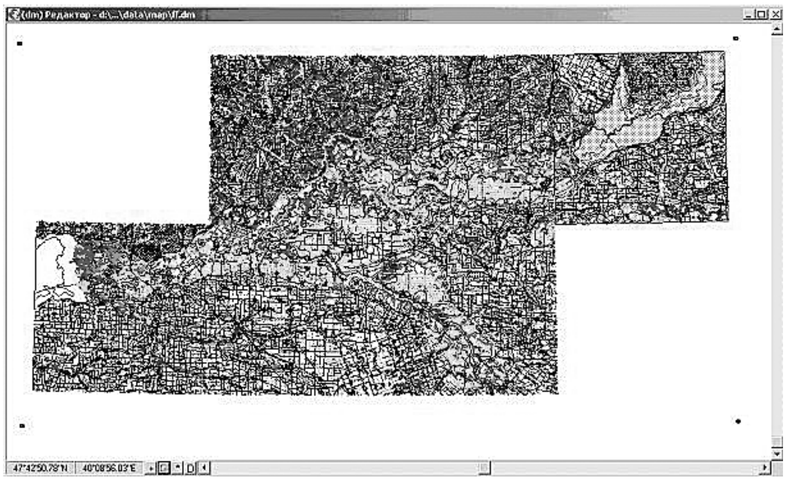
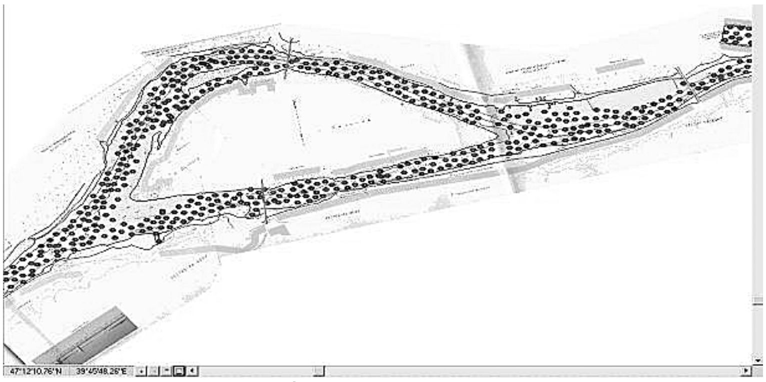


Рисунок 3. Цифровые карты М 1:200 000 на район Нижнего Дона в ГИС «Нева»

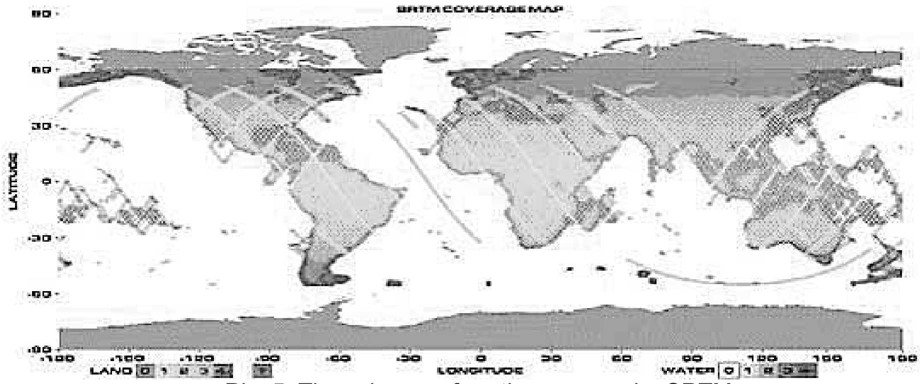
To enter the relief of river bed of Nizhniy Don pilot maps from Atlas of single deep-water system of Russia were used. When the Atlas was created materials of hydrographical works of 2003-2005, aerial photography of 2004, correction collected into navigation in 2005 were also used.

The initial material that is double A3 formatting was scanned, attached to neighbour sheets, digitized and coordinated by basic digital map in Neva. It allowed 20 metres accuracy saving of pilot maps raster on the terrain and the accuracy of deep 0,1 metres (Picture 4).



Pic. 4. Fragment of pilot map raster with digitized objects.

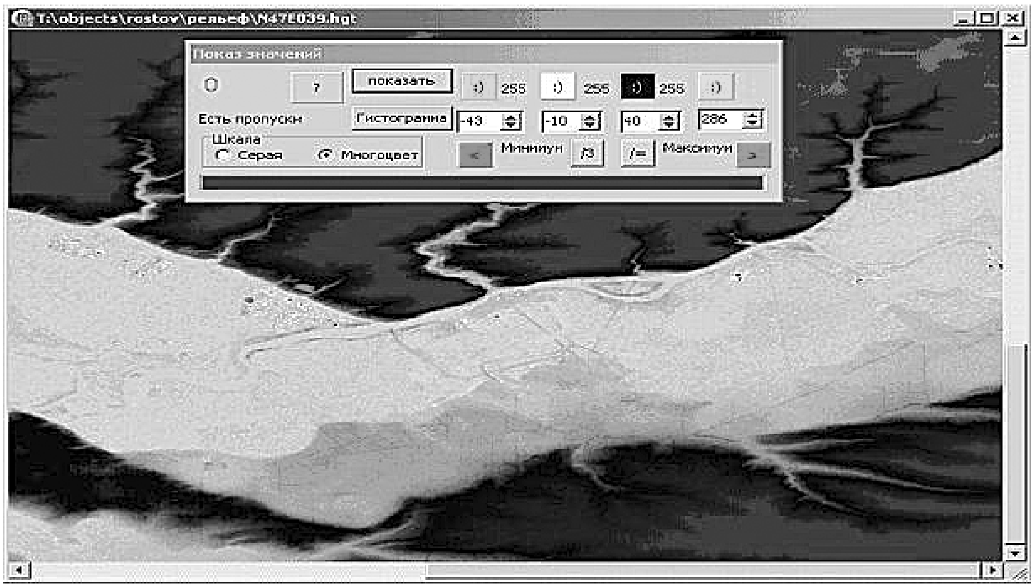
But rather flat plain part of Nizhniy Don basin due to rear step of the horizontal line (20 metres) turned out to be unexpressed. With this end in view the map was completed with radar satellite topography Shuttle radar topographic mission (SRTM) made in February 2000 with two radar sensors SIR-C и X-SAR (рис.5) [1].




Pic. 5. The scheme of earth coverage by SRTM
(Land 0-1-2-3-4, Water 0-1-2-3-4- so many times was the terrain pictured.)

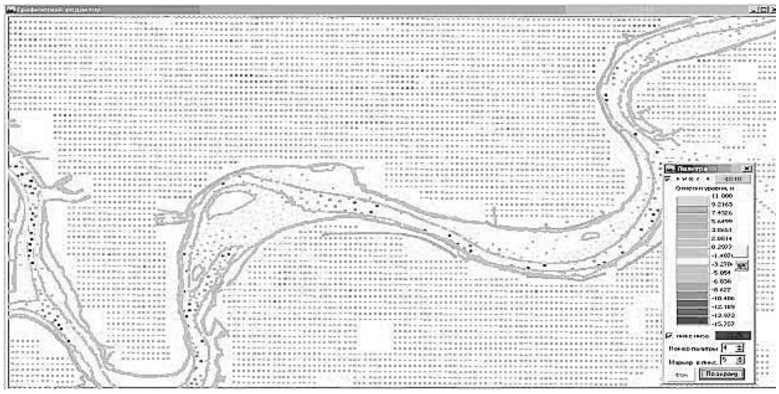
The picture was initially planned to show photos with maximum resolution on the terrain 30 metres (1 angular second) but, due to terrorist attacks general data with resolution 90 meters (3 angular seconds) on all pictured terrain except the USA that has data with maximum resolution on it was decided to be given out.

The results are equal to the specific of interferometer data about the relief (Interferometric Terrain Height Data (ITHD)-2) i.e. the dimension of the element is 30 to 30 metres so 12 meter accuracy by height for plains. Matrica_SRTM.exe(picture 6) was set up to operate this data.




Pic. 6. Radar Matrix of Heights View on Rostov-na-Donu

The data was transformed into appropriate condition, placed to the digital model of the relief and coordinated with the data. The digital model of the relief is in the picture 7

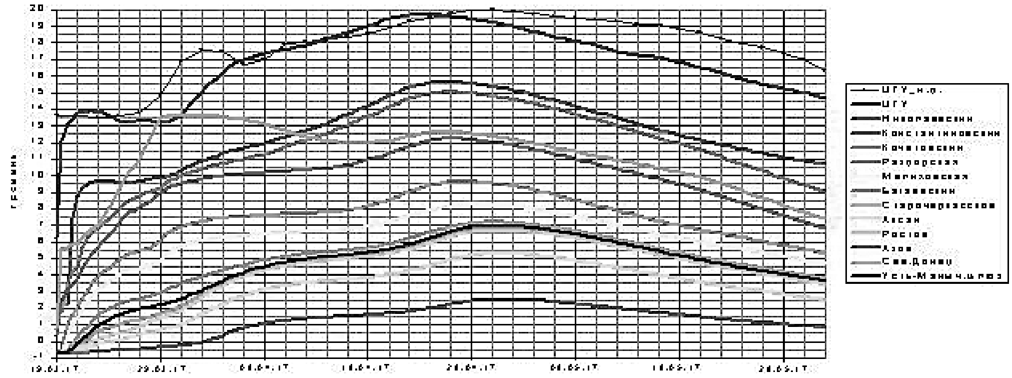


Pic. 7. Fragment of Nizhniy Don Relief Digital Model

According to the developed model of the relief, coordinating with the topographic the Don and its tributaries location adaptive hybrid triangle-quadrangular net of non-constant structure was made.

**RESEARCHING ON THE MODEL**

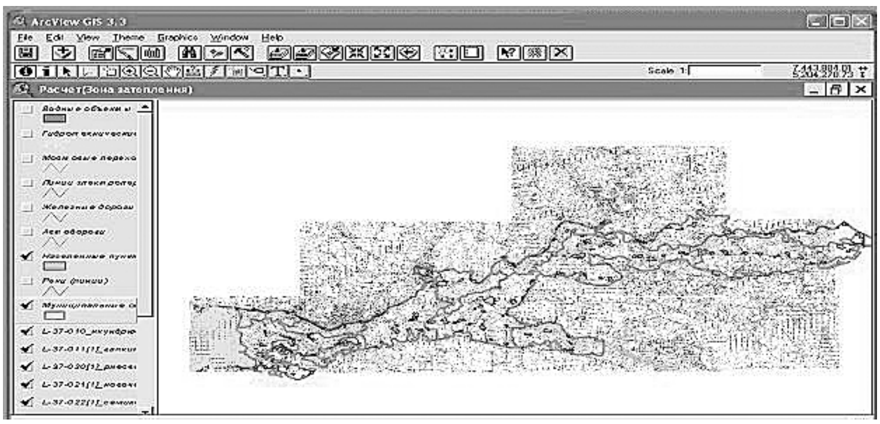
In the Don database information about the flood of 1963 provided by 50 percent (1 time two years) and the high water of 1917 provided by 0,5 percent (1 time 200 years) was put into the system. According to 1963 mathematical model was calibrated. The results show that verification of levels on gages. The results were satisfied.



Pic. 8. High water of 1917. the Comparison of researched and natural data.

After the research a number of themes is created in SHP files. They include flood areas that are built on the basis of characteristics of the stream (levels, deepness, speed of the stream) on showed by a user at moments of time it gives all the information for maximum levels of the period. The files are transferred to the Don Data store and are available for observation (simultaneously with cartographic material) in Arc View.

The demand of or two (even from different researches) flooded themes is foreseen. It allows colliding one to each other, look through the dynamic of high water and the differences between the results of researches. (Picture 9)




Pic. 9. Municipal districts and community in the flooded area.

Afterwards, by means of Arc View themes are built. They are developed by crossing flooded areas built thematically with different themes on the map and the reports of the objects in flooded areas (square of flood, length of roads, population) are given out.

**CONCLUSION**

After the research we can come to the following conclusion:

1. To rise the accuracy of flooded areas by high water a specification and improvement of the worked out electronic model using maps with bigger scale, with the information about roads, bridges etc.

2. Aiming at rising of the accuracy of the research, providing reliability and operability of making prognoses of emergency of high water in flood period it is recommended to improve the system of monitoring of gages of Nizhniy Don basin:

To set up extra gages on each inflow of the Don (Sal, Manich etc)

Within the periods of high water to carry on research by means of the model of Nizhniy don flooded area and coordinating it with data at gages on daily basis.

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## THE ELABORATION OF THE HYDRODYNAMIC MODEL FOR FORECASTING OF DEVELOPMENT AND DISTRIBUTION OF AREA OF POLLUTION IN THE BASIN OF THE AMUR RIVER

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**INTRODUCTION**

Today the emergencies become considerably the dominating factor witch defines the ecological problems of superficial water objects. Thus one of the basic mechanisms allowing effectively minimizing their probable consequence is the presence of the effective methods of forecasting of the development and the distribution of areas of pollution. First of all, the traditional methods of forecasting applied by territorial divisions of Federal Hydrometeorology and Environmental Monitoring Service, was developed before active using modern computer and GIS-TECHNOLOGIES. As a rule it is not yet effective at the decision of complex practical problems. Theoretical researches and practical experience showed that efficiency of the prediction models is appreciably defined by completeness and adequacy of the task of the initial information, first of all, on the morphometry waterway channels. Therefore hydrodynamic models completely adapted for their features should be created for each large, significant water object.

**THE HYDROLOGICAL AND HYDROCHEMICAL MODE OF THE AMOUR RIVER**

In November-December, 2005, the bad experience of forecasting of "cloud" of pollution on Amour confirms very well the position, that the especially model is not adapted for concrete water object and can not show the comprehensible results.

The Amour river flows in East Asia and enters into ten the largest rivers of the world. About 5 million people of the Russian Federation live in 6 subjects in the basin of Amour. The population in "the Chinese part" of Amour basin is 70-100 million people.

The river basin of Amour treats Far East type on conditions of a water mode with strongly pronounced prevalence of a rain fall during the summer autumn period. The share of rain nutrition in total volume of an annual drain makes from 50 to 80 %. On snow nutrition it is necessary from 5 to 20 % and on underground 10-30 % [3]. The mid-annual expense of water of the basin of the Amour river in the region of the city Komsomolska-on-Amour makes about 11 000 $m^3/s$. Take into account the complex morphometry of this drain, its multifunctional, the presence of numerous islands, the model should be build in 2 measured approaches as within the frames of one-dimensional model it will be difficult to describe the merphometrical features of this drain.

The problem of the elaboration of the model of the Amour river consists of some stages. At the first stage, the model of the river is constructed of the rather small section: from a mouth of a confluence of the Sungari river to Khabarovsk in the extent of 240 km. At the second stage, the hydrodynamic model of a section of the Amour river from Khabarovsk to Komsomolska-on-Amour was developed. The extent is 325 km.

More than 70 percent of the Russian population of river basin use water for drink from Amour and its inflows - the Argun rivers, Shilka, Zeya, Bureya, Ussuri and others. Daily consumption by the city of Khabarovsk of superficial waters of the Amour river and its channels makes 442.000 m cube. The economic-drinking water supply consists of 289 m. cube [4, 5, and 6].

In the territory of the Russian Federation, in 1997, the volume of the sewage dumped in the basin of Amour has made 691 million $м^3$. The total volume of polluting substances is 234.000. In comparison with 1991, the volume of dumped polluting substances has decreased twice in the basin of Amour (in 1991 - 467000) [2].

The part of the Peoples Republic of China in the total amount of pollution varies from 75 to 90 %, in particular, in connection with influence of the Sungari river on its reservoir the industry and agriculture quickly develops, cities grow.

As in China with its quickly growing economy in northern areas and particular basins of the Sungari river, the probability of the large men - caused damages will be only increase [7]. Therefore, there is the necessity of the elaboration of constantly operating hydrodynamic models to increase the stability of the system of the water supply of the basin of Amour. This model is capable not only effectively to describe the distribution to them of the polluting substances

**PROBLEM STATEMENT**

The hydrodynamic model of the Amour river from the confluence of the Sungari river to Komsomolska-on-Amour is developed in 2 measured statements with use of licensed software product SMS V 9.2. Specific feature of the considered section of the Amour river is its complex morphometry, the presence of considerable quantity of islands and complex system of the channel in the channel Complexity morphometry water object defines also the complexity of its hydrodynamics, and accordingly transportation of polluting substances.

For the proved task of the initial hydrological and hydro chemical data in the model of calculations, the analysis of the hydrological and hydro chemical mode of the Amour river in its middle course was carried out. It was used the materials of network supervision on the network of Federal Hydrometeorology and Environmental Monitoring Service from 1964 on 2005 .During the year, the structure of variability of a drain of the Amour river was carried out. [1] The presence of the statistically significant tendencies (with use of Stiudent`s criterion and nonparametric criterion of Mann - Whitny) increases of water - content the rivers during the winter period (December-March) was showed. At the same time, during other period of year, it was observed the considerable stability of the considered numbers of the drain. On separate months the functions of the distribution of the expense of water for convenience of using was constructed.

**GENERAL CHARACTERISTIC OF HYDRODYNAMIC MODEL**

In 2006, in the laboratory of the modeling of the environment of the University Brigham Young, the software product SMS V 9.2 was developed. Under the order and participation of the Center of hydraulic researches (HEC) cases of military engineers of army of the USA and Federal management on highways of the USA (FNWA) (www.ems-i.com). The general documentation on software product SMS V 9.2 is stated in 7 volumes [8-15]. The total volume is over 2000 pages of the text.

The mathematical model used in software product SMS V 9.2 is based on the well investigated, classical system of the shallow - water equations of lays. It became already for the decision of considered problems.

The basic equations of quantity of the movement of shallow - water and the continuity of the equation have the following appearance:

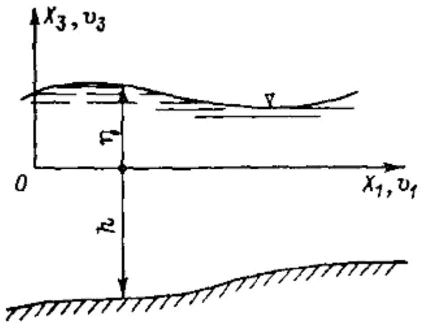


Figure 1: To designations in. the shallow - water equations

$$\frac{\partial q_1}{\partial t}+\frac{\partial}{\partial x_1}\left(\frac{q_1^2}{H}\right)+\frac{\partial}{\partial x_2}\left(\frac{q_1 q_2}{H}\right)=\frac{\partial}{\partial x_1}\left(N_{11}-N_p\right)+\frac{\partial N_{12}}{\partial x_2}+B_1;$$

$$\frac{\partial q_2}{\partial t}+\frac{\partial}{\partial x_1}\left(\frac{q_1 q_2}{H}\right)+\frac{\partial}{\partial x_2}\left(\frac{q_2^2}{H}\right)=\frac{\partial}{\partial x_2}\left(N_{22}-N_p\right)+\frac{\partial N_{12}}{\partial x_1}+B_2; \quad (1)$$

$$\frac{\partial q_1}{\partial x_1}+\frac{\partial q_2}{\partial x_2}+\frac{\partial(\rho H)}{\partial t}=0,$$

Where

$$B_1=fq_2+\gamma^2\rho_a W\cos\theta-\frac{g}{c^2}\frac{1}{\rho}\frac{q_1\left(q_1^2+q_2^2\right)^{\frac{1}{2}}}{H^2}+\rho_a\frac{\partial H}{\partial x_1}+\rho g H\frac{\partial h}{\partial x_1};$$

$$B_2=-fq_1+\gamma^2\rho_a W\sin\theta-\frac{g}{c^2}\frac{1}{\rho}\frac{q_2\left(q_1^2+q_2^2\right)^{\frac{1}{2}}}{H^2}+\rho_a\frac{\partial H}{\partial x_2}+\rho g H\frac{\partial h}{\partial x_2}. \quad (2)$$

$$N_p=\int_{-h}^{\eta}p\,dx_3=\rho g\frac{H^2}{2}+H\rho_a; \quad N_{11}\approx 2\varepsilon_{11}\frac{\partial q_1}{\partial x_1};$$

$$N_{22}\approx 2\varepsilon_{22}\frac{\partial q_2}{\partial x_2}; \quad N_{12}\approx\varepsilon_{12}\left(\frac{\partial q_1}{\partial x_2}+\frac{\partial q_2}{\partial x_1}\right). \quad (3)$$

$$q_k=\int_{-h}^{\eta}\rho\upsilon_k\,dx_3=\rho\int_{-h}^{\eta}\upsilon_k\,dx_3, \quad H=h+\eta,$$

Where $q_k$ – the quantity of fluid flow (the weight of the fluid falling to unit of length and time);

$\varepsilon_{ik}$ – The generalized coefficients of vortical viscosity; for isotropic character of current $\varepsilon_{11}=\varepsilon_{22}=\varepsilon_{12}=\varepsilon$;

$x_1, x_2, x_3, t$ – The Cartesian co-ordinates and time;

$\eta$ – Eminence of a free surface (fig. 1);

h – Depth measured from a base surface (not necessarily horizontal);

$f=2H\omega\sin\varphi$ – Effect of Coriolis, where $\omega$ – the speed of angular rotation of the earth, $\varphi$ – local latitude;

$g/c^2$ – Dimensionless coefficient;

g – Acceleration of gravity;

c – Friction coefficient or factor of Chezy;

$\rho$ – Water density.

$\gamma^2$ – Dimensionless coefficient, or the coefficient of the wind tension approximately equal 0,0026;

$\rho_a$ – Air density;

W – Speed of a wind;

$\theta$ – An angle between axis and a wind direction.

The equation convectional-diffusion carrying over can be written down in such manner:

$$\rho\left\{\frac{\partial\theta}{\partial t}+\upsilon_i\frac{\partial\theta}{\partial x_i}\right\}=\rho p+\rho\frac{\partial}{\partial x_i}\left(K_{ii}\frac{\partial\theta}{\partial x_i}\right), \quad (4)$$

Where $\theta=\rho_1/\rho$ - concentration of substance;

$\rho$ - Density of substance plus the fluid density, i.e. $\rho=\rho_1+\rho_2$;

$\rho_1$ - Weight of substance in individual volume of a mix, diffusing in the fluid of full density $\rho$;

$\rho_2$ - Fluid density;

$\rho$ - An external supply (the speed of the distributed supply falling to a mass unit);

$K_{ii}$ - Full coefficient of the diffusion, i.e. $K_{ii}=K_{ii}^m+K_{ii}^t$;

$K_{ii}^m$ - The coefficient of molecular diffusion;

$K_{ii}^t$ - The coefficient of turbulent diffusion.

Table 1. Set boundary and initial conditions on a section of the modeling of the Amour from the confluence of the Sungari river to Khabarovsk.

| The water expense in the rivers, Q, cubic m./s. | | | | Water level, H, abs. M. |
|---|---|---|---|---|
| The Sungari river | The Amour river new | The Amour river - a channel middle | The Usury river | The Amour river - below of Khabarovsk |
| 800 | 600 | 300 | 200 | 30 |

**RESULTS OF MODELLING**

The results of modeling are presented in fig.2 - 5.

The moment from animation of a field of speeds is shown in fig. 2. It can be made in program SMS V 9.2 by results of the calculations.

On the river Amour in the region of the confluence of the Sungari river, the field of speeds is shown in fig.3. It turns out at modeling with particularly set boundary and initial conditions

On the river Amour in the region of the confluence of the Sungari river, the card-scheme of model of calculations of distribution of "stain" of pollution, in 1 days of measurement is shown in fig. 4. It turns out at modeling with particularly set boundary and initial conditions and as with the set initial conditions of the formation of the area of pollution.

On the Amour river in the region of Khabarovsk, the card-scheme of model of calculations of the distribution of "stain" of pollution in 24 days of measurement is shown in fig. 5. It turns out at modeling with particularly set boundary and initial conditions and as with the set initial conditions of the formation of the area of pollution.

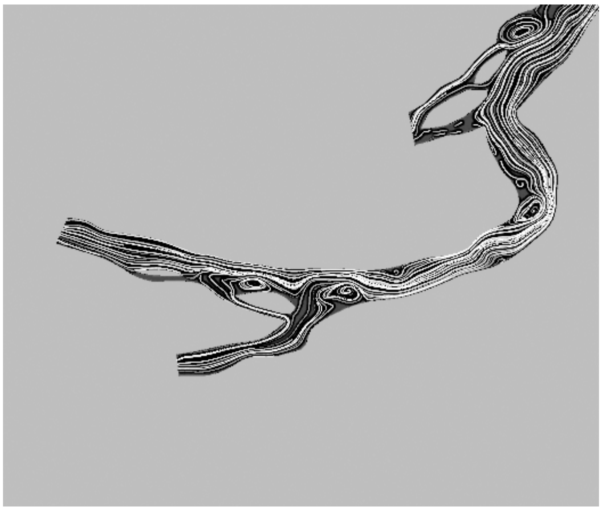

Fig. 2: the picture of the animation of the field of speeds on the Amour river in the region of the confluence of the Sungari river

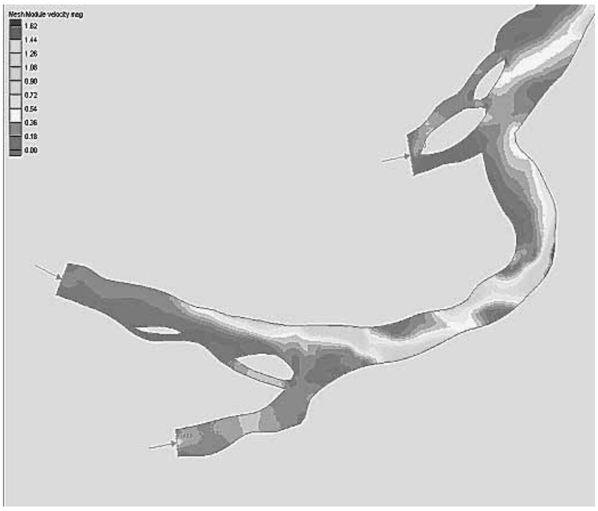

Fig. 3: the distribution of the field of speeds to the Amour river in the region of the confluence of the Sungari river

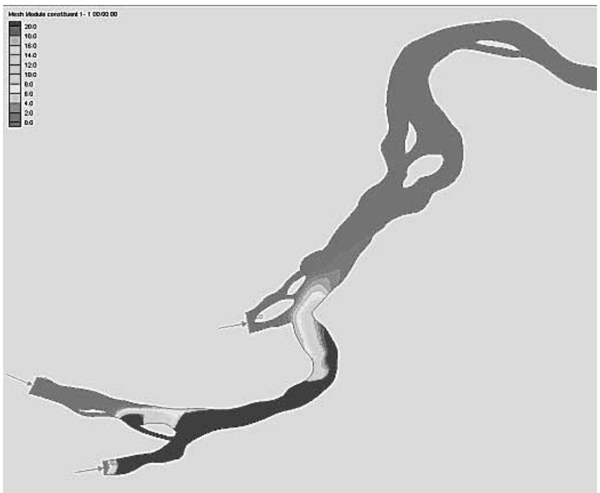

Fig. 4: the card-scheme of the model of calculations of the distribution of the "stain" of pollution in 1 days of measurement on the Amour river in the region of the confluence of the Sungari river

Fig. 5: the card-scheme of the model of calculations of the distribution of the "stain" of pollution in 24 days of measurement on the Amour river in the region of Khabarovsk

**CONCLUSION**

The hydrodynamic model of the river Amour from the confluence of the Sungari river to Komsomolska-on-Amour with use of licensed software product SMS V 9.2 was developed in 2 measured statements. Specific feature of the considered section of the Amour river is its complex morphometry, the presence of the considerable quantity in the drain of islands and complex system of the channel. Complexity morphometry water object defines also complexity of its hydrodynamics and accordingly the transportation of polluting substances.

As initial data for creation electronic schemes of maps the considered section of the Amour river and the subsequent construction of the settlement grids were used:

- Large-scale maps of territory of M 1:25000, M 1:50000;
- Specialized cards-schemes of ship courses (pilot charts of the Middle Amour of survey of 2004 and cameral processing of 2005).
- Large-scale space pictures, presented by cartographical server “The Earth” in Google.
- Created the hydrodynamic model, witch demands the task for carrying out of the operative calculations of following the initial data:
- Co-ordinates and capacity of the sources of pollution (if pollution has arrived through the river of the

Sungari river and Usury river the operational expenses of the given water currents were set;

- Structure and concentration of limiting polluting substances;
- Background concentration of considered limiting substances in the Amour river;
- The expense of the Amour river in a background alignment (above the Sungari river);
- The water levels on border of a settlement section (at Khabarovsks or Komsomolsk-on-Amour).

In November-December, 2005 and January, 2006, for the verification of the parameters, the model materials of supervision over stain passage nitrobenzene pollution of the Amour river have been collected, analyzed and transferred on technical carriers.

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## ZONING OF RUSSIA BY HIGH FLOOD HAZARD IN THE CONTEXT OF CLIMATE CHANGE, AND OPPORTUNITY TO IMPROVE INFORMATION SUPPORT ON FLOOD GENERATION

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Climate changes at the turn of 20/21 centuries throughout territory of Russia contributed to frequent occurrence of high (exceptional) or catastrophic floods causing damage to farming, communities, and infrastructure. Annual data, collected by GU BNIIGMI-MDTs, on hazardous flood with recorded damage in the period of 1991-2007 indicate that in many economic regions of Russia, at the beginning of 21 century, recurrence of high and catastrophic floods increased, and the average increase over 2001-2007, as against past decade, is 15%. Maximum increase in catastrophic flood occurrence was observed in rivers of North Caucasus, south of the Far East, western Siberia, and the Volga region. Hazardous flood cause analysis over the past decade is indicative of the increase in their levels during spring tide caused by snow or snow-and-rain, as well as abundant rainfall, and blockage on early flooding. High water and rain freshet were responsible for hazardous flood in 85% of cases, ice block in 10%, wind surge in 5%, out of total number of floods. Average time of hazardous flood is 5 days, maximum is more than 40. Long total duration of hazardous flood is characteristic of piedmont regions of the Caucasus, Altai, Trans-Baikal, Primorye.

To improve the information-and-prediction support, and to alert to the possibility of high, or catastrophic flood, Roshydromet should renew and extend route observations of snow cover in mountains, proceed with gamma survey, design computer database covering the whole period of observations. Moreover, it should be taken into ac- count that the most important cause for flood is growth of water capacity in snow cover, particularly in highland catchment area. It is necessary to enlarge the network of rainstorm gauging station to predict high water period. Hydrological observation data that are prepared and published every year should contain information on hazardous floods, and hydrometeorological factors responsible for their generation.

## ANALYSIS OF EXTREME WATER LEVELS IN THE RAPIDLY CHANGING ENVIRONMENT IN THE PEARL RIVER DELTA, SOUTH CHINA

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### INTRODUCTION

River deltas are natural dynamic coastal systems that are unique in their close links to both land-based fluvial and coastal ocean processes, holding the ecological and economic value throughout the world (Ericson et al., 2006; Pont et al., 2002). The crisscross river network (density: 0.68-1.07 km/km$^2$) in the Pearl River Delta (PRD) is one of the most complicated deltaic drainage systems in the world (Chen and Chen, 2002). Represented by the “Golden Triangle” of Zhuhai-Hong Kong-Macau, the PRD has a highly dense agglomeration of over 100 towns and cities. It has been the fastest developing region in China since the country adopted the “open door and reform” policy in the late 1970s. On less than 0.5% of the country’s territory, the PRD region produces about 20% of the national GDP, attracts about 30% of Foreign Direct Investment, and contributes about 40% of export (therefore called “World Factory”). Highly developed social economy makes the PRD vulnerable to flood, drought, and other natural hazards. Moreover, increasingly intensified human activities have caused considerable hydrological alterations in the PRD. Since the early 1980s, human interferences and impacts of sea-level variations on hydrological processes in the PRD are: 1) intensive in-channel dredging and sand mining, which caused significant in-channel geomorphological alterations and broke the natural balance of the filling-scouring process within the river channels; 2) reallocation of the streamflow and sediment loads within the river channels of the PRD because of construction of levees and sand dredging; 3) elevating sea level in the estuary leading to the backwater effect, which further intensified the prevalent sediment deposition in the river mouths and results in the salinity intrusion in the PRD. Therefore, better understanding of water level behaviors over the PRD region will be of scientific and practical merits in regional human mitigation of flood/drought hazards and water resource management. The objectives of this paper are: 1) to detect trends and variations of the frequency extreme water levels over certain time intervals (relative frequency); 2) to examine the spatial patterns of the relative frequency trends of extreme water levels and possible underlying causes; and 3) to analyze change points and the associated statistical properties.

DATA AND METHODS

The monthly mean high/low water level data covering 1958-2005 were collected from 19 gauging stations in the PRD. The location of the gauging stations can be referred to Fig. 1.

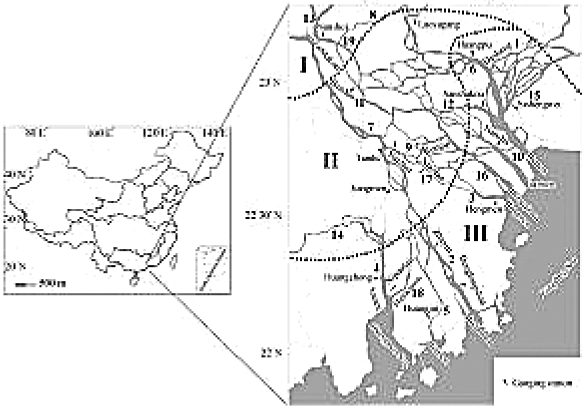


Figure 1. Location of the Pearl River Delta in China and gauging stations. The river channels denoted with numbers are where the gauging stations are located. The names of the river channels are listed as following: 1: North mainstem East River; 2: Modaomen channel; 3: Hengmen channel; 4: Yamen channel; 5: Jitimen channel; 6: Mainstem Zhujiang River; 7: Xijiang channel; 8: Xi'nanyong channel; 9: Ronggui channel; 10: Jiaomen channel; 11: Shunde channel; 12: Shawan channel; 13: Beijiang Channel; 14: Tanjiang channel; 15: South mainstem East River; 16: Hongqili channel; 17: Xiaolan channel; 18: Hutiaomen channel; 19: Dongping channel. The Pearl River Delta is divided into three parts based on its geomorphology as: I: the upper Pearl River Delta; II: the middle Pearl River Delta and III: the lower Pearl River Delta. Region I, region II and region III divided by dashed lines are the upper, middle and lower PRD.

The lengths of the data vary and some stations have missing data for some periods. The missing data are filled based on neighboring stations using regression method ($R^2$ > 0.8 and even $R^2$ > 0.95). The current research focuses on the extreme monthly water levels (the monthly highest/lowest water levels), because the extreme high/low water levels are closely related to floods, salinity intrusion, which have the paramount role to play in the local water resource management and human mitigation to flood hazards in the Pearl River Delta. The extreme water levels are defined as those exceeding/falling below a given threshold (known as partial duration series) (Bordi, et al., 2006). In PD analysis, we are interested in the behavior of large numbers of observations that exceed/fall below a priori threshold. The thresholds decided herein are two cases, i.e. mean±std, which can be applied for better comparison between the data collected before and after the possible abrupt changes resulted from intensive human activities which are common in the PRD (e.g. Yoo, 2006). The trends will be detected by the simple linear regression method. In terms of change point analysis, there are many methods available for abrupt changes in the hydro-meteorological series. However it is not the main objective of this text to compare the advantages/disadvantages of those available methods. In this paper, two methods are used in this study, i.e. the Bayesian model for a single change in the mean levels of the time series (Chernoff & Zacks, 1963; Berger, 1985; Kotz & Wu, 2000; Xiong and Guo, 2004) and Lepage test (Lepage, 1971). The Bayesian model requires that the time series follow the normal distribution. In the case that the hydrologic data fail the normality test, the Box-Cox transformation (Box & Jenkins, 1976) must be implemented to transform the original data series into a new series with a normal distribution (Xiong & Guo, 2004).

**RESULTS**

**Linear trends of the extreme water levels**

Fig. 2A demonstrates linear trends of the relative frequency of the extreme high water level above mean+std threshold (HWLa). It can be seen from Fig. 2A that the HWLa of majority of the stations in the Pearl River Delta (PRD) is decreasing, and these stations are mostly located in the middle and upper PRD (see regions circled by the dashed line). The stations with decreasing HWLa account for about 59% of the total stations in the PRD. However, only 4 stations have the significant decreasing HWLa, accounting for about 30% of the total stations with decreasing HWLa. The stations with increasing HWLa are located sparsely along the coastal regions of the lower PRD (Fig. 2A, Fig. 1). Statistically speaking, if the trend of the time series is not significant at the priori defined confidence level (95% confidence level in this study), the time series is suggested to be in no trend. Therefore, the HWLa of most stations of the PRD is not in significant trend. 8 stations have significant trend of the HWLa, accounting for 34.8% of the total stations of the PRD. Fig. 2B shows the linear trends of the relative frequency of the extreme water level defined as those falling below mean-std threshold (HWLb). Most stations in the PRD are dominated by the decreasing HWLb. The decreasing HWLb are mainly identified across the middle and lower PRD. Only 6 stations are featured by the increasing HWLb, accounting for 18% of the total stations. The majority of the stations are dominated by significant trend of the HWLb, accounting for 65% of the total stations of the PRD. The significant trend of the HWLb is largely identified in the upper and middle PRD. The PRD is dominated by the significant decreasing LWLa (Figures now shown here), and the stations with decreasing LWLa are uniformly distributed across

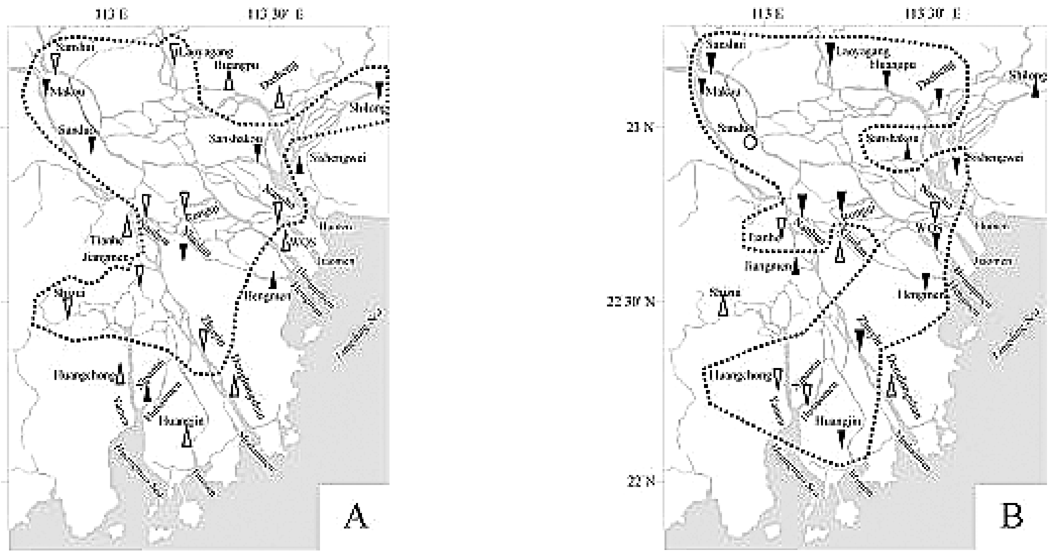


Figure 2. Annual variability of the relative frequency of the extreme water levels exceeding/ falling below certain thresholds. A: The trends of the relative frequency of the extreme high water level exceeding mean+std threshold; B: The trends of the relative frequency of the extreme high water level falling below mean-std threshold. The triangles denote increasing/decreasing relative frequency of high/low water level (no trend); The solid triangles denote significant increasing/decreasing trend of the relative frequency of the high/low water level. The circles denote zero frequency. Stations dominated by decreasing water level are circled by dashed lines. WQS is the abbreviation of the Wangquanshaxi station.

the PRD. The stations with decreasing LWLa account for about 59% of the total stations of the PRD. The upper PRD, middle PRD and parts of the lower PRD are dominated by significant trend of the LWLa. The significant increasing LWLa is identified mainly along the coastal regions. The upper PRD is dominated by the significant decreasing LWLa. 3 stations have significant decreasing LWLa, i.e. Zhuyin, Xipaotai and Denglongshan. No trend can be detected in the LWLa of Rongqi, Xiaolan, Tianhe and Huangpu in the middle PRD and along the Qianhangxian channel and Ronggui channel (Fig. 1). The upper PRD is dominated by significant increasing LWLb (Figures now shown here), however the significant decreasing LWLb can be identified in the lower PRD. 3 stations in the lower PRD are featured by significant increasing LWLb, i.e. Xipaotai, Zhuyin and Denglongshan. The middle PRD seems to be a transitional zone with significant increasing LWLb and significant decreasing LWLb. However majority of the stations have significant increasing LWLb, accounting for 55.6% of the total stations in the middle PRD.

**Change points and associated properties**

Seven out of 19 stations have two change points. Wherein, 4 stations are located in the middle PRD (i.e. Laoyagang, Rongqi, Sanduo and Xiaolan) and 3 stations in the lower PRD (Sanshakou, Sishengwei and Denglongshan). 11 out of 19 stations have one change point, and only one station, i.e. Xipaotai, has no change point. The first change point of 1979-1981 is identified mainly in the middle PRD region. The statistic characteristics of the summer mean high water level (SmH) prior/posterior to the change point suggested decreasing mean SmH for Sanduo, Laoyagang, Rongqi, Xiaolan and Denglongshan, and increasing mean SmH for Sanshakou and Sishengwei. Decreasing Cv can be observed in Laoyagang, Sishengwei, Rongqi, Xiaolan and Denglongshan, and increasing one in Sanduo and Sanshakou. The second change point largely occurred to two time intervals, i.e. 1991-1994 and 1979-1981. The first time interval involves 13 stations, accounting for 68% of the total stations and the second time interval involves 4 stations, accounting for 21% of the total stations.

The change point of SmH series of the Sanshakou occurred to ~1988. Thereby, the change point of the SmH across the PRD mainly occurred to 1991-1994. Fig. 3A depicts increased mean SmH after second change point (i.e. 1991-1994 and 1979-1981). The lower Xijiang channel, the upper Modaomen channel, the lower Shawan channel and the Tanjiang channel are dominated by decreased mean SmH after second change point. Larger Cv after second change point can be observed in the upper and lower PRD. A majority of the middle PRD is dominated by the decreased Cv. Fig. 3 indicates that the PRD region covered by Sanduo, Rongqi, Sanshakou and Huangpu is characterized by increased mean and decreased Cv of SmH. The Sanshui and Makou exhibit decrease mean and increased Cv of SmH. Decrease mean and Cv of SmH after second change point characterized water level changes in the lower Xijiang channel, the upper Modaomen channel and the Tianjiang channel.

Five out of 19 stations have two change points in 1979, 1974 and 1970. 3 stations with change points of 1979 are located along the Ronggui channel in the middle PRD (i.e. Rongqi, Sanduo and Xiaolan), and 2 stations have change points occurred in 1974 and 1970 in the lower PRD (i.e. Nansha and Sanshakou). The decreased mean and increased Cv of SmL are observed in Nanshan Sanshakou. 8 out 19 stations have second change point during 1979-1985; 7 out of 19 stations have change points during 1990-1995. Only 2 stations have change points in 1967 (i.e. Sishengwei and Huangchong) and 2 stations (i.e. Denglongshan and Xipaotai) have no change point. The upper PRD, upper Modaomen channel, Tanjiang channel and lower PRD are dominated by the decreased mean SmL. The rest parts of the PRD are controlled by the increased mean summer mean low water level (SmL). The spatial patterns of the Cv of the SmL seem to display the adverse patterns, except the Ronggui channel and the Shunde channel. Therefore, posterior to second change point the decreased mean SmL is usually accompanied by increased Cv and vice versa.

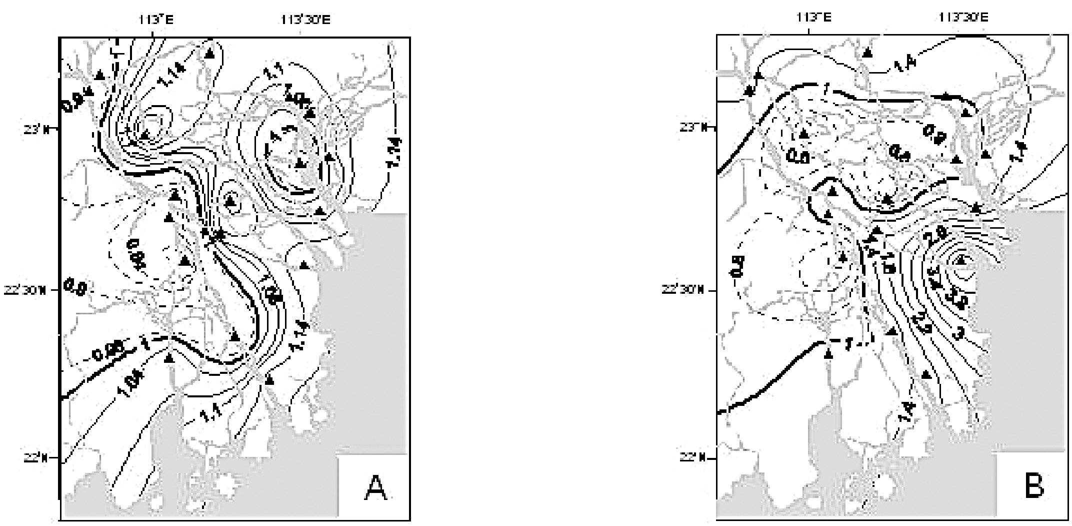


Figure 3. Spatial patterns of the mean and the coefficient of variations (Cv) of the segments divided by the change points. Fig. 3A shows the ratio of the average of the summer mean high water level posterior/prior to the second change point. Fig. 3B shows the ratio of the coefficient of the variations of the summer mean high water level posterior/prior to the second change point. The solid triangles in the figure and in the following figures are gauging stations.

The timing of change points of mean high water level in winter (WmH). First change points occurred mainly during 1969-1975. The stations having change points during 1969-1975 are mostly located in the lower PRD. 1993 witnessed the second change points in the lower PRD. Second change point in the middle PRD is detected mainly during 1981-1988. The second change point in WmH series of Makou and Sanshui in the upper PRD was found in 1995 and 1983 respectively. No significant abrupt changes can be detected in the WmH series of Zhuyin. The increased mean WmH characterized the first abrupt changes of the WmH. Decreased mean WmH can be identified in the Tanhe channel, the lower Modaomen channel and the Xijiang channel (Figures not shown here). Decreased Cv can be observed in the Tanjiang channel, the lower Modaomen channel and the south mainstem East River. Most parts of the PRD are characterized by increased Cv posterior to the first change point. The south mainstem East River is dominated by increased mean and decreased Cv of WmH (Figures not shown here). However, decreased mean and increased Cv of WmH can be observed in the Xijiang channel. Decreased mean and Cv of WmH are detected in the Tanjiang channel.

The stations having two change points account for 74% of the total stations. No abrupt changes can be detected in the WmL series of Huangpu station. 47% stations have first change point during 1967-1975 and 21% stations during 1983-1985. The second abrupt changes occurred mainly during 1990-1995 and 1980-1983. The first abrupt changes in the Modaomen, Yameng, Jitimen, Tanjiang, Shunde and Ronggui channel are characterized by increased mean WmL. Larger increase of mean WmL can be identified in the upper Modaomen channel. Most parts of PRD are dominated by increased WmL Cv, decreased WmL Cv however, can be observed in the upper Modaomen, south mainstem East River and Humen. The upper Modaomen channel is dominated by increased mean but decreased Cv of WmL (Figures not shown here). Decreased mean but increased Cv of WmL can be identified in the lower Xijiang channel. Increased mean WmL characterized second abrupt changes over large parts of the PRD (Figures not shown here).

**CONCLUSION**

The relative frequency of the high water level exhibits changes not significant at >95% confidence level. The variations of the relative frequency of the high water level are characterized by the decreasing variability, especially in the middle PRD. The significant increasing frequency of the high water level occurred in the south mainstem East River channel, the Hengmen channel and the Hutiaomen channel. However more stations show significant changes of the relative frequency of the low water level across the PRD. The upper PRD is dominated by the significant decreasing trend of the lower water level, and significant increasing low water level can be identified in the lower PRD. No confirmative changing patterns of the relative frequency of the low water level can be detected in the middle PRD.

Abrupt changes of SmH/SmL largely occurred to two time intervals: 1979-1981 and 1988-1995. Less than 37% stations have two change points. The lower PRD is dominated by increased mean and Cv but decreased mean and Cv of the SmH can be identified in Tanjiang and lower Xijiang channel. Decreased mean but increased Cv characterized SmH in the upper Xijiang channel. The PRD region covered by lower Shunde channel, Shawan channel and Mainstem Zhujiang River is dominated by increased mean but decreased Cv of SmH. SmL of the Mainstem Zhujiang River is characterized by increased mean but decreased Cv. Increase mean and CV of the SmL can be observed in Shunde and Shawan channel. With respect to WmL and WmH, about 74% stations have two change points. The first abrupt change occurred mainly during 1969-1971 and the second abrupt change during 1993-1995. The first abrupt changes are characterized by increased mean and Cv of WmH but decreased mean and increased Cv of WmL across major parts of the PRD. Larger Cv of WmH/WmL can be identified in the Ronggui channel, lower Xijaing channel and Shawan channel. After the second change point, the lower PRD is dominated by increased mean and Cv of WmH, decreased mean but increase Cv of WmL. The Xijiang and Tanjiang channel are dominated by decreased mean, increased Cv of WmH and by increased mean and Cv of WmL. No distinct spatial patterns can be identified for the mean and Cv of WmH/WmL across the PRD, showing the complicated and various factors for alterations of the winter mean high/low water levels across the PRD.

Changes of the water level across the PRD are heavily influenced by human activities, especially by the in-channel sand dredging. The construction of the levee may aggregate streamflow in the channel and which may be beneficial for the rising of water level. However, more streamflow in the channels will lead to more serious scouring process and deepening of the river channel, which will lead to the decreasing water level. This offset effect will be changing in different river channels and will also be influenced by different intensities of the in-channel dredging and sand mining. The different roles of the sand dredging and the construction of levees in tidal alterations within the river channels in the PRD are necessary for further research in the future. It should be noted herein that the climatic changes (precipitation changes and changes of the streamflow from upper PRD) and sea level changes also exert tremendous impacts on the spatial and temporal variability of the water levels in the PRD. In addition, when do the abrupt changes occur? And what are the statistical features for the water levels before/after the change points? All these questions will be addressed in the further research.

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## PROBLEMS OF MONITORING AND MANAGEMENT OF A RIVER-WATER INTAKE UNDER THE CONDITIONS OF EXTREMAL INFLUENCE OF A MEGAPOLIS

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**INTRODUCTION**

The Moscow megapolis (14 million inhabitants) is located in the middle, in terms of water abundance, of the river Moscow (nowadays, the monthly average flow rate at an inlet to the city makes 35 m3/s). It has caused a significant part of environmental problems of the river-water intake. It has extremely various polluting inflows, its hydrological regime has been disturbed (the flow rate is doubled due to the Volga water); the river has been regulated by dams. As against the majority of large cities in Europe, in Moscow a separate system of water removal has been adopted, at which a contribution of diffusive pollution originated from superficial drain is always significant. Within the boundaries of the city, a probability exists, of unexpected discharges of polluting substances, associated with failures on transport, or with switching-off of electric power (at industrial objects and purifying facilities). Under the prevalent situation, the functioning of water-resource system should be considered as extremal. No standard approaches are applicable to the given conditions in terms of supervision and regulation of the quality of water in the river. This article sets forth the ways of obtaining solutions to the problems arising in the various areas of ecological monitoring.

**The tasks of monitoring**

The tasks of ecological monitoring of the river: 1) evaluation of today's situation; 2) evaluation of the trends and forecasting of future situations; 3) acquisition of information for the water quality control system.

**THE PROBLEMS WHILE FINDING SOLUTIONS FOR THE TASKS OF MONITORING**

Problems of evaluation of today's condition of the river

The adopted ways of evaluation of the condition of water intake: 1) comparison against background parameters, 2) comparison against standards (hydro-chemical, hydro-biological, toxicological).

The river, at an exit from the city, consists of 55% of biologically purified waters (BPW), of actually, of the Moscow River and Volga water, in approximately, equal portions. The problem is: to determine the background parameters of the river.

Hydro-chemical parameters. In the Russian Federation, the pisciculture-economic (MPCp/e) hydro-chemical standards have been adopted as the basic standards. These standards characterise the quality of water which is not influencing ability to live of the most sensitive water organisms. The majority of water quality evaluations, including calculation of the water pollution index (WPI) are based on comparison against these standards [1]. Based on this parameter, the river at the exit from the city, during the last 50 years, should have been attributed to the category of "very dirty" and "extremely dirty". However, starting from 1996-1997, the water in the river was not toxic, according to bio-testing [2], and a plenty of fishes inhabit the river within the city boundaries [3]. The problem is: to adjust the hydro-chemical parameters, develop new approaches towards the water quality evaluation.

Hydro-biological parameters. It has been acknowledged, that nowadays there is no unified, complete and balanced technique for evaluation of the quality of water based on hydro-biological parameters [4]. Along with BPW, hydrobionts of active sludge related to the groups of poly-and meso-saprobes, are discharged into the river. Presence of such organisms in samples, "automatically" worsens hydro-biological parameters of water. At the same time, the latest investigations have shown that the introduced biocenosis plays an essential role in self-purification [5]. The problem is: to select hydro-biological criterion, not only fixing the difference from natural hydro-biocenosis, but also evaluating the vector of development of the ecological system.

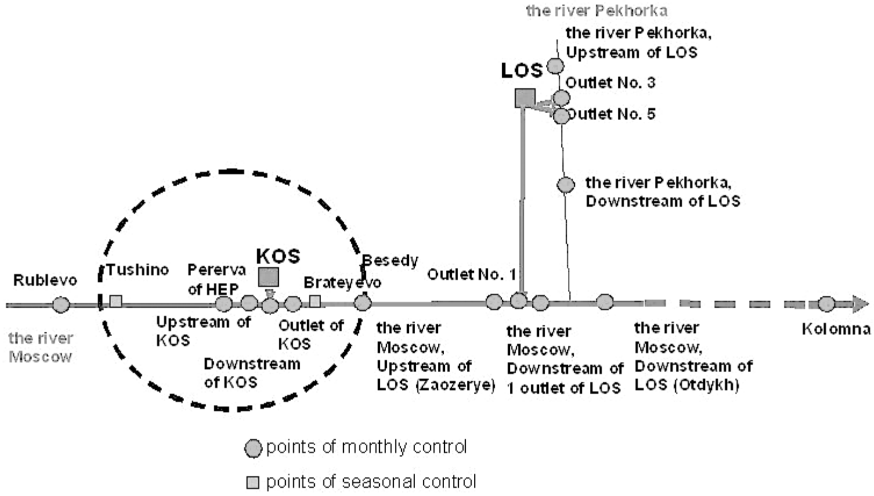


Figure 1. Location of the points of ecological monitoring of the "Mosvodokanal" MSUE and nowadays existing purifying facilities (Kolomna is the point of control of the MosCGMS-R).

Toxicological parameters. In the discharging area of KOS (Kuryanovo Waste Water Treatment Plant) (fig. 1) the waters differing in their composition mix up, which assumes chemical interactions. In the river, the prevailing pollutants upstream of the discharge include: petroleum products, organic toxic agents, heavy metals. In the BPW these include nutrients (phosphates; ammonium, nitrite and nitrate salts), organic substance (suspended and dissolved). In the area of mixture the index of toxicity [2] is reduced. At that there are evidences, that decrease in toxicity is possible in case of forms of existence of toxic agents [6]. The problem is: to select the most sensitive objects for testing.

Thus, hydro-chemical, hydro-biological and toxicological standards (and methods of their determination) should be adapted to the conditions of high antropogenic loading.

**Problems of forecasting**

Quantitative index of loading of the river. Loading in the river that collects drains of a megapolis is determined by drains that vary extremely in their quality and hydrological regime. The quality of the majority of them (except for economic-household) is not subject to forecasting. The problem is: to find the parameters allowing to predict the overall loading of the river.

Forecast of the quality of water downstream of the outlet of the drains is constructed based on the account of processes of self-purification (calculation of dilution, or application of the known empirical dependences). The forecast is complicated by that the processes of self-purification change in time. Empirical dependences typical for one year cannot be used the next year without corrections. The problem is: to evaluate the processes of self-purification that determine these dependences.

Problems of water quality control for a river with a prevalence of diffusive drain

In a water-intake river, either spot, or diffusive sources of pollution prevail. Control of the quality in such situations should be built based on different algorithms. In the first case – according to the current legislation (search of the polluting source, normalization of its discharge, introduction of modern technologies of purification). In the second case, this is the intensification of the processes of self-purification in the water intake itself. The river Moscow is related to the second case. For the purpose of improvement of quality in the rivers with the prevalence of diffusive pollution there are no commonly adopted algorithms of management; neither there is a normative base and legislative mechanism for application of possible methods of intensification of self-purification.

The programs of management of the quality of water in a water intake are developed for a long-term perspective (planning of the development of purifying and hydraulics engineering constructions) and for elimination of emergency situations. Biologically purified waters influence hydrological, hydro-chemical regimes of the river and the structural-functional characteristics of biocenosis. The problem is: to develop an algorithm for application of this effect in the management of water quality for the case of emergency situations and in a long-term outlook.

**The purpose of this work**

The above discussed problems form a unified complex (Fig. 2); many of them are associated with each other and cannot be solved separately. Revealing of the problems ecological monitoring of the river subjected to such a considerable anthropogenic influence, and seeking of their solution constitute the purpose of the given work.

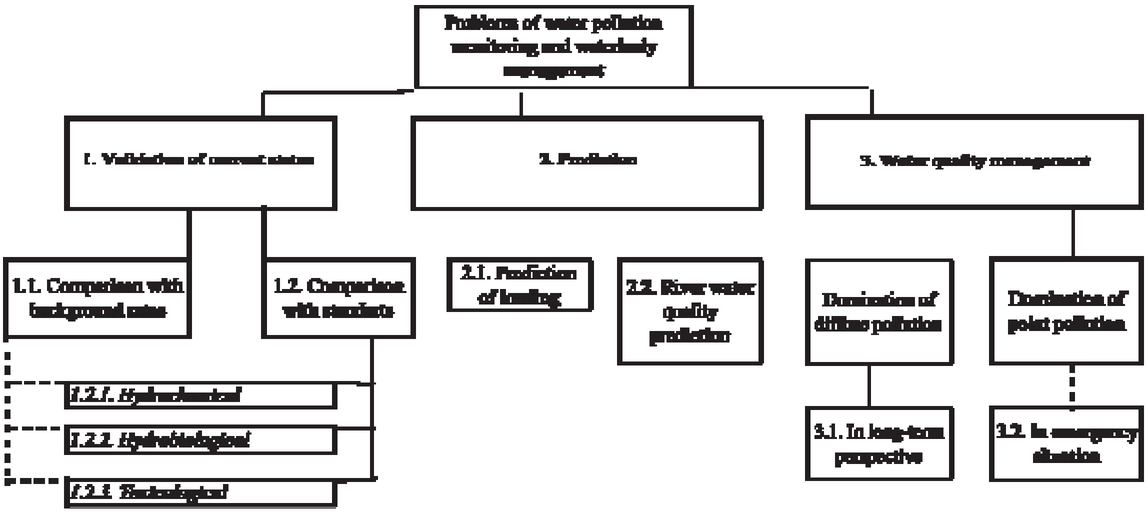


Figure 1. Complex of problems of ecological monitoring for a river-water intake with high anthropogenic loading.

**OBJECTS AND METHODS**

The given research has been accomplished on the basis of a database created using the results of chemical, biological and hydrological observations performed by the "Mosvodokanal" MSUE (within the sector of the river more than 100 km from the entry of the river into the city, up to the mouth) during the years of 1898-2007. The composition of water, bottom sediments and biota of the river were analyzed (using standard methods). Nowadays the "Mosvodokanal" MSUE performs regular ecological monitoring in 10 points along the river Moscow, within the city boundaries and downstream thereof (Fig. 1).

**RESULTS AND DISCUSSION**

1. Evaluation of today's condition of the river

1.1. Comparison against background parameters. One of the methods of evaluation of pollution of natural environments consists in comparison against background parameters. The background parameters obtained for the various rivers which analysis was carried out at the end of the 19th - beginning of the 20th century in many respects defined the level of the standards now adopted in the world. The estimation "based on background" assumes an opportunity of returning of the environment (water, soil, air) to the background condition. Ecological monitoring of the river Moscow was being performed starting from the end of the 19th century in the points upstream of the city, downstream thereof, and within the boundaries thereof. There is considerable information available about the quality of water, for a period of 100 years of observations. From among the points which can be selected for "background", the most regular observations were performed in Rublevo (the river upstream of the entry to the city). The analysis of the database shows that within the sector of 57 km which the river passes from Rublevo up to the outlet of the first purifying facility (KOS) mineralization of water nowadays raises from 220 up to 390 mg/l, the ionic composition of water changes considerably. The basic cations and anions rating of water (in %/ equiv.) shows: the composition changes from hydrocarbonate magnesium-calcium to chloride-hydrocarbonate magnesium-calcium-sodium. The share of nitrates, sulphates, salts of potassium and ammonium becomes noticeable among soluble salts downstream of the outlets of purifying facilities. The characteristic of water at the exit from the city: nitrate-sulphate-chloride-hydrocarbonate calcium-potassium-sodium. In the city sector acidification of the river water takes place (pH is reduced from 8.2 to 7.4), associated, in the first place, with the increase in the share of nitrates, and secondly, with formation of organic acids while decomposition of allochtonous organic substance (OS). The general mineralization downstream of the city, up to the mouth of the river (Kolomna) stays at the level of 430-500 mg/l. Similar changes in the composition of salts are typical for the majority of the rivers in the world [7, 8]. The above mentioned changes in the composition of water within the sector of the city for the river are not convertible.

The increase in a mineralization of more than by a factor of 2 entails change in the ionic force of solution, which influences the processes of sedimentation/cosedimentation, solubility of salts and organic compositions in bottom sediments. In addition, it influences sorption properties of suspended substances (SS) of the river. And the main thing is that such ionic composition changes the forms of existence of toxic agents, either "masking", or increasing their toxicity. Our bio-testing data (on ceriodaphnia, fishes, infusoria and algae) have confirmed the data of other laboratories: from the middle of 90s, the water within the city boundaries and downstream thereof is not toxic without diluting, whereas earlier dilution safe for bio-tests made 10-20 times. Regular hydro-biological monitoring since 1999 has shown, that ecological system of the river functions as a complete one, it represents all trophic levels, the density of fish populations downstream of the outlets is one of the highest along the river [9].

Thus, for the river in which pH and general mineralization are changed irreversibly, comparison of the content of anthropogenic toxic agents (petroleum products, heavy metals) against their background values would be incorrect. The direction of further research should become the evaluation of influence of increased mineralization of water on toxicity, and advisably, development of "correction factors" for MPC.

1.2.1. Hydro-chemical specifications. The impossibility to return background ionic composition and mineralization of water dictates new approaches to hydro-chemical standards. In case of pollution with a prevalence of diffusive sources, the tendencies in improvement of the quality of water in terms of content of anthropogenic pollutants appear on the foreground, rather than the estimation of absolute pollution. These tendencies are offered to be estimated in terms of the speed of self-purification for the various sectors of the river (mg/(l day)). Comparison of the speed of self-purification against the data on the variety of species of the river communities (for long-term series of observations), allows to assert, that the maximum speed of self-purification by general nitrogen and OS corresponded to the periods with maximum variety of species of plankton and benthos communities and minimal values of the index of toxicity [10].

Thus, the speed of self-purification within a certain sector of the river can be an integrated parameter of ecological condition of the river. Such method of valuation is especially topical for shallow rivers suffering from significant loading by economic-household drains. The evaluation here should reflect which maximum quantity of non-conservative pollutant the river is capable to "process". Monitoring in such a case is not so much hydrochemical or hydro-biological, but continues technological, carried out in purifying facilities. While realisation of this monitoring, it is possible to recommend observance of some rules: 1) between the points of monitoring, contribution of inflows should not exceed 15%; 2) the control of flow rates of the river is obligatory; 3) acquisition and analysis of the data should cover all points of monitoring, for creation of a database of speeds of self-purification.

1.2.2. Hydro-biological methods. Saprobe index, adopted in hydro-biological monitoring for plankton communities does not reflect long-term changes of quality of river water. This was demonstrated by the analysis of observations performed within the city sector of the river. For almost 100 year period of observations, the saprobe index for zoo- and phytoplankton corresponded to -mesosaprobe river, despite of significant changes of water quality. Thus, BOD5 for the section line downstream of the city (Otdykh) during 1950s – 70s and during 2000s, was on the average equal to 10 and 3 mg $O_2$/litre, respectively.

The majority of hydro-biological methods are extremely laborious, they demand involvement of highly skilled experts and can not always be applied in industrial ecological monitoring. The most commonly used and developed technique consists in evaluation of biomass of plankton communities: zoo-, phyto- and bacterial plankton. We propose to perform evaluation of the share of OS and N in plankton communities (phyto-, zoo- and bacterial plankton) in the total suspended OS and N. In case where such evaluation is performed in the points of hydro-chemical and hydrological monitoring, then the result would be determination of the speed of involving of OS or N in plankton communities.

In this case, the speed of growth of plankton communities (by analogy with the speed of self-purification), and also the ratio between the quantity of OS (and Ntot) in plankton communities and the total content of suspended OS (and Ntot), serve as quantitative indexes for evaluation of production processes in the river.

Increase in the share of OS in hydrobionts and, accordingly, decrease in the share of detritus testifies to development of ecological system. The deviation from the norm should be deemed to be decrease in these parameters from average value for a particular sector of the river.

1.2.3. Methods of bio-testing are applied in ecological monitoring by the "Mosvodokanal" MSUE since 1999. It is known, that hydro-chemical monitoring does not cover the entire list of dangerous pollutants of the river. As it was mentioned already, decrease in toxicity was observed in 90s, which did not have an effect on WPI. The analysis of long-term data has shown, that the most sensitive for BPW is the evaluation of toxicity based on chemotaxis of Infusoria using the "Biotester-2" device [11]. The method has revealed increase of toxicity in BPW during spring and autumn periods, which is associated with supply of highly toxic superficial drains to the purifying facilities.

The investigations performed, have allowed to develop new approach to revealing the source of pollution. In the section line, upstream of all outlets of the city purifying facilities (Pererva), the index of toxicity was determined monthly. Dependence of the share of superficial drain upon the index of toxicity was revealed within the city boundaries, which was calculated based on the difference of the flow rate of the river at the entry to the city (Tushino), and the flow rate of the river upstream of the outlet of KOS (Pererva). Direct dependence between the index of toxicity and the share of superficial drain has been found (factor of correlation 0.66). Thus, a direct dependence between the index of toxicity in the section line of the river and the flow rate of the drains supplied upstream of the section line can serve as an indirect confirmation of toxicity of these drains.

The reason of the observed decrease in the index of toxicity downstream of the outlets of BPW can be sedimentation/cosedimentation of heavy metals in the form of poorly soluble compositions [12]. The factors promoting this process include increased content of phosphates in BPW and growth of SS downstream of the outlets due to production of phyto- and bacterial plankton. This problem requires studying, and moreover, in two aspects: 1) influence of sedimentation/cosedimentation of metals in the zone of outlet of BPW on toxicity; 2) use of the process in the management of quality of water downstream of the outlet.

2. Forecasting of the river loading and quality of river water

2.1. Forecasting of the loading. As the analysis has shown, loading of the river is reflected adequately by general loading from the city by bio-oxidized organic and inorganic substances [13]. Decrease in loading occurred due to reduction of the share of non-purified economic-household drains and increase if efficiency of purification. We have shown that achievement of critical level of loading from the city (40 t of BOD/day), which took place in the mid 90s of the last century, had an effect on the stabilisation of the oxygen regime, and, as a consequence, on the increase of biodiversity and a biomass of river communities.

2.2. Forecasting of the quality of water in the river. Until the mid 90s, the process determining the oxygen mode of the river and the structure of biocenosis, was oxidation of OS. Now, the oxygen regime is stable, the processes of nitri-denitrification take place more distinctly. The last 10 years have shown that while forecasting the quality of water in the river based on N, it is necessary to take these processes into account. The speed of removal of nitrogen in the river is proportional to the biomass of nitrification bacteria supplied into the river along with BPW [5].

3. Water quality management

The river Moscow is related to rivers with prevalence of diffusive pollution. With the development of new technologies of purification and their introduction in municipal economy, the share of diffusive drain will only grow. Therefore the task of intensification of self-purification of the river is extremely topical. Monitoring of the processes of self-purification and development of the ecological system of the river along the sector from the entry into the city (Rublevo) up to the mouth of the river have allowed to reveal the major factors on which the self-purification depends. This has allowed to develop the concept of water quality management in the area of outlet of BPW. The management is possible due to changes in the quality of BPW (within hours-days and in the long-term outlook).

3.1. In the long-term outlook. The anthropogenic increase in the flow rate of the river (twice) and temperature of water (the river does not freeze along to the very mouth since 70s of the 20th century) cannot be reduced without special technical solutions. An uncooperative attitude towards change of water balance of the city water systems, or thermal influence of cities should be replaced with constructive search of optimal utilization of this additional energy supplied into ecological systems of rivers-water intakes. It is known, that rise in temperature accelerates biochemical processes. The zone of the river downstream of outlets of BPW with temperature in the river not below 8°C during the winter period can be considered as a zone of creation of specific ecotopes that clean the river most effectively.

The water encroachment of the river resulted in increase of current in the lower reaches with respect to upper reaches. That disturbed hydrological regime at which the velocities became lower towards the mouth. The new hydrological regime has caused creation in the river of an atypical (for the rivers of our climatic belt) sector functioning as nitri-denitrification running reactor. In the thickness of water, nitrification process takes place, and in the constantly muddled benthonic layer (because of high speeds of current) – denitrification process. The availability of sufficient mixing between the zones allows the river to remove more than 50% of nitrogen supplied in it from the city. Nowadays the efficiency of functioning of the described reactor depends on the supply of nitrification bacteria along with BPW.

It is known, that the course of denitrification process is accompanied by degradation of many complex OS, which plays a role in purification of bottom sediments from organic toxic agents. Until the time, when toxic organic compositions are supplied along with a superficial drain of the city territory into the river, the content of forms of nitrogen and SS (contents of a biomass of bacteria), an effective course of denitrification should be provided in the purified waters. That is, the standards for BPW, regarding N and SS, should be developed with the account of this process.

An indirect influence of the quality of BPW on the quality of river water is shown through changes in biocenosis of the river. It is possible through such parameters of BPW, like N/P, concentration of biomass of bacteria and specific structure of plankton community (active sludge). With traditional ways of biological purification (without removal of biogenic elements), the management would only be possible through increase of SS and biomass of bacteria. With realisation of technologies of removal of nutrients, management through the ration of N/P in the purified water becomes possible. Thus, transfer of SS from purifying facilities should be considered as not only a pollution, but also as a way of management of the quality of river water. For more details about a possibility of influence, through the quality of BPW, on structural-functional characteristics of ecological system (fine adjustment of ecological system), see the work by N.M. Shchegolkova published in the same collection.

3.2. In emergency situations. Purifying facilities function in a non-standard mode in case of emergency switching-off of electric power. It is necessary to take into account the emergency buffering of the facilities shown in the ability to perform partial purification under the conditions of nominal discontinuance of their operation (when switching-off electric power supply). According to the results of monitoring of man-caused failure of May, 2005 (after sudden switching-off of electricity), and additional laboratory-industrial research, that value was established. For classical purifying facilities of biological purification, it makes 5-10 hours, depending on the design volume of the facilities [14].

As it has already been noted, while mixing of the polluted river waters and BPW, sedimentation/cosedimentation of heavy metals downstream of outlet takes place, as well as formation of sediments with lowered mobility of metals. The use of this process for purifying of the river to remove toxic metals supplied upstream of the outlet of BPW requires special research, and can be applied in case of extreme ejection of toxic metals upstream of the outlet of BPW.

Thus, the processes of self-purification of the river, which can be controlled in an emergency and regular mode, include removal of nitrogen and organic toxic agents, sorption and sedimentation of conservative toxic agents (through changes in concentration of SS).

**CONCLUSIONS**

Quality of water in rivers with an increased anthropogenic loading should be evaluated based on the parameters describing the processes of self-purification of ecological system. Such parameters include speed of self-purification with removal of nitrogen and organic substance, speed of growth of plankton communities. Loading is predicted based on total supply of bio-oxidized organic and inorganic substances from drains of the city. Forecasting of quality of water downstream of outlets of BPW should take into account the processes of biological self-purification which are changeable in time and depend on the properties of the system of "the river - purification facility - the river". While monitoring and management of the water-resource system subjected to significant loading from diffusive pollution, it would be necessary to use hydro-chemical and hydro-biological influence of BPW for intensification of self-purification of the river.

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## DECISION SUPPORT SYSTEM RECASS FOR LARGE-SCALE RADIOACTIVE CONTAMINATION OF WATER BODIES

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**INTRODUTION**

As consequences of large-scale nuclear accident large amount of rivers and lakes around potential dangerous nuclear facilities could be polluted. For people and environmental risk assessment in case of emergencies the decision making support systems are developed. The decision support system in case of emergencies entailing radiation contamination of environment RECASS (RadioECological Analysis Support System) have been developed in FEERC NPS Typhoon of Roshydromet. Hydrological module of RECASS system is the component part of this system. It has been developed for assessment and prediction of surface water contamination after atmospheric deposition of radioactive materials and their further transport into river network.

Hydrological module of RECASS includes the software for simulations of contyaminant transport and dispersion in surface waters after their deposition from the atmosphere and also after direct spill of pollutant into rivers or reservoirs. Hydrological module contains GIS-oriented hydrological database and software for collecting and calculations of hydrological parameters for contaminant transport simulations.

Operational forecasts are conducted for short-term assessments (several days after nuclear accident) and must be prepared in very short time. Thus simple one-dimensional and two-dimensional models are used for predictions. They include main radionuclides transport processes (advective transport, hydrodynamic dispersion in rivers and turbulent diffusion in reservoirs). The processes or radioactive decay also included in the models.

For determination of real hydrological and hydrometrical parameters of rivers parametrical relations between these parameters is used based on analysis of long-term hydrological measurements with using of operative hydrological data from gauging stations.

Hydrological module of RECASS is used for simulations of radionuclides concentration distribution in water bodies. Results of simulation can be presented on computer maps as distributions of concentration at some time after accident and as time-varying concentration of contaminant curves for the individual river points near inhabited localities.

**THE MODEL OF RADIONUCLIDES TRANSPORT IN SUFACE WATER SYSTEM**

Advection-dispersion-decay transport equations could be written for depth and width averaged (for rivers) and depth-averaged (for lakes) concentration of radionuclides for all river network around NPS or other nuclear facilities. River system is divided into series of parcels (reaches) which characterized by uniform average hydrological and hydrometrical parameters (length, width. depth, discharge, stream velocity)

The continuity equation for radionuclide transport in rivers and channels is:

$$\frac{\partial C}{\partial t} = -U\ \frac{\partial C}{\partial x} + D\frac{\partial^2 C}{\partial x^2} - \gamma \cdot C + q\ , \quad (1)$$

were C is linear concentration of radionuclide, Bq/m; t is time, s, x is longitudinal coordinate, m, U is average stream velocity, m/s, D is hydrodynamic dispersion coefficient, $m^2/s$, is radioactive decay constant, $s^{-1}$, q is source of radionuclide, Bq/(m•s).

Hydrodynamic dispersion coefficient $D = D_x$ for rivers having width less than 10 m can be defined by following formula [1]:

$$D_x = 1.806 \cdot H \cdot u \cdot c^{-0.63}\left(\frac{B}{H}\right), \quad (2)$$

where B is average width (m), H is average depth (m), c is Shezy coefficient ($m^{0.5}/s$). For streams with B>10 another formula is used:

$$D_x = 43000 \cdot H \cdot u \cdot C^{-02.63}, \quad (3)$$

Large lakes and reservoirs are also divided into parcels which are exchanged the water through flow streams and turbulent diffusion. For lake and reservoirs two-dimensional analogue of equation (1) is used where $D=D_l$ . Parameter $D_l$ depends on specific length of contaminant patch according to formula:

$$D_l = a \cdot L^{\beta}, \quad (4)$$

where a= 3.2 $10^{-4}$, b= 1.1. Mean width of individual lake parcel is used for specific length value.

The analysis of vertical mixing data for lakes [2] shows that after deposition of contaminant on the surface of stratificated lake it very rapidly mixed in upper several-meters layer and very slowly penetrates into deeper layers. Thus for short-term prediction model the depth of lakes and reservoirs is restricted by value H=5 meters. For uniform parcels an approximation of full mixing is used.

**HYDROLOGICAL MAKET**

Main problem in modeling of surface water contamination is the wide river network situated around nuclear power stations or other nuclear facilities. The river systems contain hundreds or even thousands river and lake parcels which could be contaminated in the case of large-scale nuclear accident. For installation of model simulations we must define all hydrological and hydrometrical parameters for each particular parcel (depth, width, stream velocity etc.), their geographical coordinates and relationships between all parcels. In order to enable input parameters for model simulations of radionuclides transport in river network a special software tool Hydrological maket has been developed. Hydrological maket can be used for creation of hydrological database for particular regions around nuclear facilities. The basis of Hydrological maket is cartographical data obtained with using of GIS MapInfo. These data can be converted to Hydrological maket format (*.RHM – RECASS HydroModel). For creation and editing of Hydrological maket special software Redactor of Hydromaket has been developed. It allows not only creation of new databases but also operative correction of existing ones.

Hydrological maket are presented by sets of graphical items corresponding to water objects – river or lake parcel. Each water object has a set of average hydrological and hydrometrical parameters. Logical relations defining water exchange direction between neighboring water objects are established.

Hydrological maket are developed on the basis of average annual historical discharge data from gauging stations. In the absence of annual data the average discharge $Q_{ave}$ values can be calculated from river parcels length and water balance at river nodes. For river parcels which are sources $Q_{ave}$ are calculated by formula:

$$Q_{cp} = 0.0014 \cdot \left( \frac{L}{L_0} \right)^P, \quad (5)$$

where L is parcel length, m, $L_0$, P – are varying regional coefficients.

For regions around a nuclear facilities discharge and hydrometrical data are available only for several river parcels. Analyzing long-standing historic data from gauging stations we builded parametric relationships between hydrometric parameters and discharge for each particular region. These relationships are used for calculation of hydrometrical parameters of all river parcels.

Hydrological maket contains all geographical and hydrological parameters for rivers and reservoirs in the region of several kilometers around nuclear plants. Another complication in simulation of contaminant transport arises from great variability of hydrological data during the year. In order to consider the seasonal variations we developed databank of current values of stage and discharges for all hydrological measuring network of Roshydromet. The data are accepted automatically during simulations. Set of parameters are introduced into Hydrological maket which enable the correction of depth, width and stream velocity of rivers according to real hydrological conditions. Real river parameters are calculated as function of discharge measuring at basic gauging station using parametric relationships for each geographical region. The empirical relations between hydrological parameters are:

$Q=Q_{cp} \bullet K$, $B=B_{cp} \bullet K^{pB}$, $H=H_{cp} \bullet K^{pB}$, $U=Q/(B \bullet H)$, (6)

where $K = Q_{опер}/Q_{cp}$ – discharge coefficient , Q is long-term average discharge $Q_m$ is measured discharge from basic gauge station, $B_{cp}$ is mean depth corresponding to average discharge, m, $H_{cp}$ is average width, relating to long-term average discharge, m, $U_{cp}$ is average velocity, relating to long-term average discharge m/s, $p_B$ , $p_H$ are empirical constants.

**MODEL SIMULATIONS OF EMERGENCY CONTAMINATION OF SURFASE WATERS BY RADIONUCLIDES (RESULTS OF EXERCISES ON LENINGRAD NPS)**

As technical support center of Roshydromet FEERC typically participate in several emergency response exercises each year. In September 19-20 2007 we participated in full-scale emergency respond exercises on Leningrad nuclear power station. The training accident have been related to category 5 according to international INES-scale (Mayak accident in 1957 has category 6, Chernobyl accident has category 7)

During exercises main radionuclide responsible for surface water contamination from atmospheric deposition was I-131. Full activity of this nuclide released into atmosphere was 4.6 $\bullet 10^{16}$ Bk.

The surface concentration of radionuclide on the rivers and reservoirs is inputted as a source of contaminant deposited from atmosphere. The surface concentration distributions are calculated by atmospheric module of RECASS system. Distribution of integral surface deposition of I-131 for the case of Leningrad NPS exercises is presented in figure 1.

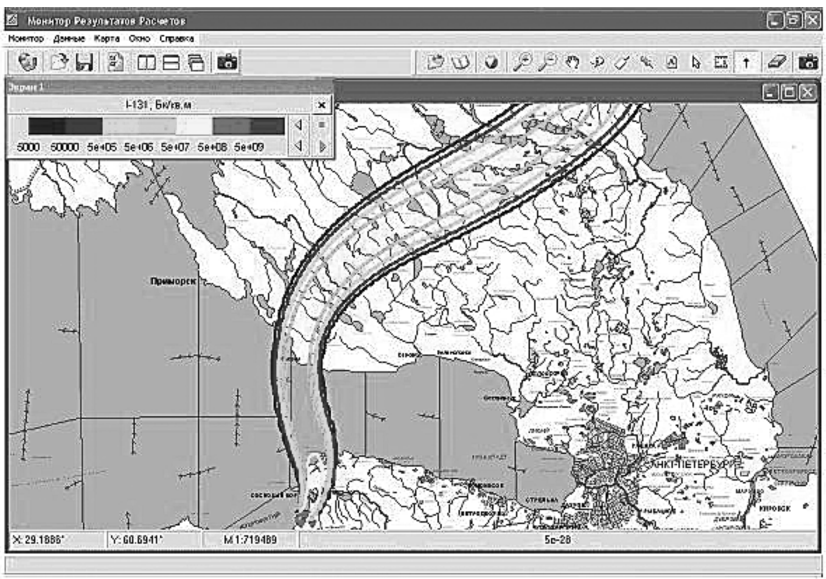


Figure 1: Distribution of integral surface deposition of I-131

Values of radionuclides concentration in water for all contaminated water objects for particular time can be shown on Monitor of Calculation Results software as coloures regions on rivers and lakes parcels. Each colour represent some concentration limits. In separate windows plots of concentation versus time (from beginning of accident) for river or lake parcels near some populates points.

There are no criteria for emergency contamination when counter-measures must be prepared. We use as a criteria 10 values of concentration level developed for long-term contamination of water by radionuclides. This critcal level for I-131 is 6.3 $10^4$ Bk/m$^2$

We have analyzed of water objects contamination in the region of Leningrad NPS. Calculated distribution of surface waters objects radioactive contamination after 3 days from beginning of training accident is shown in Figure 2. Main part of atmospheric deposition on the marine surface was in Kopor Bay and western part of Neva Bay of Gulf of Finland. Large contamination was also in river Kovashi (Sosnovyi Bor) and also in lakes and small rivers of Karelian Isthmus.

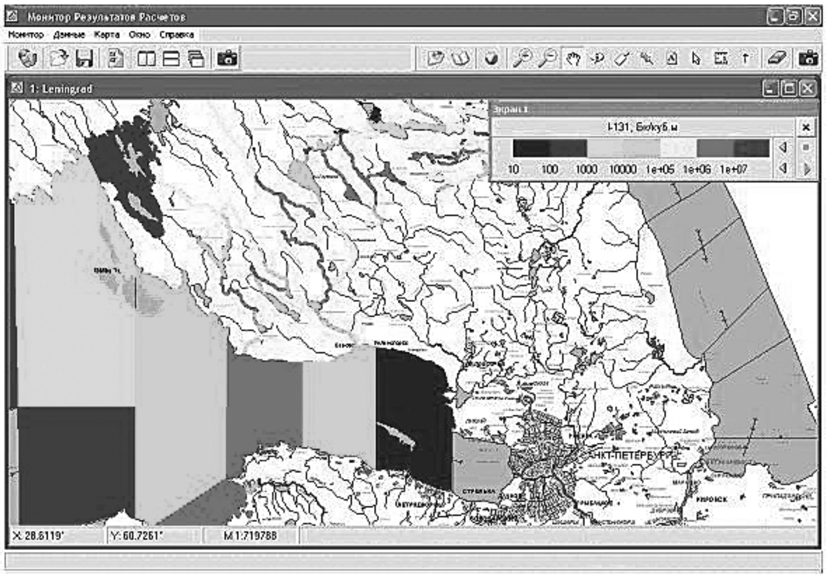


Figure 2: Distribution of surface water contamination after 3 days from training accident start

A plot of I-131 concentration versus time in Kopor Bay water is shown in figure 3.

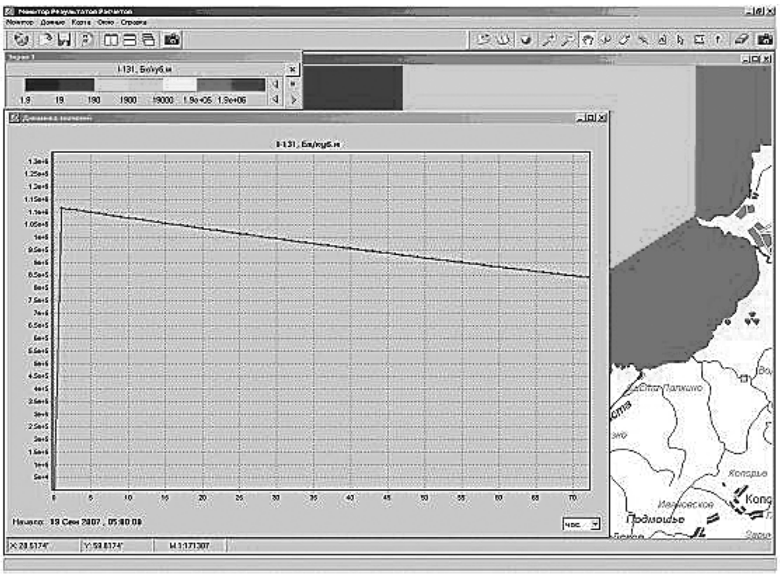


Figure 3: Change of I-131 concentration with time in Kopor Bay water

Our assessment showed that on the surface of nord-east part of Kopor Bay 2000 TBk of I-131 was deposited. It is 6% from all release of I-131 into atmosphere. Our simulations showed that average I-131 concentration in two hours after the beginning of the emergency should will exceed the critical level 20 times. After 3 days after the beginning of emergency concentration I -131 in Kopor Bay water must fall 1.3 times

Figure 4 shows the forecast of change in I-131 concentration with time in the water of Kovashi River.

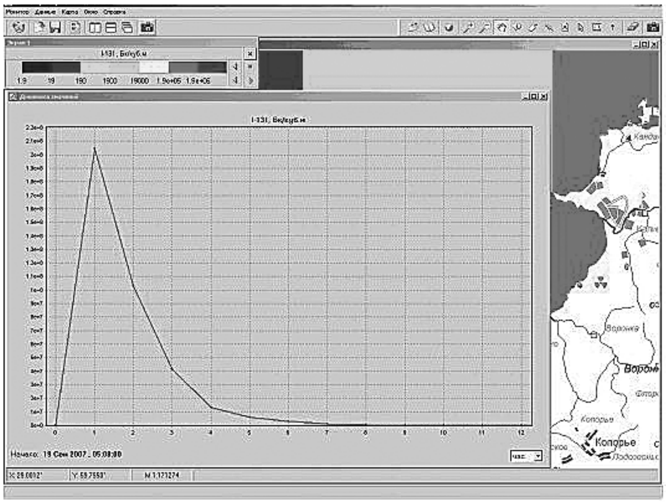

Figure 4 : Change of I-131 concentration with time in Kovashi river water

Peak concentration of I-131 in Kovashi River shoud be 2•108 Bk/m$^3$ The concentration above critical critical concentration. I-131 concentration above critical will remain at least during 9 hours

Peak concentration in lakes of Karelian Isthmus shoud be 10-330 times above critical concentration. Such dangerous concentration it will remain at least during 3 days. In small rivers which are tributaries of these lakes and also in Vuoksa River peak concentration is above 100-1000 of critical value.

After analysis of simulations results we performed our recommendations for limitations of water use of contaminated water objects and also for futher monitiring of suface waters in the region.

**CONCLUSIONS**

Hydrological module of decision support RECASS system of FEERC has wide applicability to environmental assesment and prognostic problems. Beside of problems relating to radioactive contamination Hydrologycal module has been succesivly applicated to risk assesment during large-scale chemical accidents. Although based on relatively simple models and parametric reletionships between hydrological and hydrometrical characteristics it integrates these approaches into single computer system which is useful for developing recommendations to minimize damage for people in case of larle-scale emergencies.

Hydrological module is permanently improved. At present time we have been prepared Hydrological makets for seven from ten of nuclear power stations. This year Hydrological makets for Balakovo and Volgo-Don nuclear power stations situated near big rivers would be prepared. The wind-induced flow will be introduced into the model reservoirs. Calculation of hydrological parameters on the basis of meteorological forecasts will also be introdused into the module This will improve accuracy of determination of hydrological parameters during modeling installations.

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