


ACADEMIA BRASILEIRA DE CIÊNCIAS

# *MATHEMATICAL METHODS FOR ASSESSMENT OF IMPACT OF PROJECTED LARGE DEEP RESERVOIRS (EVENK RESERVOIR AS A CASE STUDY)*

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2. Problems of large HPS construction in Siberia
3. The Evenk reservoir as a case study
4. Studies of Lake Teletskoye
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   - thermal and ice regimes
   - total mineralization
   - dissolved oxigen regime
7. Assessment of water quality in tail water
   - thermal and ice regimes
8. Conclusions

# *BACKGROUND*

**Economic development of any country including Russia depends on its energy sector development. In Russia it consists of three main energy producers: thermal power plants (TPP), nuclear power pants (NPP) and hydroelectric power station (HPS).**

**By hydro energetic potential, Russia ranks the second after China. However, by energy use the situation leaves much to be desired. Russia has a huge territory that differs greatly as by its economic development, as by the use of available hydroelectric potential in its different regions. For instance, if in the European part of Russia this potential has been practically exhausted at present, in Siberia and the Far East it is poorly developed yet.**

**The recent decisions of the RF government are evidence of the establishment of large system-forming hydro-energetic complexes (i.e. Nizhne-Angarsky,Yuzhno-Yakutsky,Vitinsky and Nizhne-Yeniseisky), and the construction of the largest in Russia -and one of the largest in the world- the Evenk HPS with output of 12 GW.**

# LIST OF LARGEST HYDRO POWER STATIONS IN THE WORLD









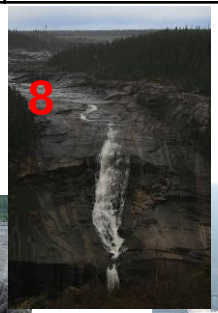

| Rank | Station | Country | River | Capacity (Mw) | Reservoir area ($km^2$) |
|---|---|---|---|---|---|
| 1 | Three Gorges | China | Yangtze | 22400 | 632 |
| 2 | Itaipu | Brazil/Paraguay | Paraná | 14000 | 1350 |
| 3 | Guri | Venezuela | Caroni | 10200 | 4250 |
| 4 | Tucurui | Brazil | Tocantins | 8370 | 3014 |
| 5 | Grand Coulee | United States | Columbia | 6809 | 330 |
| 6 | Sayano–Shushenskaya | Russia | Enisey | 6400 | 621 |
| 7 | Robert-Bourassa | Canada | La Grande | 5616 | |
| 8 | Churchill-Falls | Canada | Churchill | 5429 | 6988 |
| 9 | Krasnoyarsk | Russia | Enisey | 5000 | 2000 |
| 10 | Longtan Dam | China | Hongshui | 4900 | 18.7 |
| 11 | Bratsk | Russia | Angara | 4515 | 5470 |
| 12 | Ust-Ilimsk | Russia | Angara | 4320 | 1922 |

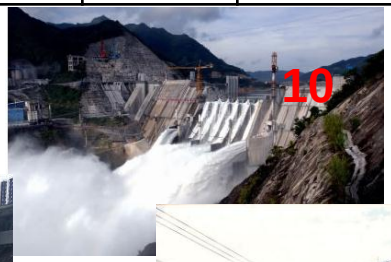








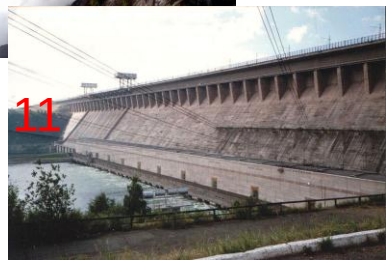











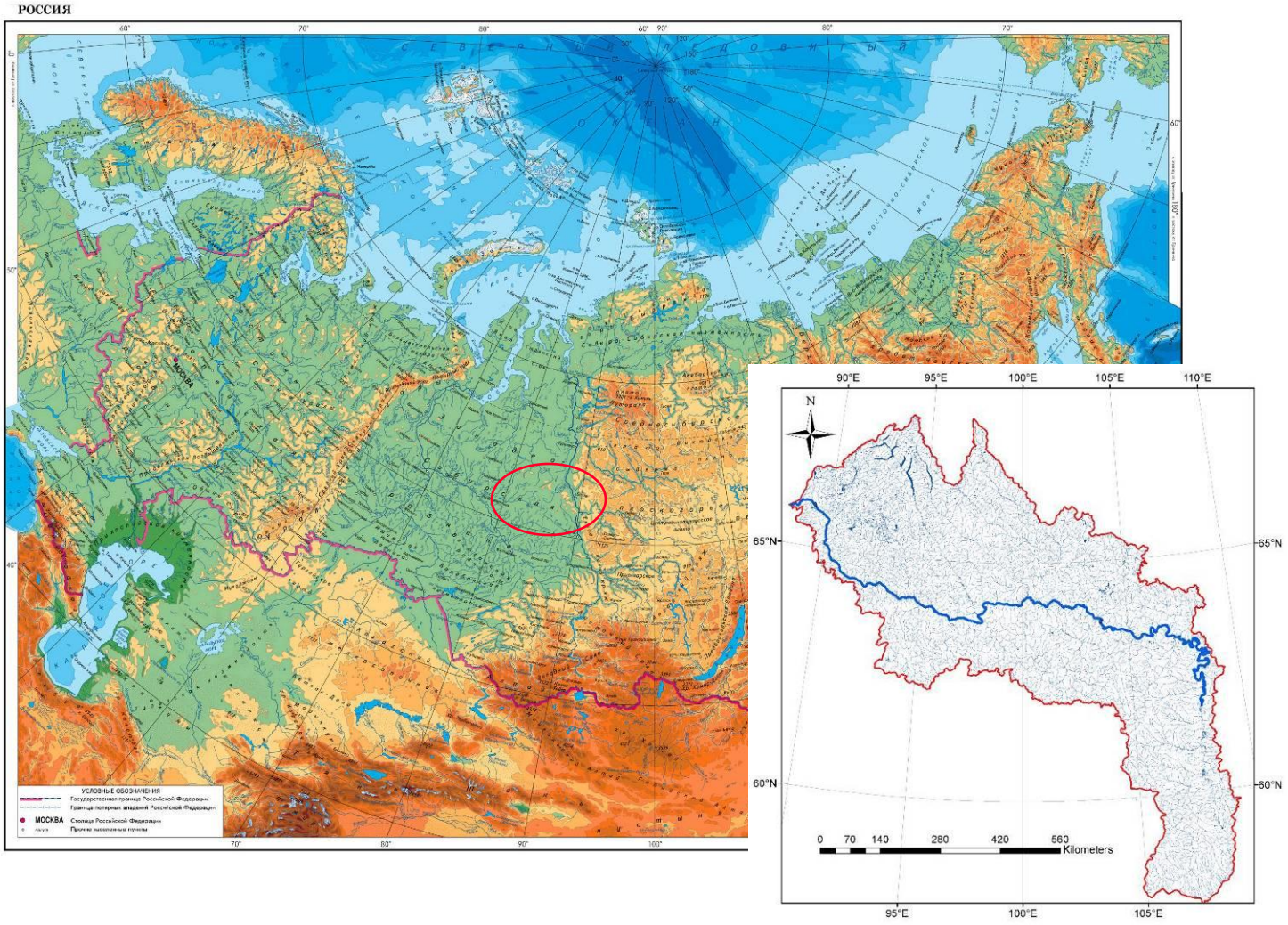

# *PROBLEMS OF LARGE HPS CONSTRUCTION IN SIBERIA*

**Large scale hydro technical constructions always impact on the environment and transforms it. To define such a transformation caused by hydro power station (HPS) construction is very complicated.**

**One of the main issues of HPS construction in Siberia is water quality assessment on the regulated river branches: a deep reservoir and tail water. It is known that the unfrozen patch of the water appears in winter period as a result of hydrothermal and ice regime changes in tail water of deep reservoir. Such changes in river water temperature and dissolved gases bring to the environment transformation that must be evaluated on the previous stages of the HPS project realization.**

**Numerous typical and specific aquatic ecological problems arise due the Evenk large reservoir construction on the Lower Tunguska River in Siberia. For instance, some problems are caused by poor preparation of the reservoir bed before the filling.**

# THE MAP OF RUSSIA AND THE EVENK HPS SITE



# BRIEF INFORMATION ON EVENK HPS

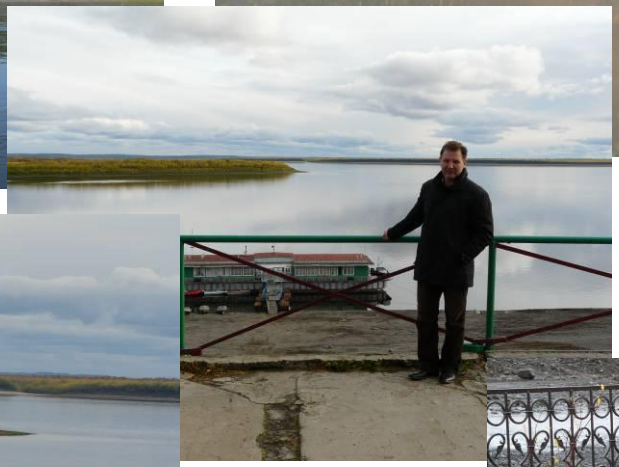
The prognosis was performed for two options of the Evenk reservoir construction. According to the first one, the length and volume of the reservoir make up 1229 km and 409 km3, correspondingly. And the dam height is about 200 m.

For the second case it constitutes 695 km, 49 km3 and 110 m, correspondingly. The flooded land areas for both options: 868000 and 74000 hectares, correspondingly.



# SITE OF THE RESERVOIR CONSTRUCTION









# THE TERRITORY TO BE FLOODED



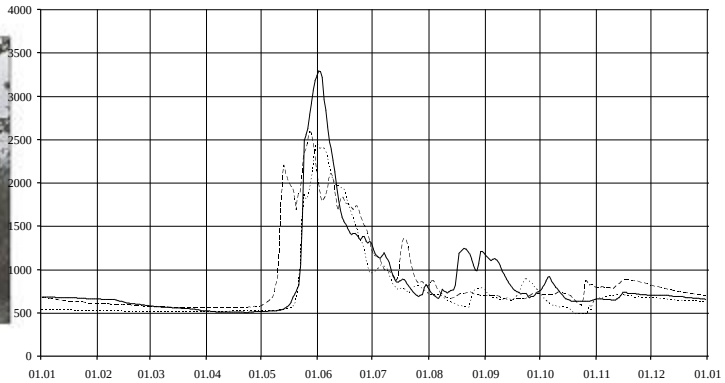
# HYDROLOGICAL AND METEOROLOGICAL CONDITIONS





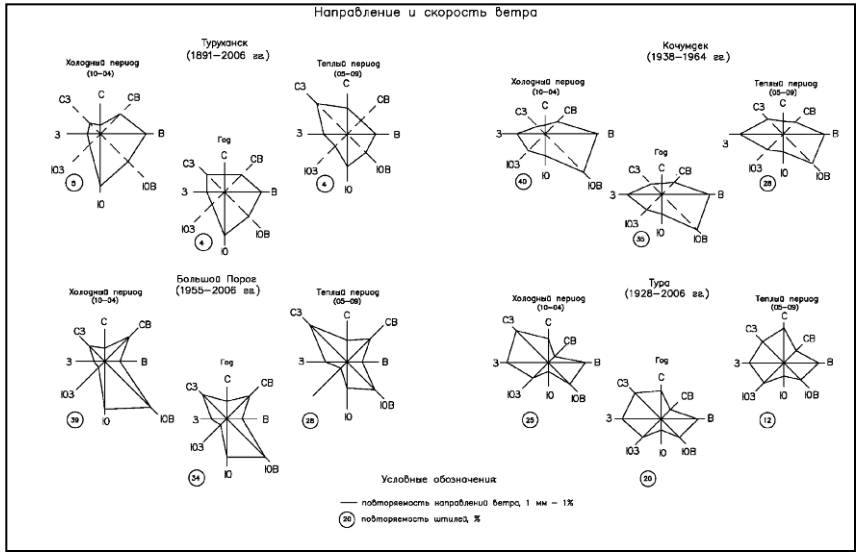


Графики колебаний уровня воды за характерные по водности годы









# *CLIMATE*

Average annual air temperature in the region varies within minus 7.1 °C – 9.4°C. The coldest month is January with the mean temperature minus 27.2-36.5°C. **Absolute minimum** observed in February is **minus 63°C**

The warmest month July has the mean air temperature plus 15.3-16.3 °C.

**Absolute maximum** of air temperature is **plus 37°C** and falls on June-Jule.

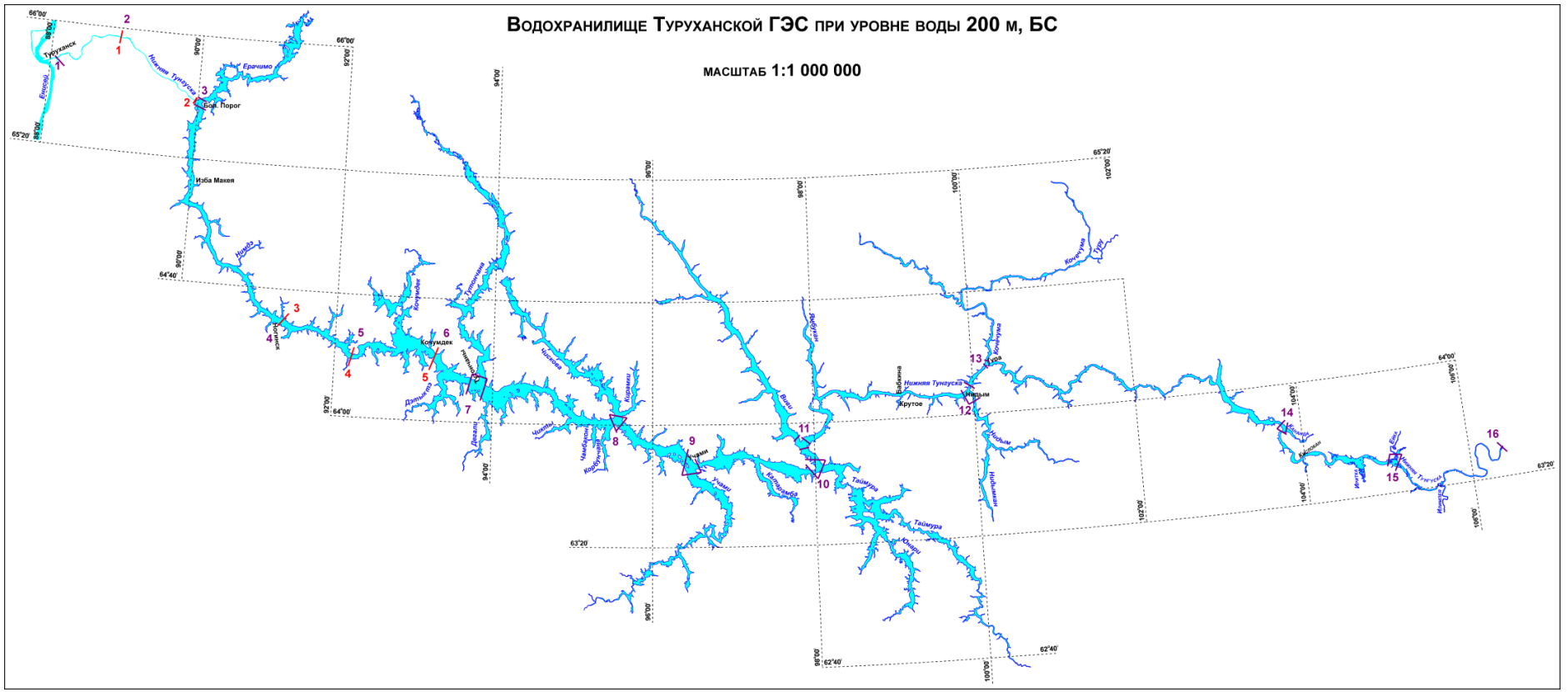
Average annual relative air humidity is 72-75%.

Summary annual rain and snow precipitations change from 368 to 525 мм. Mean annual wind is near 2.0-3.8 м/с.

Stable snow cover generally forms in the first half of October. Snow cover melts in the 2nd or 3d decade of May.

# SCHEME OF PROJECTED EVENK RESERVOIR

**Scale 1:1 000 000**



# MAJOR PARAMETERS OF THE EVENK RESERVOIR

| Parameters | Units | Value | |
|---|---|---|---|
| | | Site 59,5 км | Site 120 км |
| Normal headwater level (NHL) | мBS | 110 | 200 |
| Surface water area for NHL | км$^2$ | 1684 | 9406 |
| Volume for NHL | км$^3$ | 48,51 | 409,4 |
| Max depth for NHL | м | 104 | 185,3 |
| Reservoir length for NHL | км | 695,5 | 1229 |
| Depth variation | м | до 27 | до 12 |
| Freeze-up duration | month | 8 | 8 |
| Water change | time/year | 4 | 0,3 |

# *PROBLEMS OF EVENK RESERVOIR CONSTRUTION*

**Many typical water and ecological problems which concerning with the large reservoir constructions in Siberia take place for the Evenk reservoir construction on the Lower Tunguska River too.**

**In this case the main specific problems are the following.**

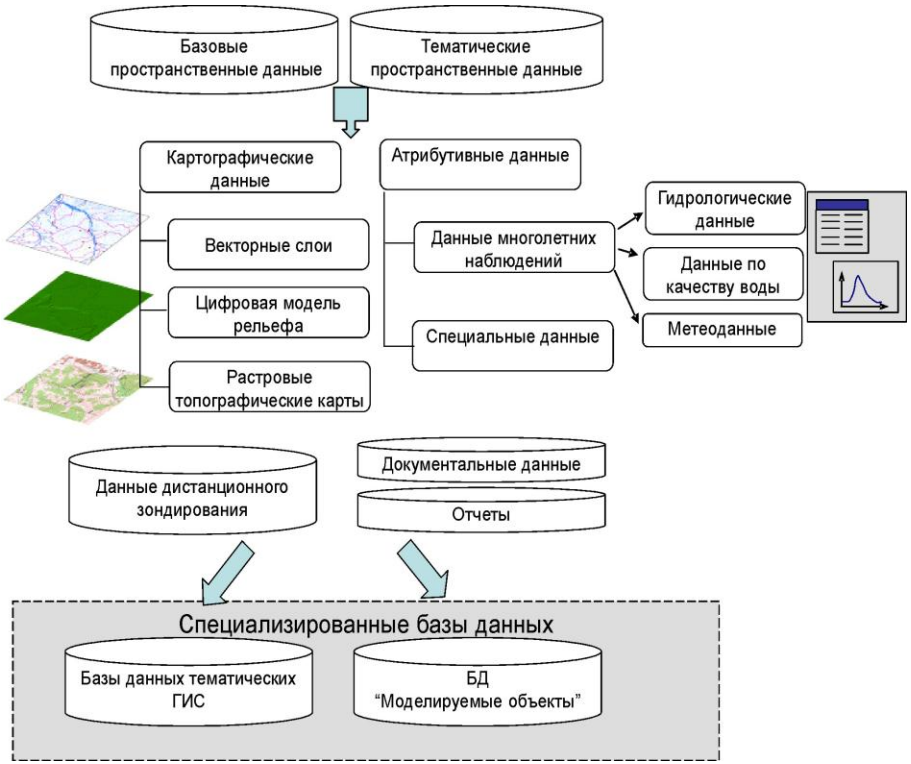
**The ice and thermal regimes of projected Evenk reservoir.**

**The values of total mineralization of water.**

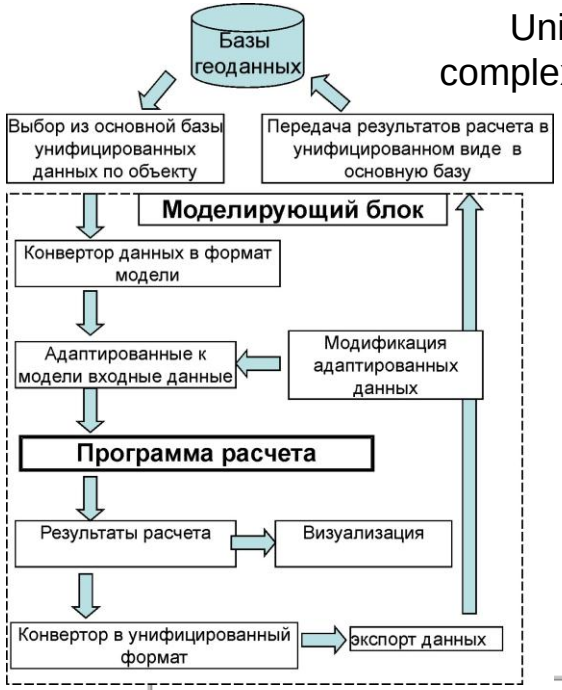
**The dissolved oxygen regime of the Evenk reservoir.**

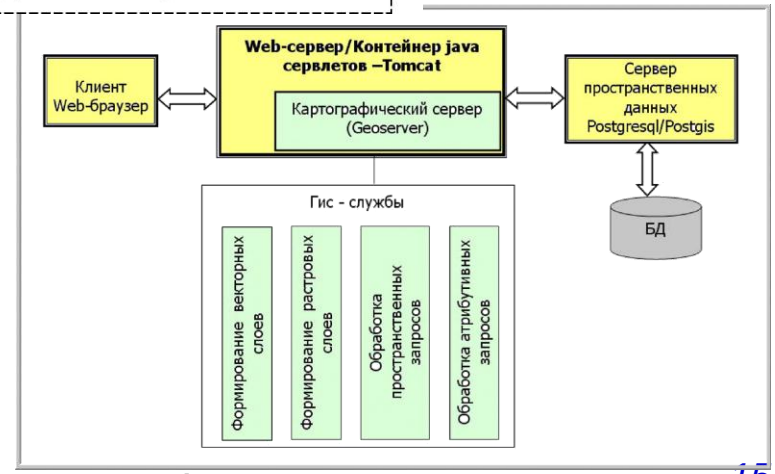
**They say about "dead" sea. Is it true?!**

# GEOINFORMATION SUPPLY



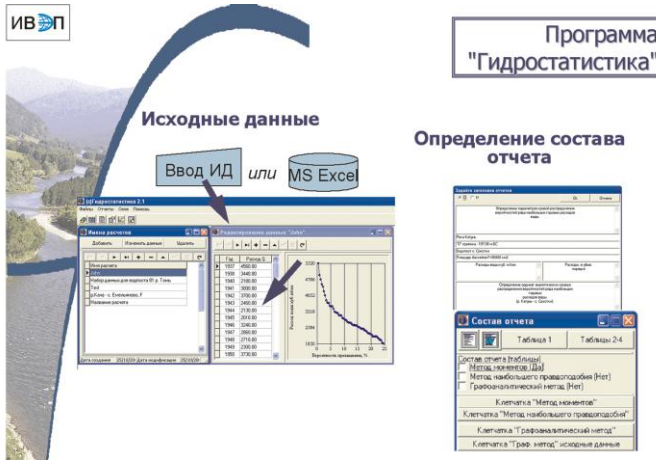

Unified way for modeling complexes inclusion into GIS




Prototype of spatial data Web-portal
http://mail.iwep.ru:8080/geoserver/www/web-gis/index.htm

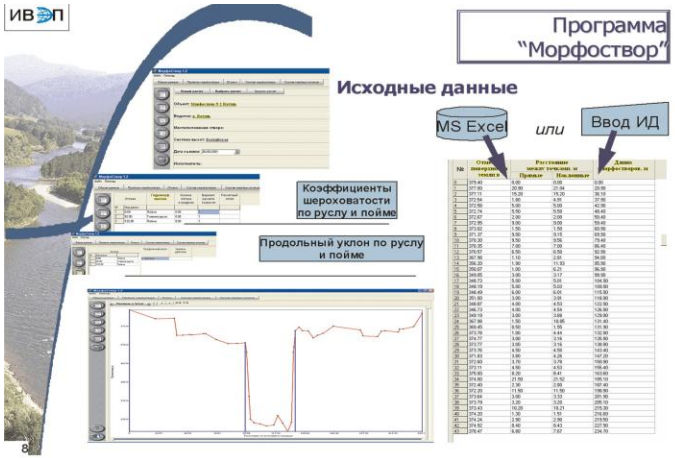
# ORIGINAL SOFTWARE FOR ENGINEERING CALCULATIONS



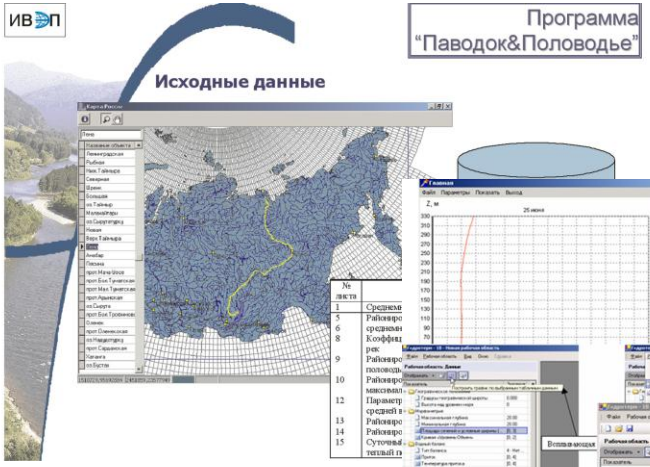

Программа "Гидростатистика"

Определение состава отчета



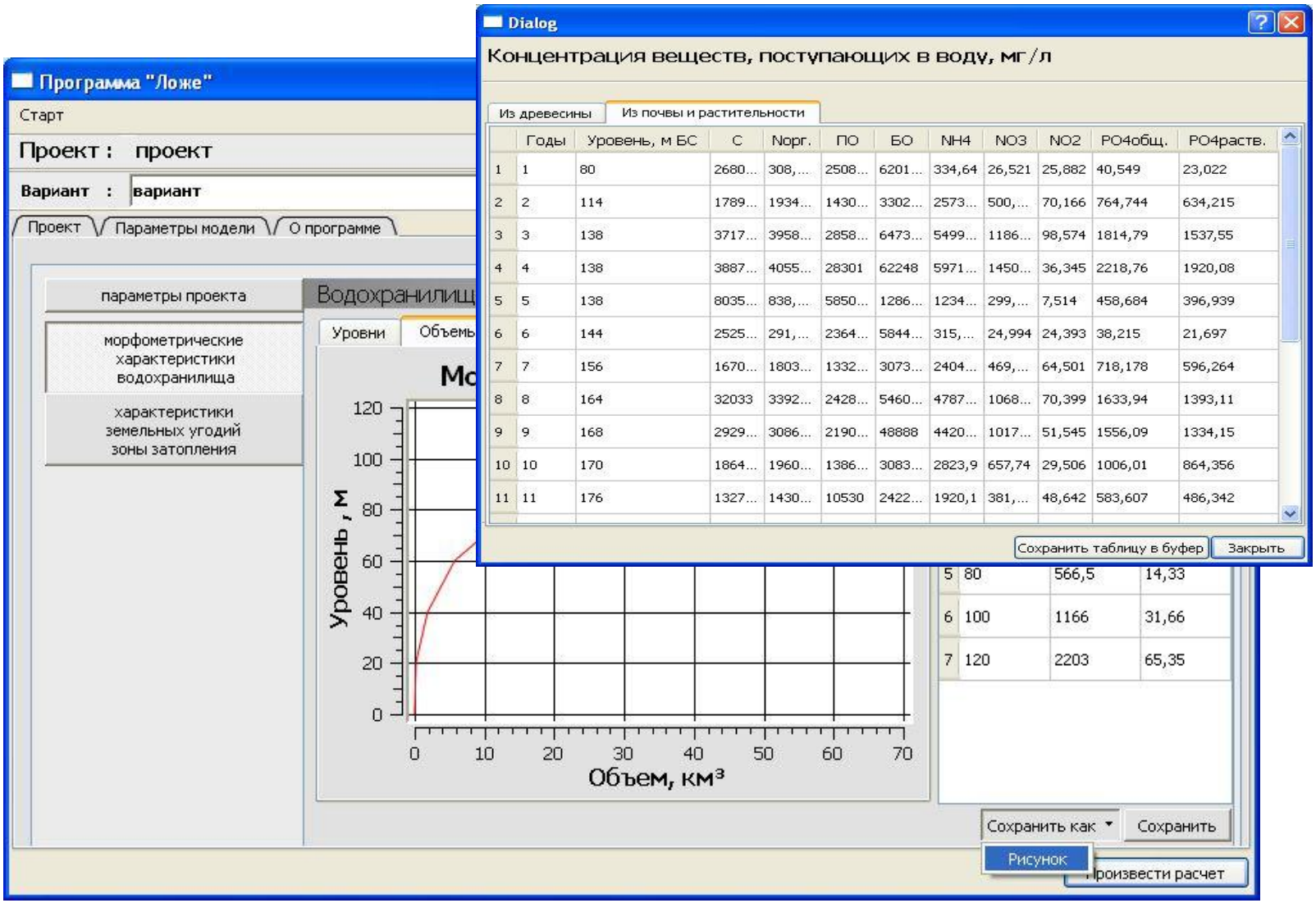




Программа "Морфоствор"




Программа "Паводок&Половодье"

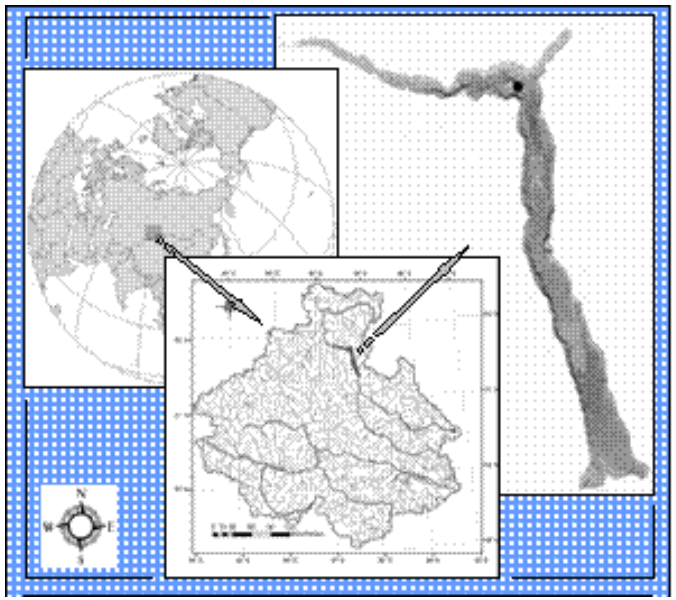
# ORIGINAL SOFTWARE “ENENK RESERVOIR BED”

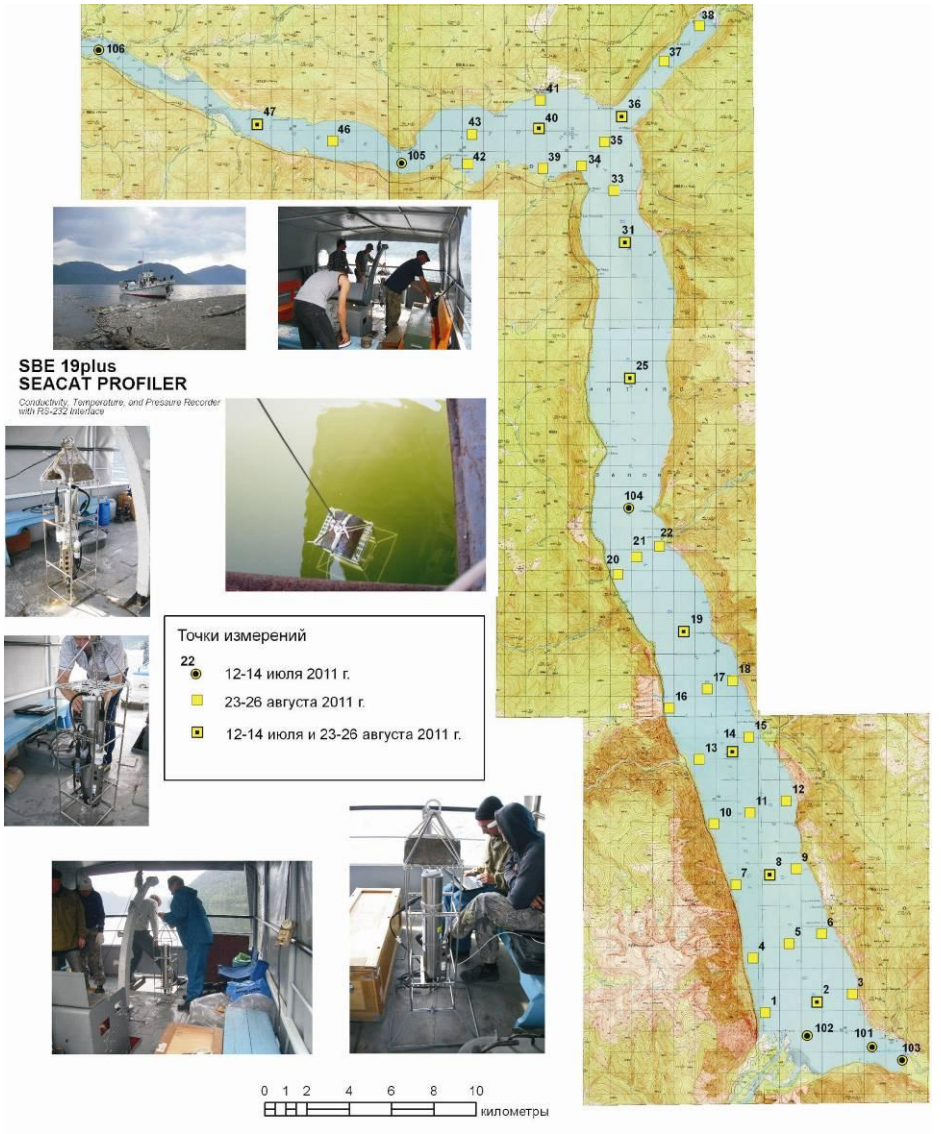


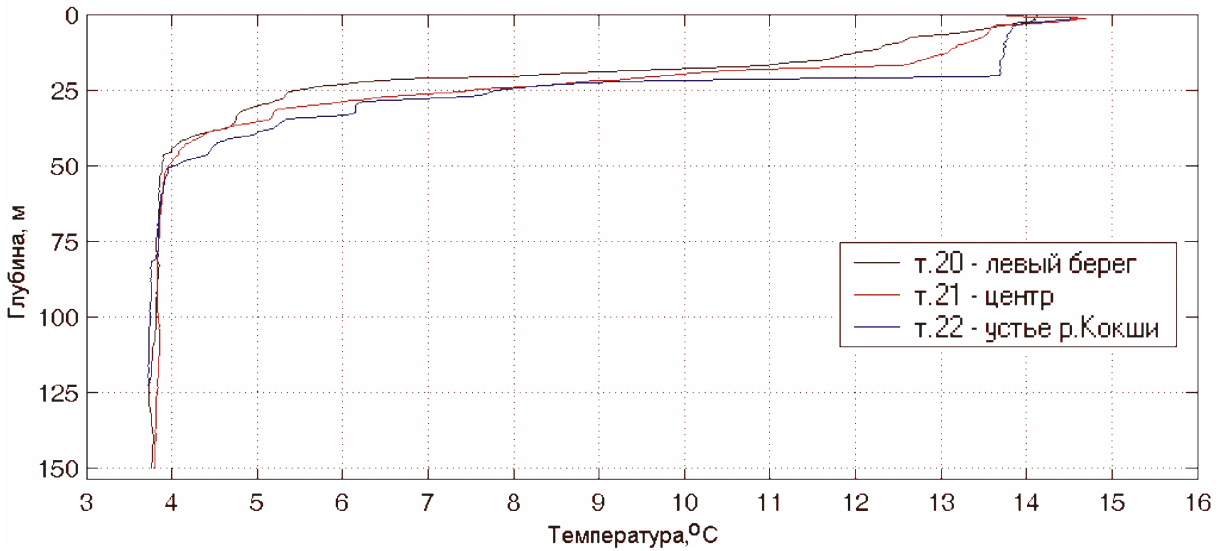

| | Годы | Уровень, м БС | С | Nорг. | ПО | БО | NH4 | NO3 | NO2 | PO4общ. | PO4раств. |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 1 | 80 | 2680... | 308,... | 2508... | 6201... | 334,64 | 26,521 | 25,882 | 40,549 | 23,022 |
| 2 | 2 | 114 | 1789... | 1934... | 1430... | 3302... | 2573... | 500,... | 70,166 | 764,744 | 634,215 |
| 3 | 3 | 138 | 3717... | 3958... | 2858... | 6473... | 5499... | 1186... | 98,574 | 1814,79 | 1537,55 |
| 4 | 4 | 138 | 3887... | 4055... | 28301 | 62248 | 5971... | 1450... | 36,345 | 2218,76 | 1920,08 |
| 5 | 5 | 138 | 8035... | 838,... | 5850... | 1286... | 1234... | 299,... | 7,514 | 458,684 | 396,939 |
| 6 | 6 | 144 | 2525... | 291,... | 2364... | 5844... | 315,... | 24,994 | 24,393 | 38,215 | 21,697 |
| 7 | 7 | 156 | 1670... | 1803... | 1332... | 3073... | 2404... | 469,... | 64,501 | 718,178 | 596,264 |
| 8 | 8 | 164 | 32033 | 3392... | 2428... | 5460... | 4787... | 1068... | 70,399 | 1633,94 | 1393,11 |
| 9 | 9 | 168 | 2929... | 3086... | 2190... | 48888 | 4420... | 1017... | 51,545 | 1556,09 | 1334,15 |
| 10 | 10 | 170 | 1864... | 1960... | 1386... | 3083... | 2823,9 | 657,74 | 29,506 | 1006,01 | 864,356 |
| 11 | 11 | 176 | 1327... | 1430... | 10530 | 2422... | 1920,1 | 381,... | 48,642 | 583,607 | 486,342 |

| | | | |
|---|---|---|---|
| 5 | 80 | 566,5 | 14,33 |
| 6 | 100 | 1166 | 31,66 |
| 7 | 120 | 2203 | 65,35 |

# LAKE TELETSKOYE AS A CASE STUDY





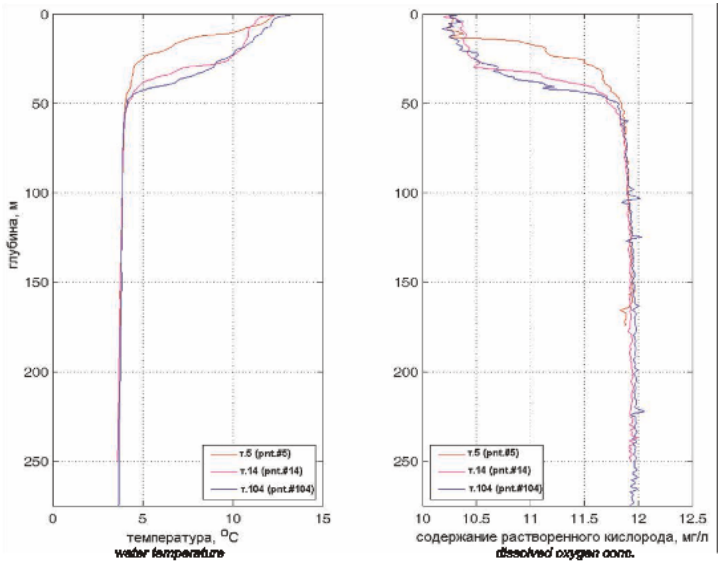



## LAKE TELETSKOYE

**Max depth - 325 m**

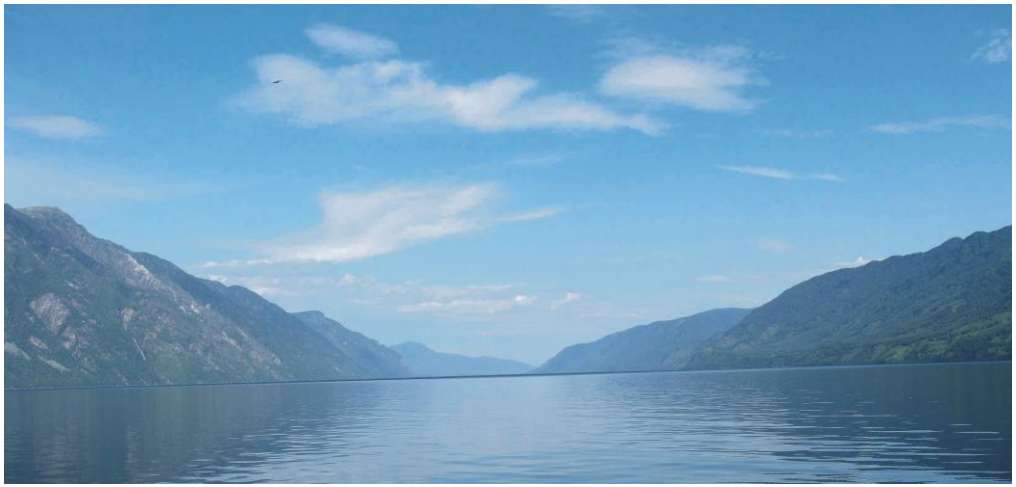
**Max length – 78 km**

**Observed vertical profiles of water temperature and dissolved oxygen**

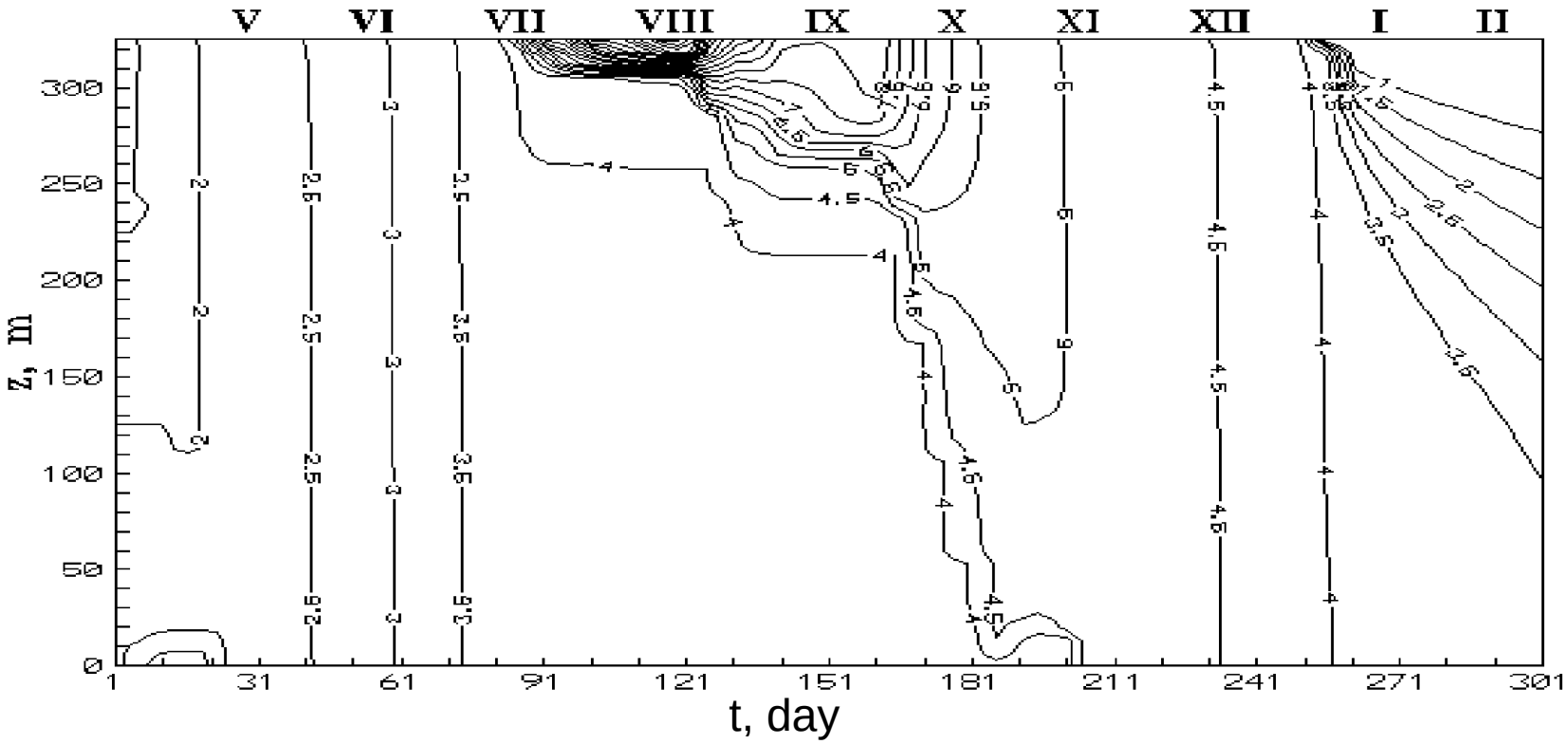



Вертикальны распределения температуры воды и растворенного кислорода 19 августа 2010 г.

*Vertical profiles of the water temperature and dissolved oxygen concentration. August 29th, 2010*



# COMPUTATIONAL THERMAL MODEL OF LAKE TELETSKOYE




**Numerical results. Annual thermal stratification of Lake Teletskoye**

# INITIAL DATA FOR TWO DAM SITES OF EVENK HPS

**Варианты створа ГЭС**

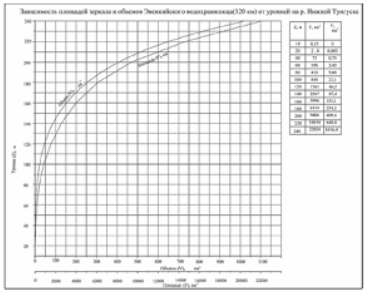
**Створ 120 км**
**НПУ 200 м БС**

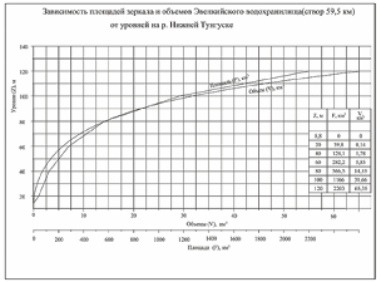
***Dam site of 120 km at 200 m absolute level***

**Створ 59,5 км**
**НПУ 110 м БС**

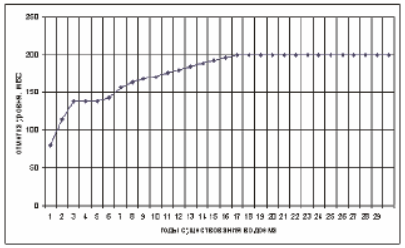
***Dam site of 59.5 km at 110 m absolute level***

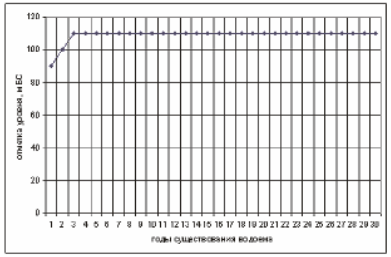
**Морфометрические характеристики водохранилища**
***Morphometric characteristics of reservoir***



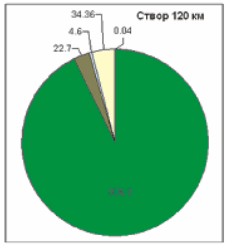


**Графики заполнения водохранилища**
***Schedule of reservoir filling***

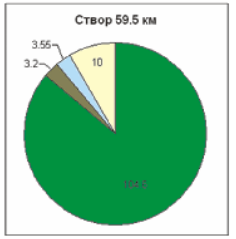



**Площади земельных угодий в зоне затопления, тыс. Га**
***Land area in the flood zone, th. ha***

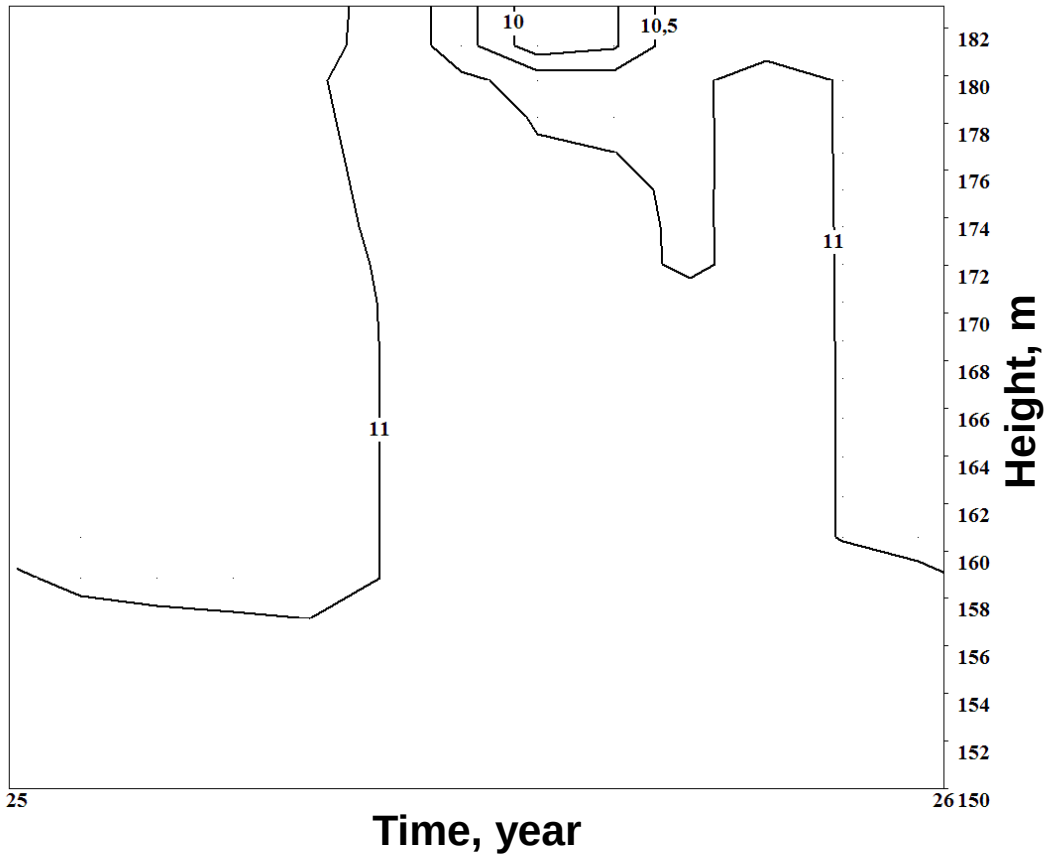



**Запас древесины 59,4 млн. куб. м**

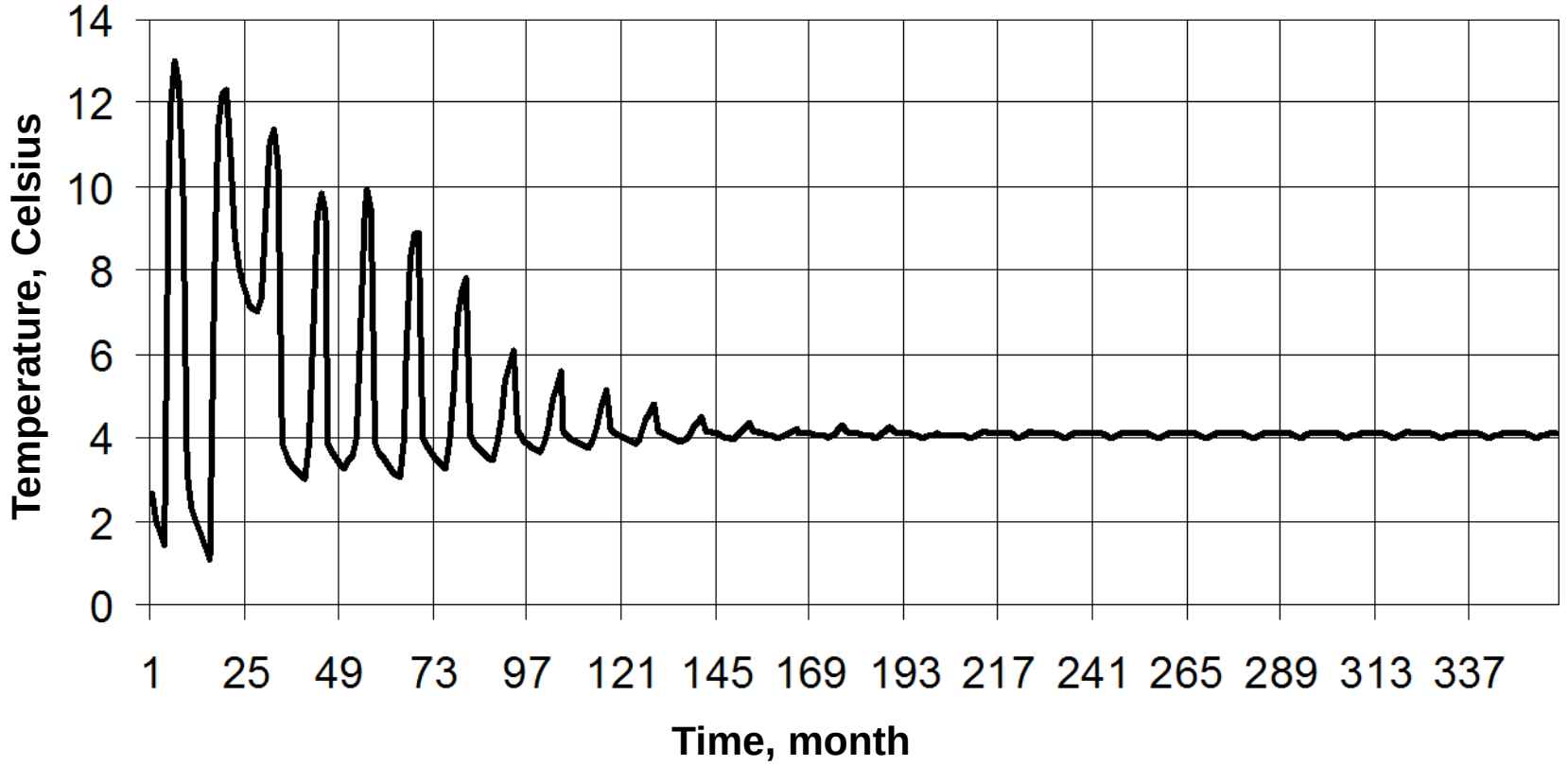



**Запас древесины 7,75 млн. куб. м**

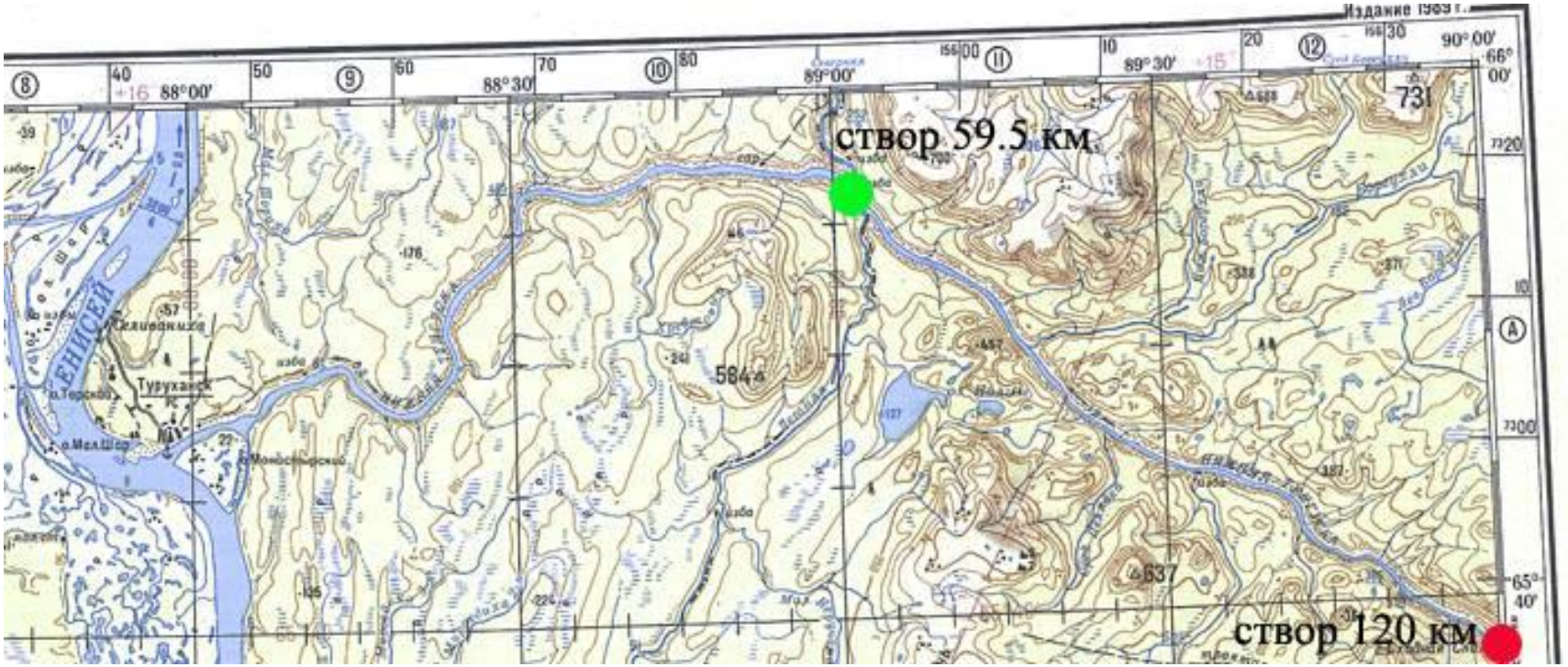
# DISSOLVED OXYGEN CONCENTRATION (mg/l) IN SURFACE LAYERS OF RESERVOIR FOR 26TH CALCULATED YEAR



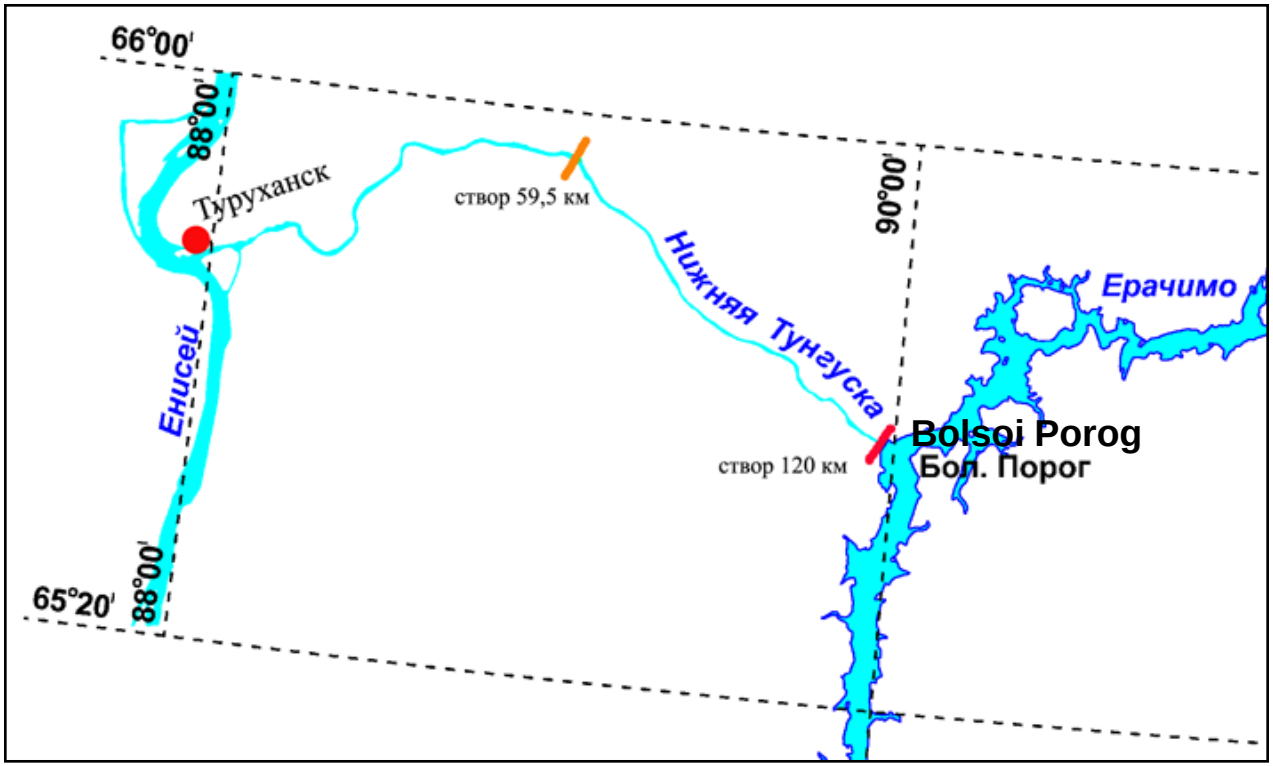
# CHANGE OF OUTFLOW WATER TEMPERATURE DURING EVENK RESERVOIR FILLING



# TAIL WATER OF THE EVENK RESERVOIR

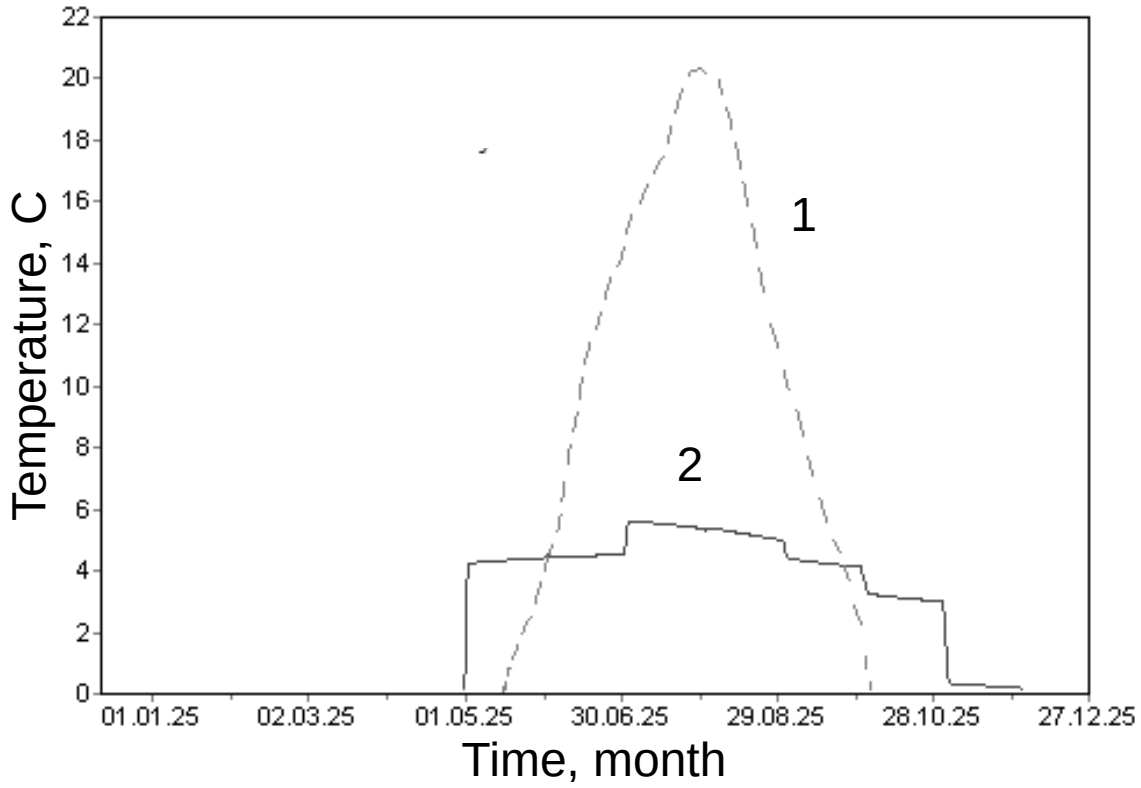


# ICE AND THERMAL REGIME OF TAIL WATER




- **Prognosis was made for two sites of dam: 1 – 120 km and 2 - 59,5 km from the R. Lower Tunguska outfall**
- **Input data: meteorological data from weather station Bolshoi Porog and calculated data for the Evenk reservoir**

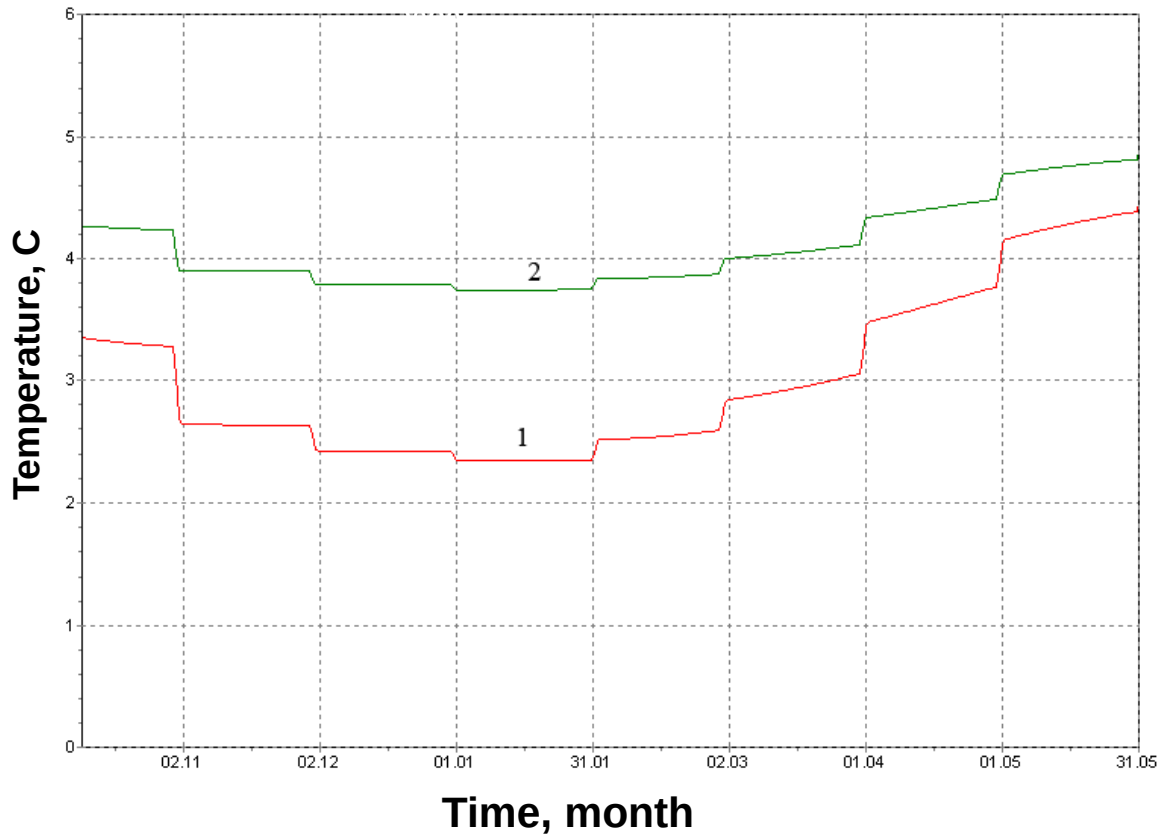
# *WATER TEMPERATURE IN THE LOWER TUNGUSKA OUTFALL. NATURAL CONDITIONS AND FILLING REGIME OF THE RESERVOIR*




**Notations:**
**1 - natural conditions**
**2 - 120 km dam site**

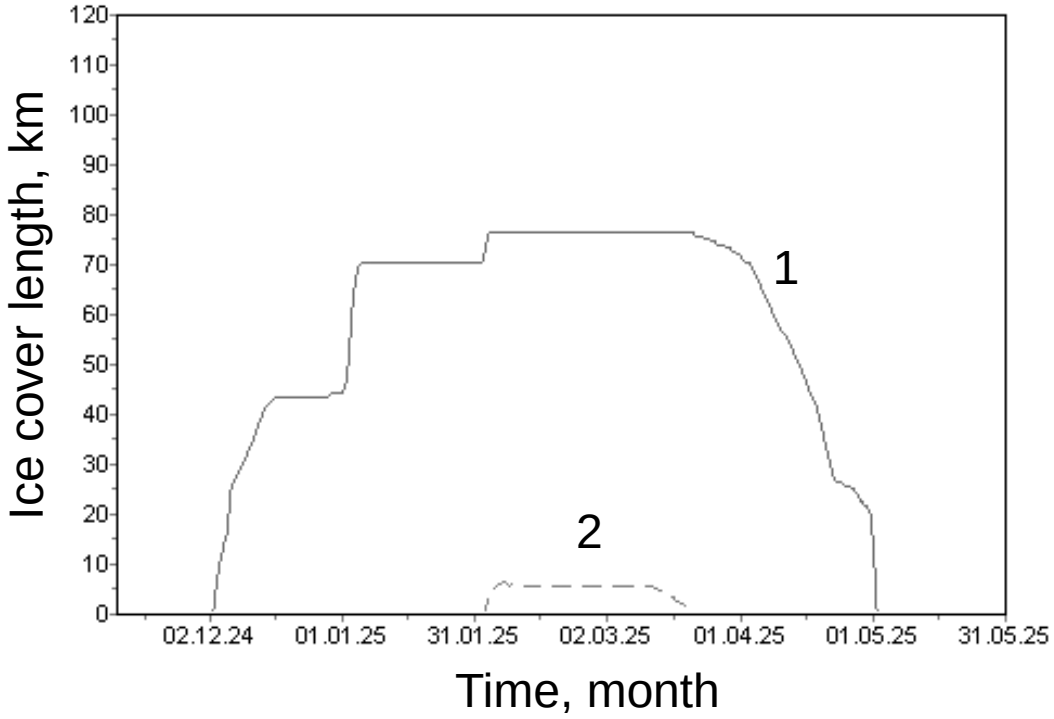
**The Evenk reservoir filling will result in 15 ºC fall of max water temperature in the Lower Tunguska outfall**

# WATER TEMPERATURE IN LOWER TUNGUSKA OUTFALL AFTER THE RESERVOIR FILLING




- After the Evenk reservoir filling, the ice phenomena at the site from dam to the Lower Tunguska outfall will be absent in winter months
- Water temperature: 1 – dam site of 120 km long; 2 – dam site of 59,5 km.

# ICE REGIME FOR 26TH CALCULATED YEAR. THE RESERVOIR FILLING




**Notations:**

**1 - 120 km dam site**

**2 - 59.5 km dam site**

**Results:**

- **Minimal length of an unfrozen patch of water will be about 45 km for**
- **120 km dam site. For a dam site of 59,5 km long, the ice cover formation is expected only in the outfall of R. Lower Tunguska.**
- **For the dam site of 120 km, ice phenomena are expected to start one month later, while ice melting – one month earlier.**

# TOTAL MINERALIZATION PREDICTION

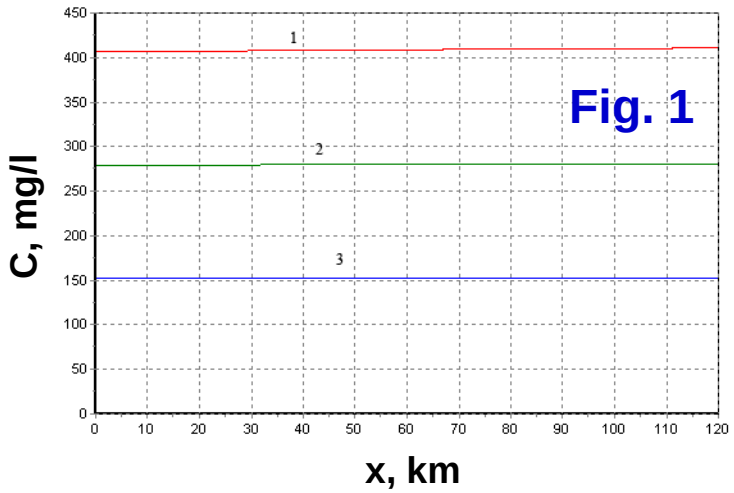



**Fig. 1. Dam site 120 km.**
**C – total mineralization as a function x (x - distance from dam):**
**1-01.05.2018;**
**2-01.06.2018;**
**3-01.07.2018**

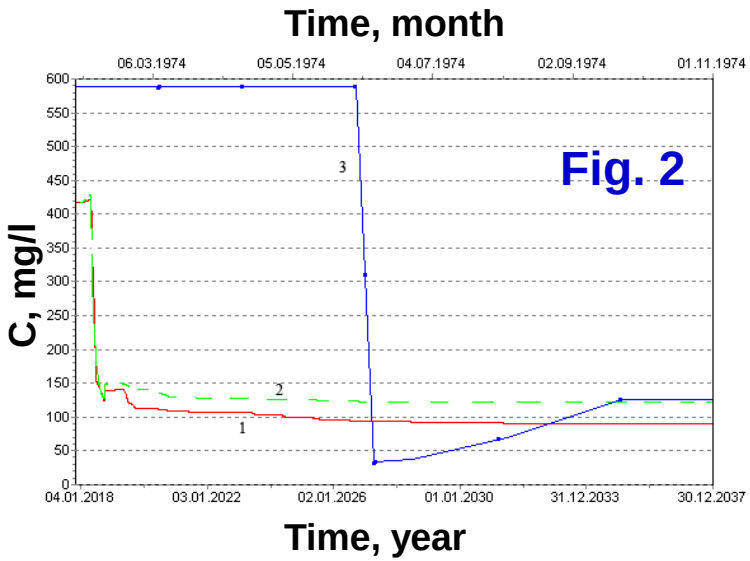



**Fig 2. Total mineralization in the Lower Tunguska River outfall:**
**1 – dam site 120 km;**
**2 – dam site 59,5 km;**
**3 – conditions like 1974 year.**

# CONCLUSIONS

**The mathematical modeling of thermal regime and processes of total mineralization and dissolved oxygen transfer shows the following:**

- **In the first stage of the reservoir filling the vertical density stratification will be formed. The most part of the water body will have the temperature of approximately + 4 °C.**
- **The ice regime of the Evenk reservoir will be similar to the one of R. Lower Tunguska.**
- 
- **The outflow water temperature will vary from + 4 °C up to + 14 °C during the year. After the Evenk reservoir filling, the estimated outflow water temperatures will be around + 4 °C.**
- **During the first years of the reservoir filling we may expect the deficit of dissolved oxygen in upper water layers under the ice during the winter period. But on the next stages of the reservoir filling, this deficit will be decreased and dissolved oxygen concentration in the reservoir will be evaluated similar to the saturation concentration.**
- **The mineralization of the upper water layers of the Evenk reservoir is expected as less than 100 mg/l. Near the bottom the expected mineralization will be near 400 mg/l. In natural environments, water mineralization of R. Lower Tunguska exceeds 1000 mg/l during the winter period. The expected situation will be better for the drinking purposes.**
- **The calculations of thermal and ice regimes of tail water demonstrate that the ice cover and other phenomena will be absent after the Evenk reservoir construction (for different options of the Evenk HPS projects). Some ice and other problems may occur in Yenisei River- in the sites below the mouth of R. Lower Tunguska. The expected ice problems will be insignificant because discharge of Yenisei River is 7 times more than the one of R.Tunguska.**
- **The values of the total water mineralization in tail water and flowing out of the Evenk reservoir are expected to be practically the same. The existing values of mineralization will be considerably less and their variations will be decreased. As a result, the characteristics of water quality will be improved.**


THANKS FOR YOUR ATTENTION!