Model based approaches to Water Resource Management in climate change conditions: case studies - Carpathian Watersheds and Dnipro River Basin

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Methodologies of Water Management under Climate Change Uncertainties

Taking into account the latest recommendations of

- IPCC,
- UNECE Water Convention Guidance on Water and Adaptation to Climate Change (2009) ,

the system of water/flood management issues developed in each country should include adaptation options to climate change uncertainty.

The contemporary methods for the quantification of regional climate changes is based on the downscaling of the IPCC global climate models (GCM) scenarios using Regional Climate Models (RCM). Using these scenarios as the common baseline, the influence of climate variability on the watershed, flood routing and reservoir operations can be simulated

How to implement (1)?

1. TOOLS

To adapt for local conditions Regional Numerical Weather Predictions Models coupled with the hydrological models of lakes/reservoirs/cooling ponds

To develop and/or customize and validate contemporary "rainfall (snowmelting)- runoff" watershed models that can assimilate efficiently GIS data, remote sensing information

To develop and/or customize and validate contemporary "1D rivernet models of flood routing",

2D shallow water models for simulation of floodplain inundation,

3D models of deep reservoirs and estuaries

To develop optimization models/procedures of reservoir operations

To implement " machine learning" approaches for historical data processing and trend analyses (classification of flood events of different probability of exceeding) in the world of non-stationary hydrology

How to implement (2)?

2. Application methodologies

To implement and to test the system in seasonal/short term forecasting mode

To develop reservoir/water use systems management /flood protection procedures and measures based on observation data processing and modeled scenarios of "stationary hydrology"

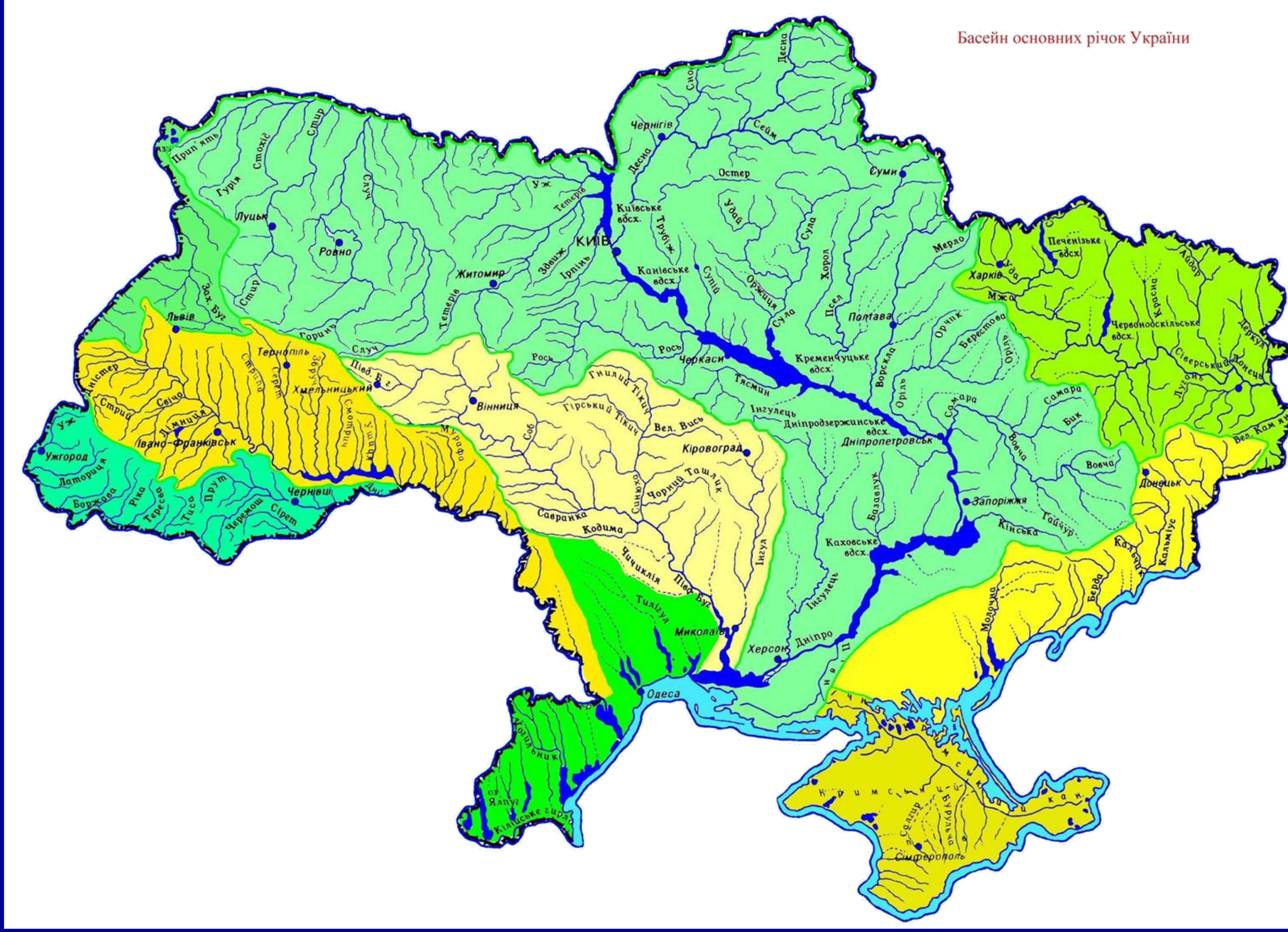
To study the influence of climate variability on water management based on downscaling of IPCC climate projections scenarios and driven by them hydrological models

To provide detailed analyses of the regional hydrometeorological process in CC conditions (deforestation and other technogenic impacts, droughts and floods extremes)

3. Case studies

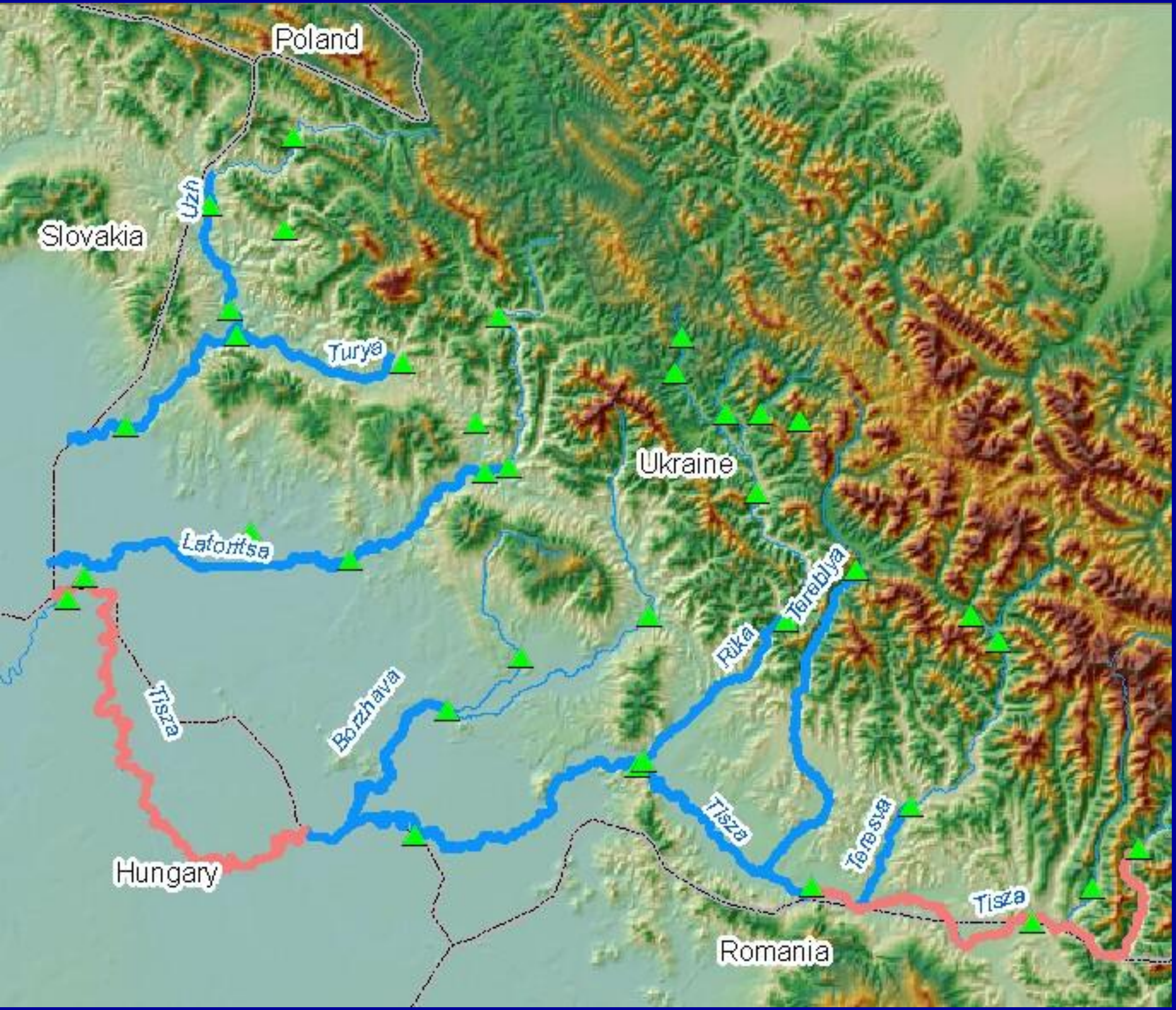
Ukrainian Carpathian Watersheds

Dnipro river basin



➪ **Dnipro**	**F=504 000 km^2**	**L=2201 km**
➪ **Desna**	**F= 88 900 km^2**	**L=1130 km**
➪ **Prypjat**	**F= 121 000 km^2**	**L=761 km**
➪ **Pivdenyj Bug**	**F= 63 700 km^2**	**L=806 km**
➪ **Siverskyj Donets**	**F=98 900 km^2**	**L=1053 km**
➪ **Dniester**	**F= 72 100 km^2**	**L=1362 km**
➪ **Tissa**	**F=153 000 km^2**	**L=966 km**

Implementation of contemporary flood forecasting technologies has started since 2000 in Transcarpatian Tisza River watershed



IMMSP/UCEWP as contractor of SCUWM and as a partner in NATO, EC TACIS, Danish DANCEE, EC MOZES Projects

Nowadays it system includes more then 40 automatic water gage stations from which at 25 using satellite communication lines

Flood forecasting system for the Ukrainian part of Tisza Basin (IMMSP design for Water Management Com. of year 2000)

Numerical Weather Prediction (NWP) Model

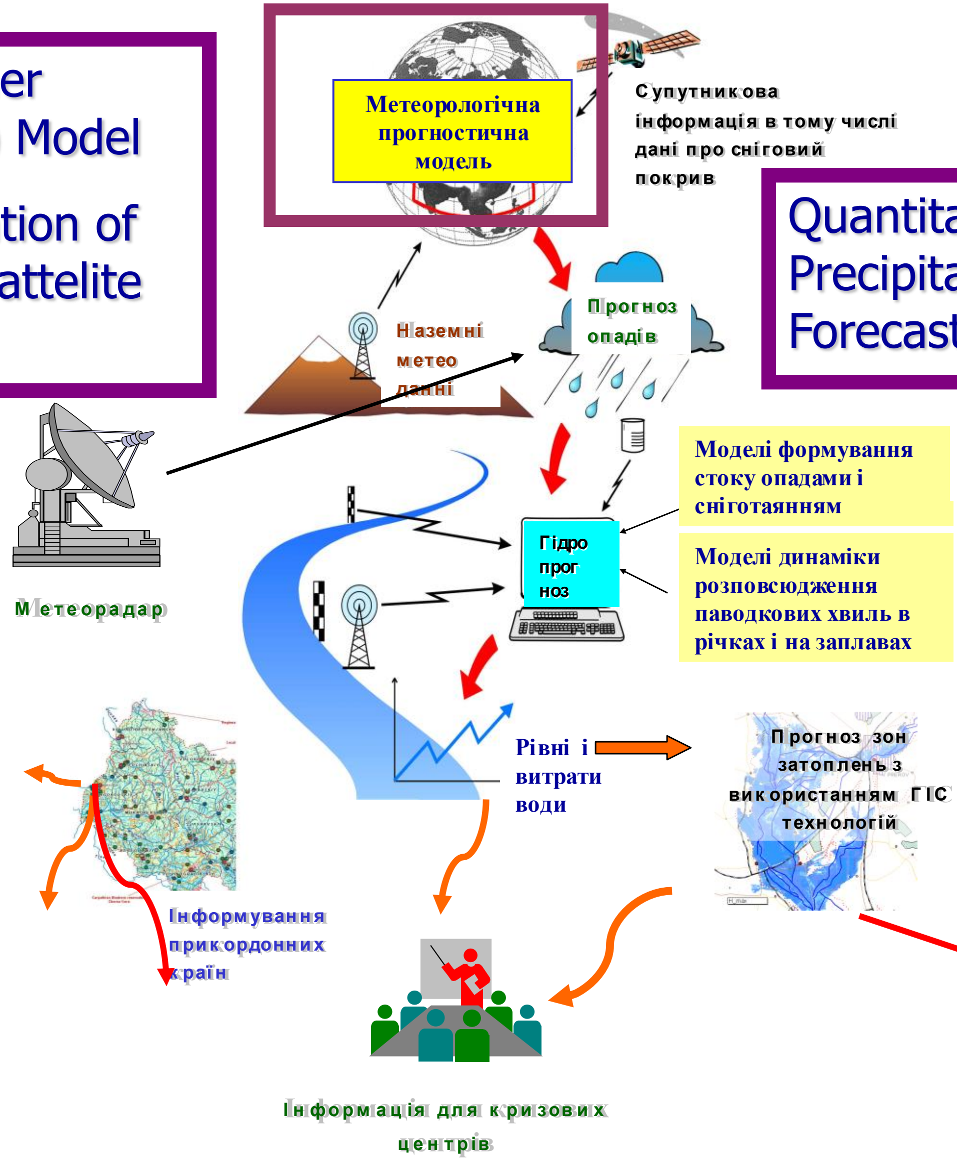
With the assimilation of monitoring and sattelite data

Quantitative Precipitation Forecasts-QPF

QPF=NWP+Radar

Flood forecsting models and flood mapping

Flood protection measures design (dambs, polders etc)



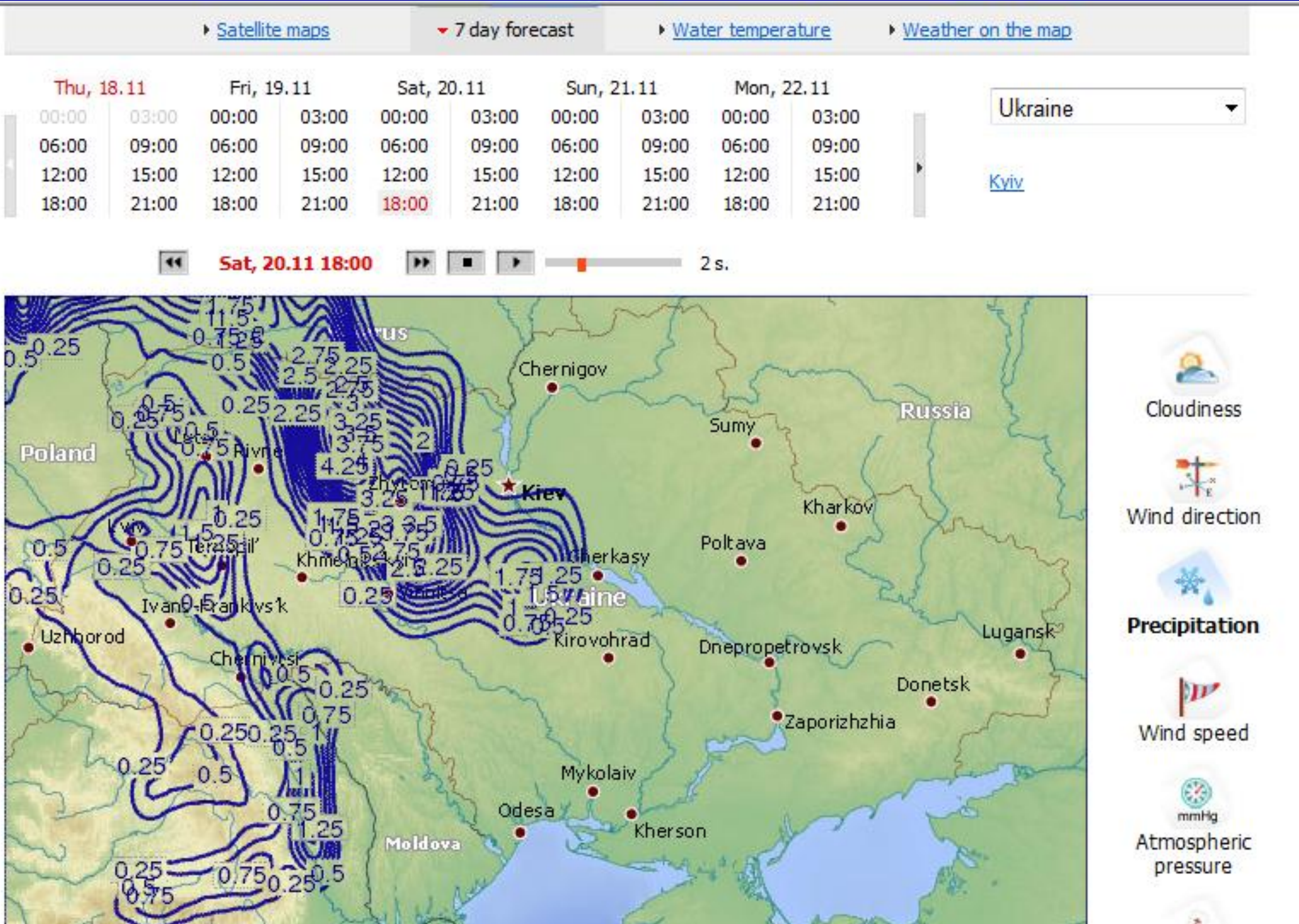
IMMSP/UCEWP team since 2002 has implemented the PSU/NCAR Numerical Weather Prediction Model MM5 and then (since 2007) model WRF for the operational use in Ukraine

Country scale model – grid 27*27 km

Regional models grid 9*9 km or 3*3 km

The country scale model results are presented by one of the most popular Ukrainian weather web-site (up to 200000 visitors per day) www.meteoprog.ua/en

The regional model METEO MODEL for Zakarpatye is integrated with hydrological forecasting model as a part of the Ukrainan Tisza basin hydrological forecating system (in Uzhgorod)

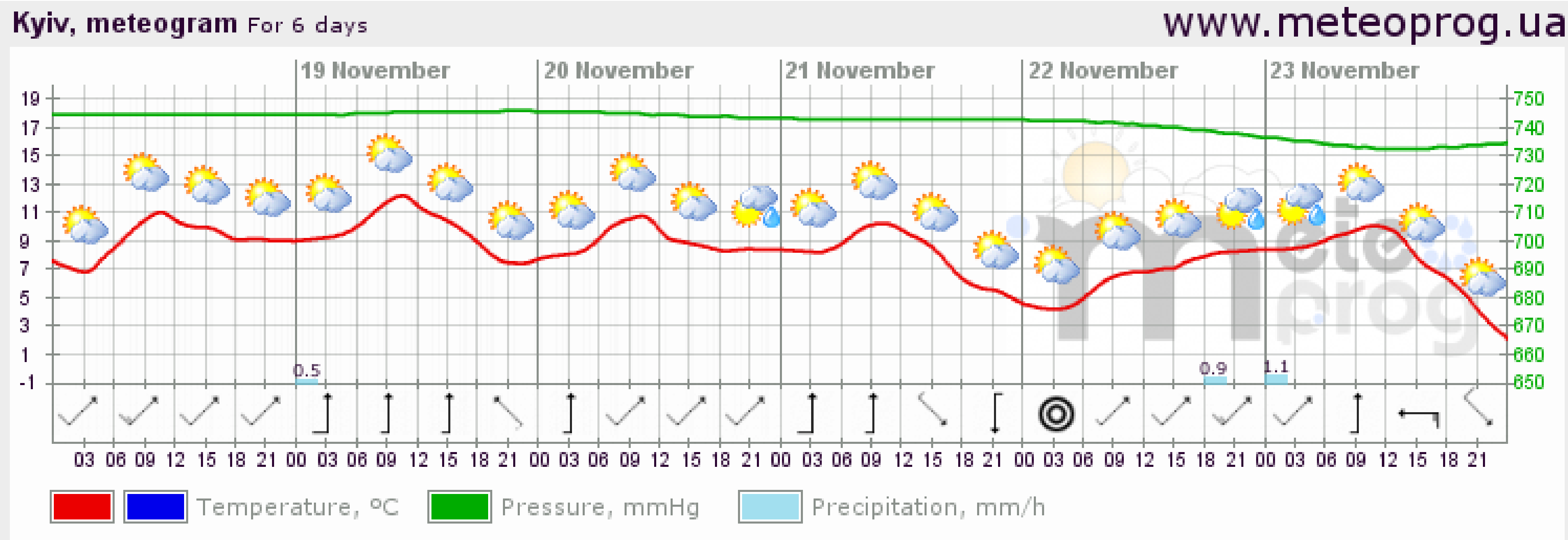


WWW.METEOPROG.UA - precipitation map 20 November, 6 pm

Forecast by WRF customized by UCEWP/IMMSP

Kyiv weather hour by hour, meteograms

meteogram on 2 days   meteogram on 6 days



Kyiv: hourly weather

Thursday, 18 November

Time		Precipitation	Temperature	Feels like	Pressure	Humidity	Wind
06:00		0 mm	+6.3°	+6.7°	752 mmHg	98%	5 mps, SE
07:00		0 mm	+7.2°	+7.5°	752 mmHg	93%	6 mps, SE
08:00		0 mm	+7.9°	+8.2°	752 mmHg	89%	6 mps, SE

July 2008 - Hazardous Flood in the Pricarpatye –the basins of Dniester, Prut and Seret Rivers, and high flood in Zakapatye- basin of Tisza River

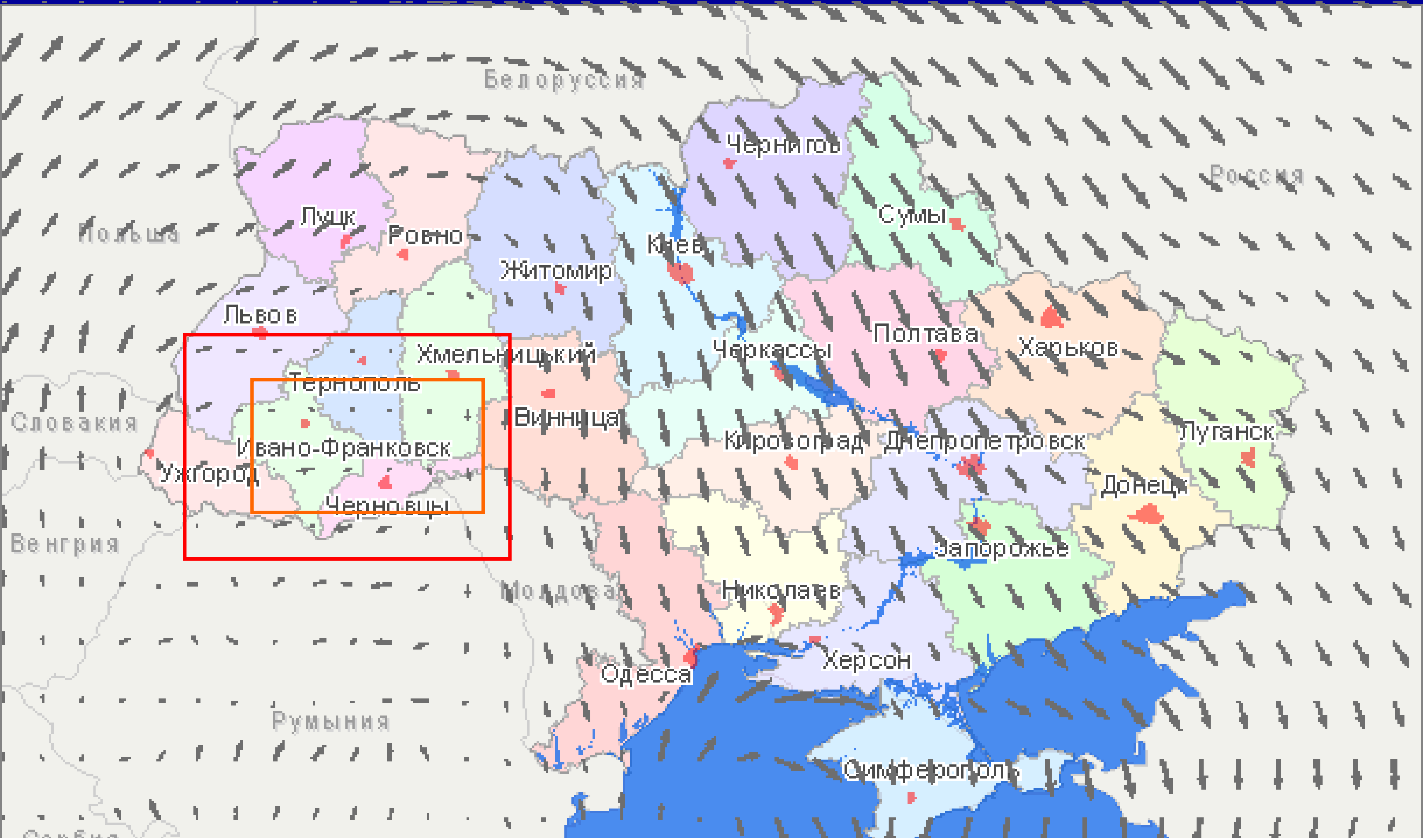
Map of the flood impacted river basins

Дністер= Dniester

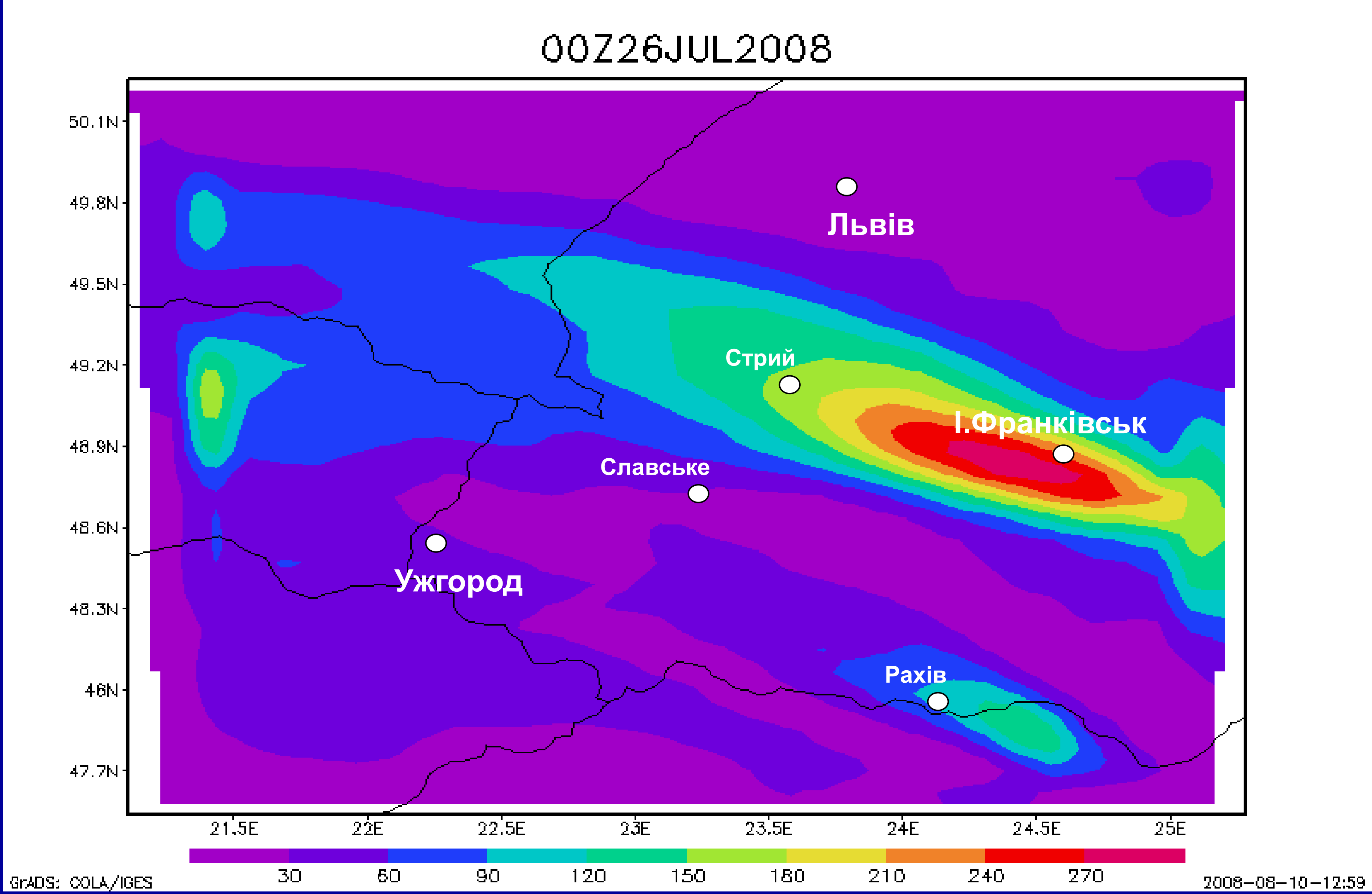
Прута=Prut

Сірет= Seret

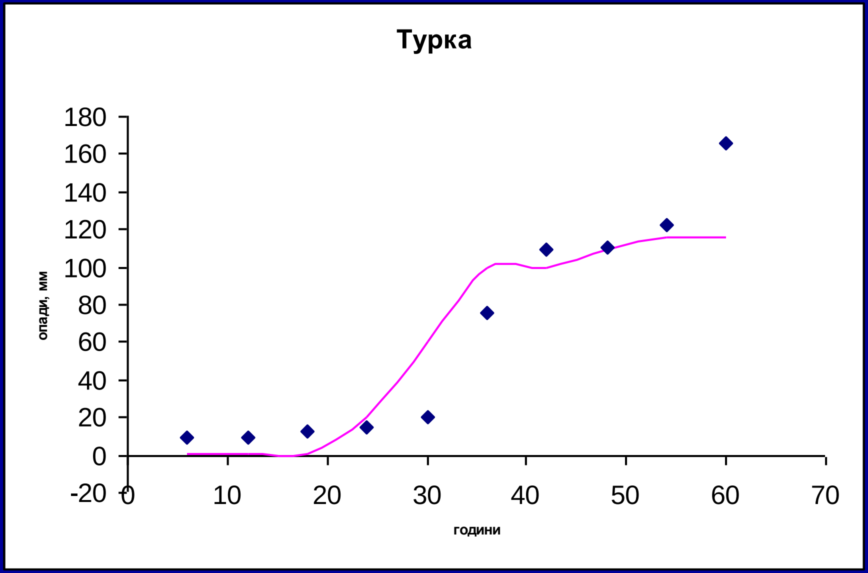
System testing for catastrophic flood July 2008

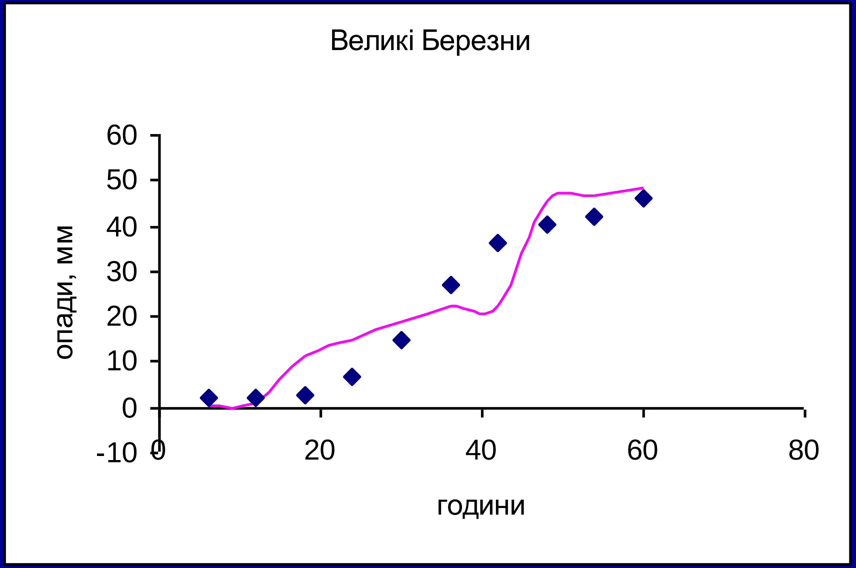


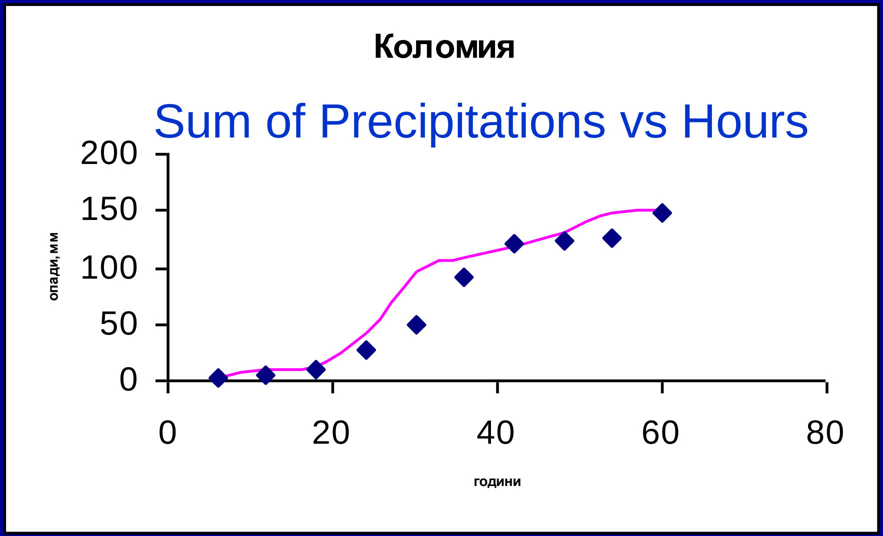
Zones of the catastrophic precipitation of 22-26 July 2008 on the Ukrainian wind map simulated by MM5- Ukraine model on the grid 27*27 km

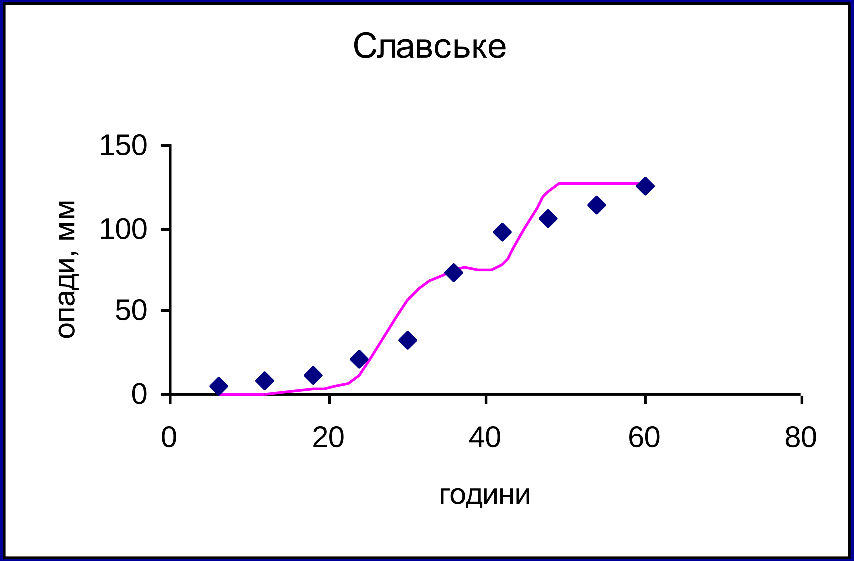


Forecast 0:00 23 .07 total precipitations (мм) by model MM5 - Carpathian (grid 9*9 km) for the period 23-25 July 2008

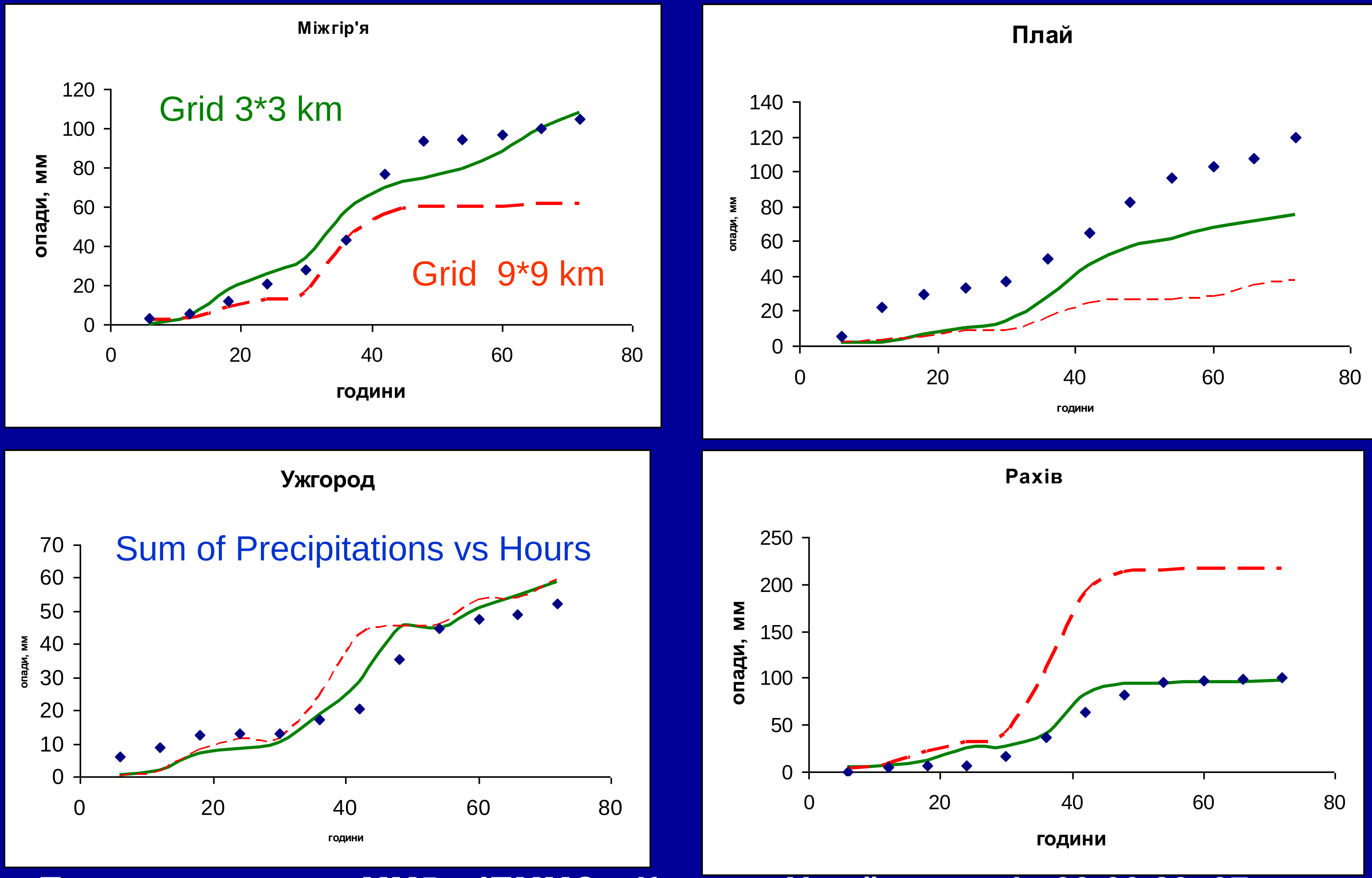








Forecast MM5 - MM5-Carpathian , grid 3*3 км. From 12:00 23 .07 total precipitation. Dots –measured data

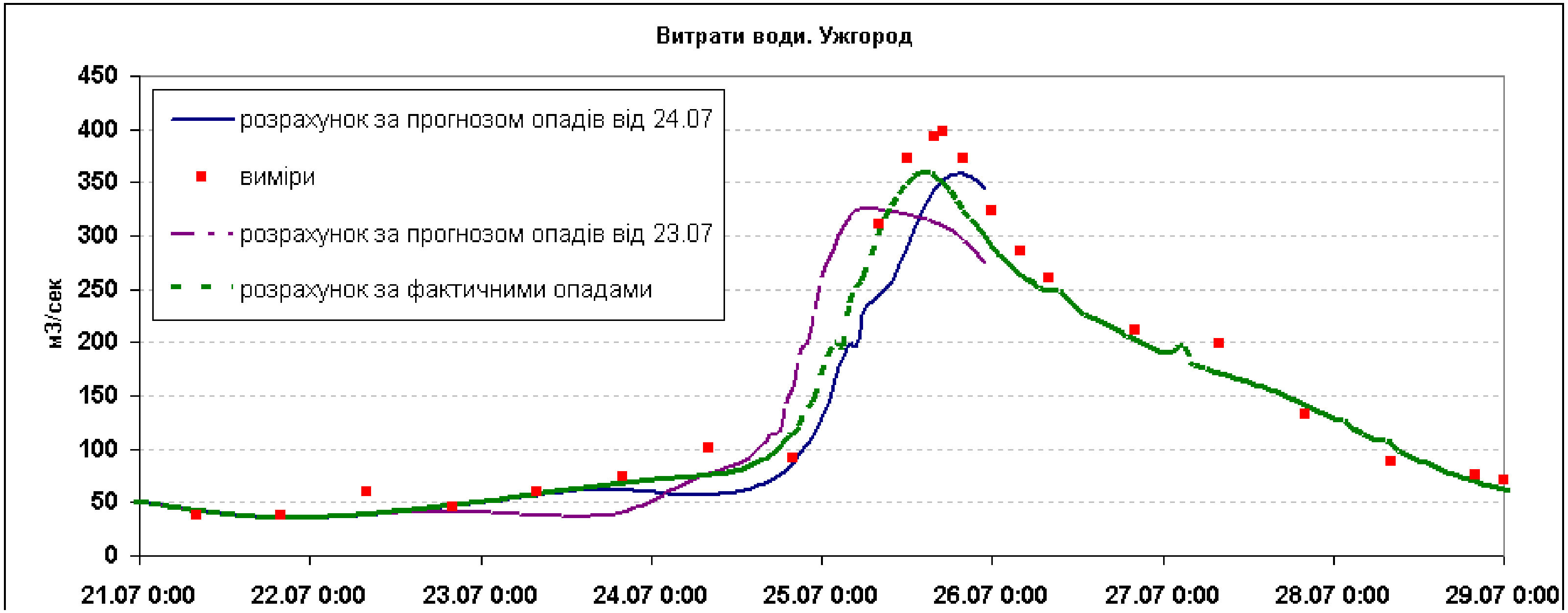


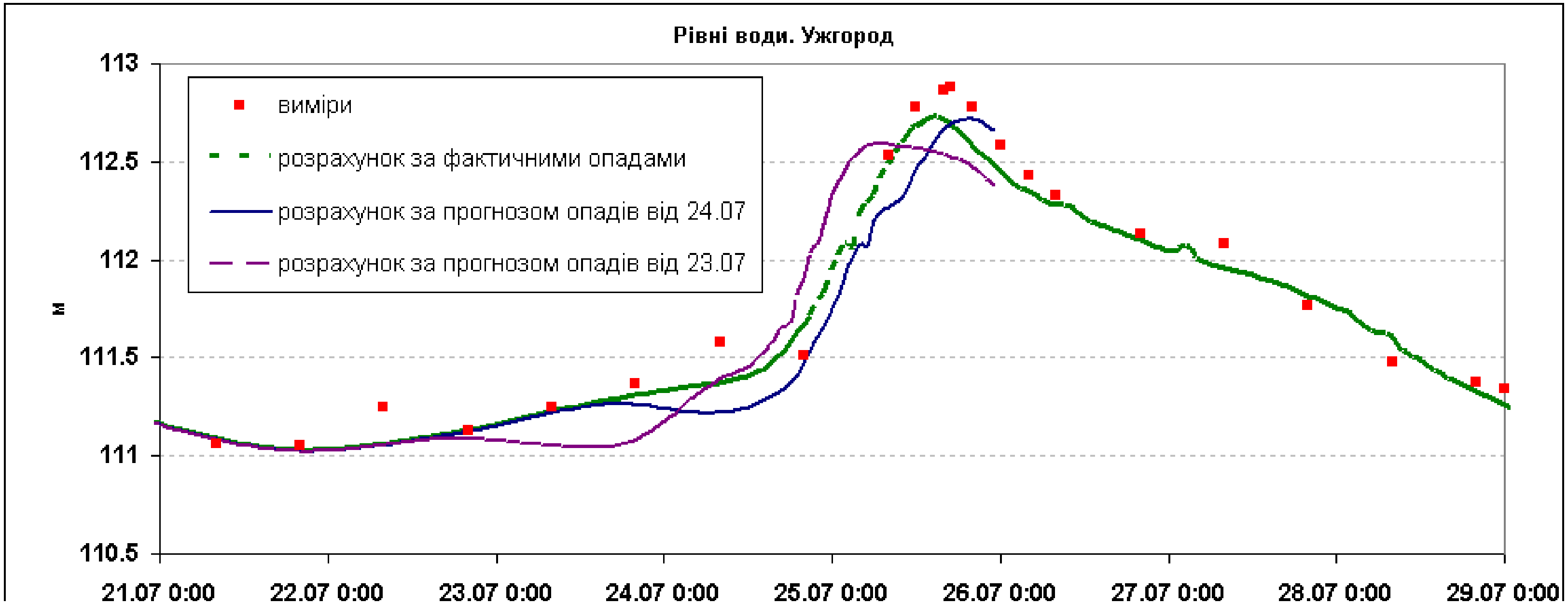
Прогноз моделлю ММ5 - ІПММС – Карпати Україна , м. від 00:00 23 .07 накопичених по окремим пунктам Закарпаття опадів (мм) Криві - прогнозні розрахунки, червона пунктирна – прогноз на сітці 9*9 км, зелена – прогноз на сітці 3*3 км точки – результати вимірів.

Таблиця.
Середня сума опадів (мм) за 72 години від 23.07.2008, 00 г по даним 11 Карпатських станцій

Table. Average accumulated rainfall (mm) during 72 h from 23.07.2008, 00 h on the basis of 11 Carpathian stations

Вимірювання Measurements	MM5, 9км сітка/9 km grid	MM5, 3км сітка/3 km grid
129	73	124



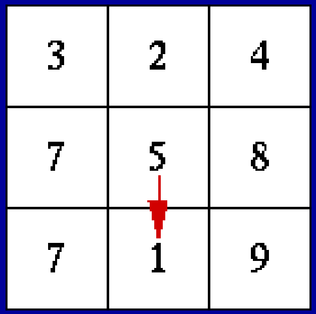


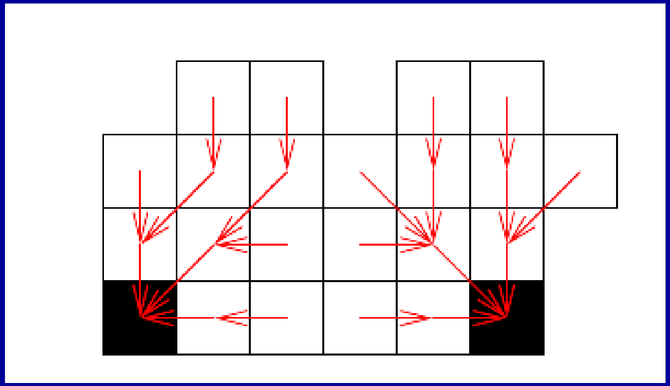
Simulation of the water levels and discharges of Uzh River near Uzhgorod based on the measured precipitations (solid line) and precipitations predicted by MM5- Carpathian models for 3*3 км grid

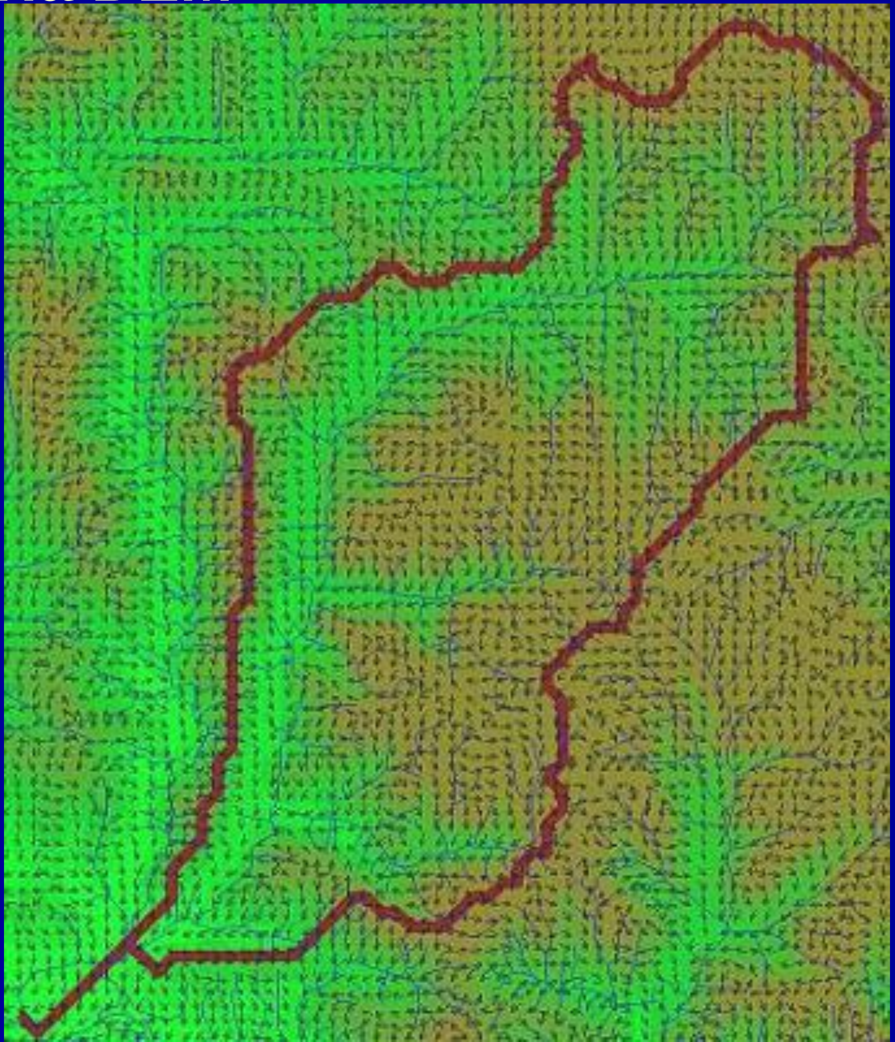
Distributed rainfall – runoff watershed model TOPKAPI-IMMSP

Model equations- E.Todini (author of ARNO and TOPKAPI models), software code – IMMPS/UCEWP inluding parallel version for super computers

- **Simulation of flow direction via DEM →**





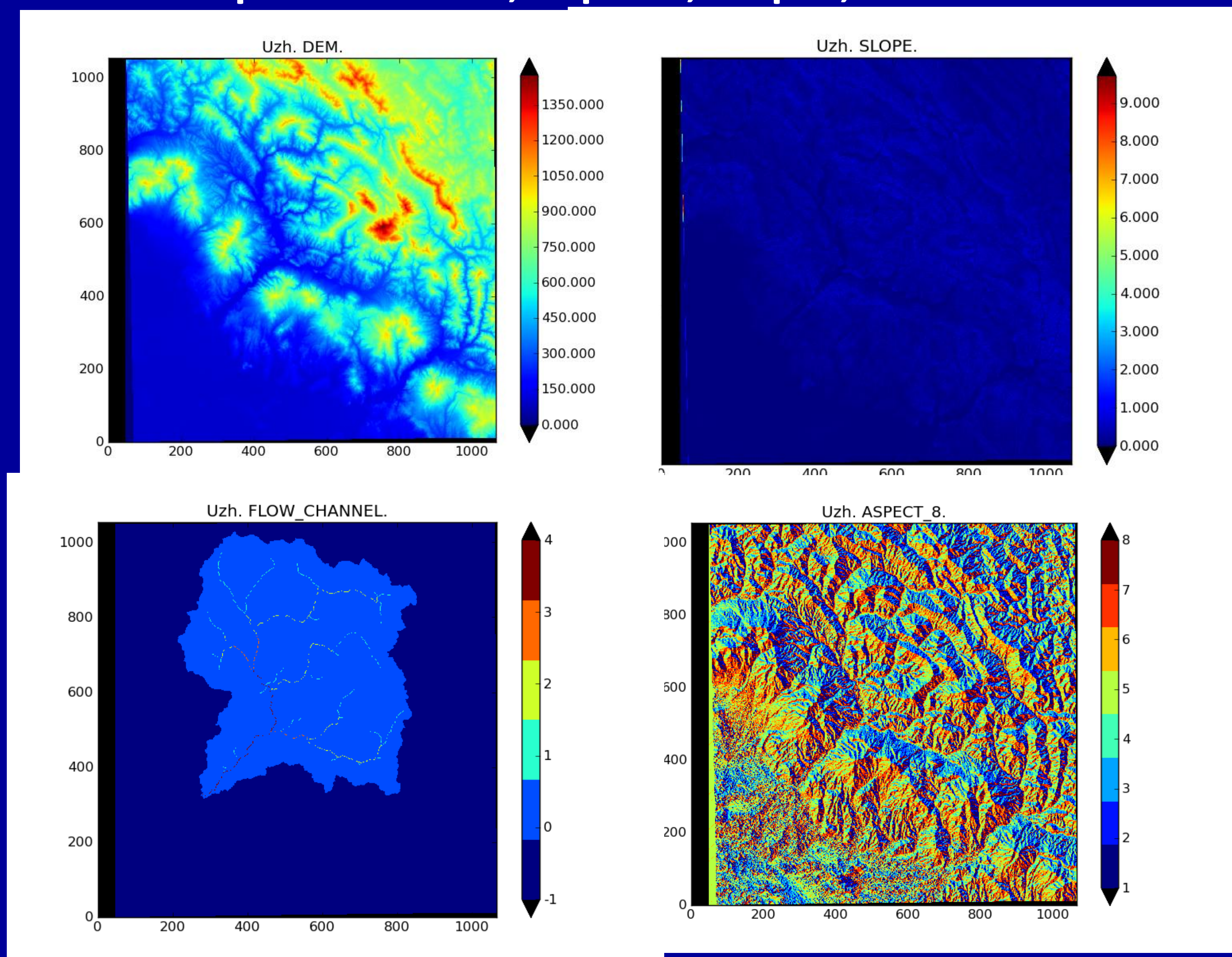


Карти водозбору р.Уж – основні вхідні данні для моделі TOPKAPI.

Карти висот, нахилів, орієнтації схилів , природних водотоків.

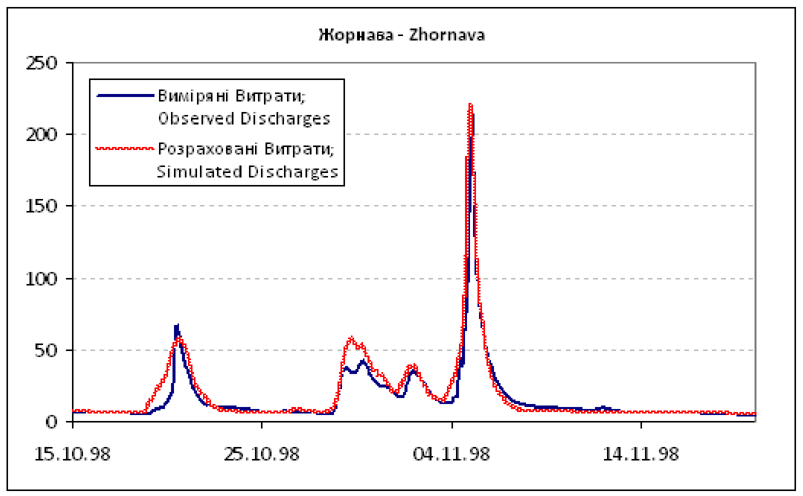
GIS maps for Uzh Watershed– input for TOPKAPI model.

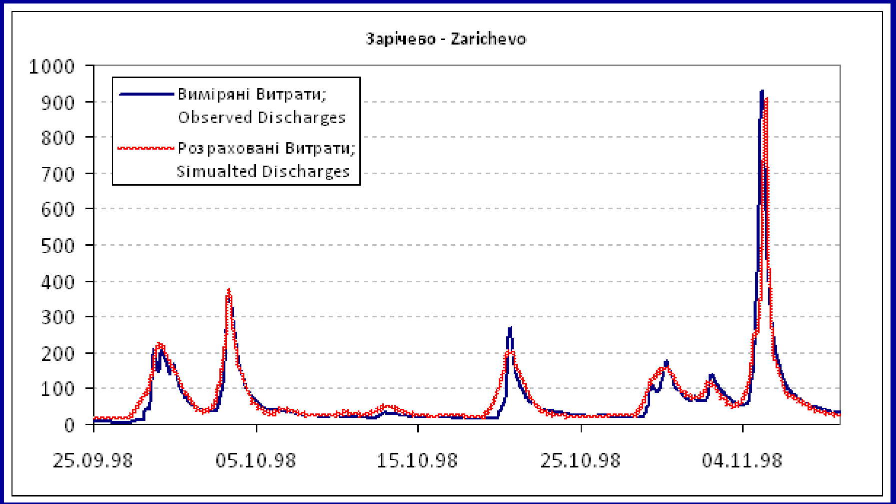
Maps: Elevations, Aspects, Slopes, Channels

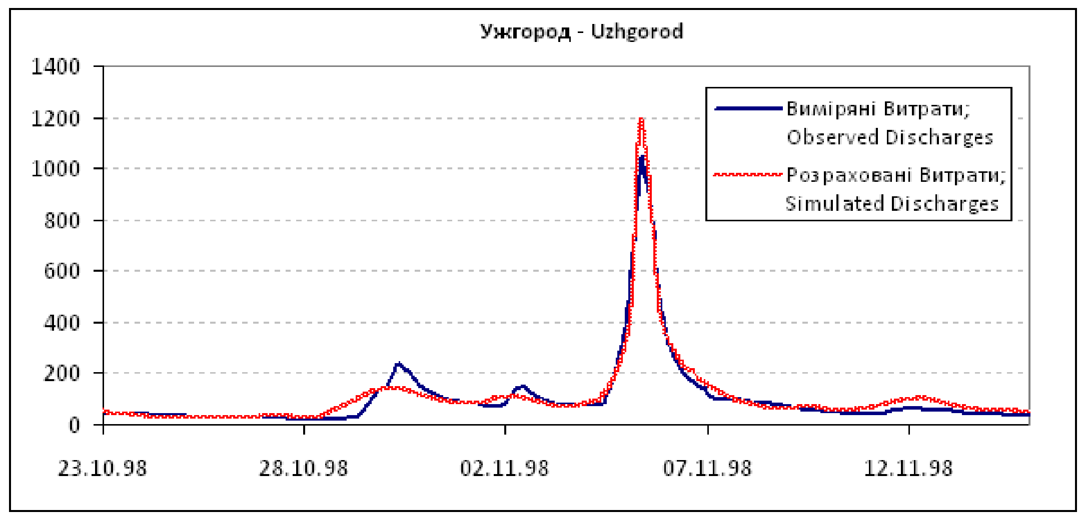


Результати моделювання для замикаючих створів водозбору р.Уж. Повінь у Листопаді 1998 року

Results of simulations for gauging outlets points of Uzh River Watershed. Flood Event of November of 1998





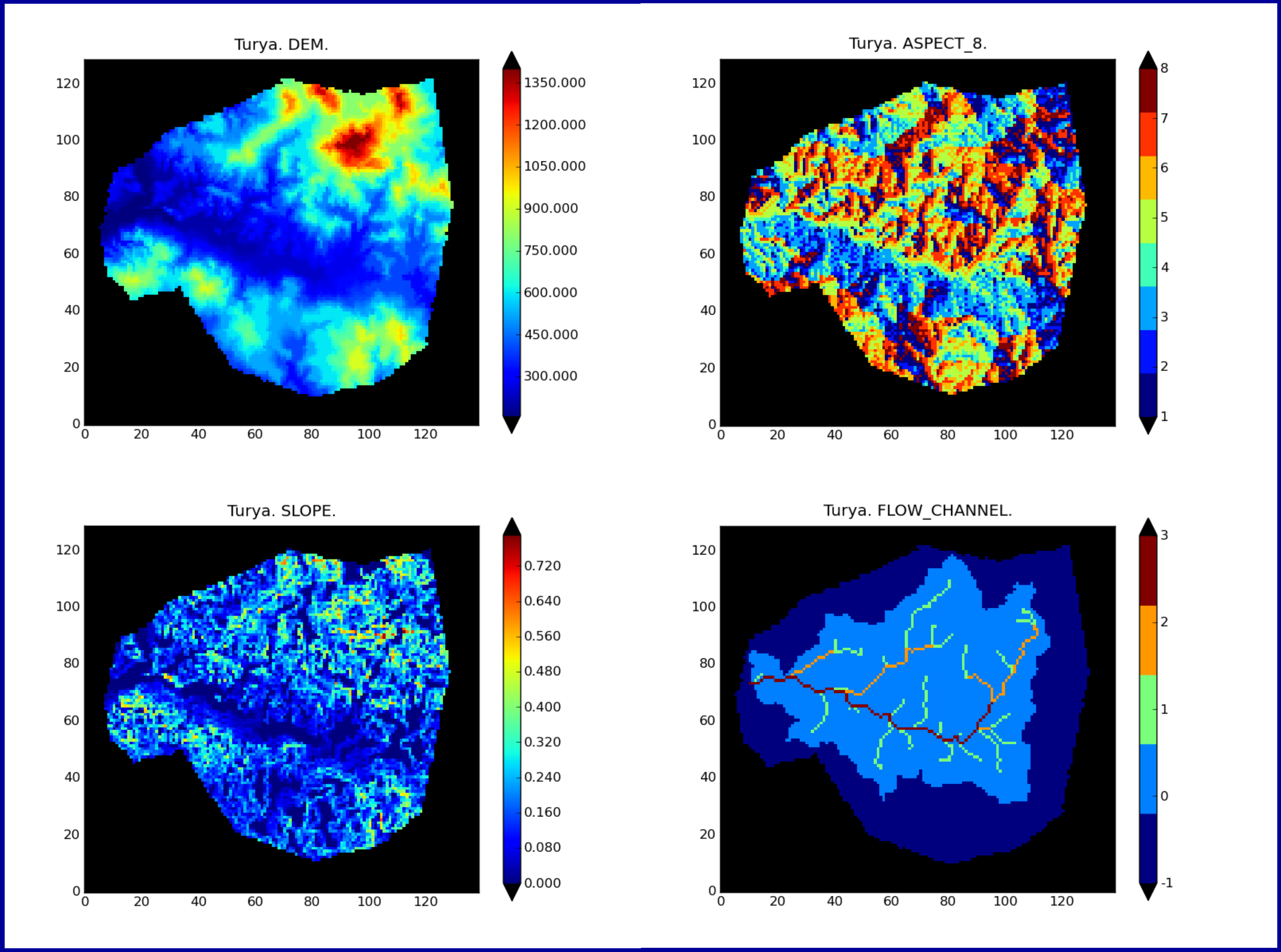


Карти водозбору р.Тур'я (притока р.Уж) – основні вхідні данні для моделі TOPKAPI. Водозбір р.Тур"я є пілотним для впровадження моделі.

Карти висот, нахилів, аспектів, природних водотоків.

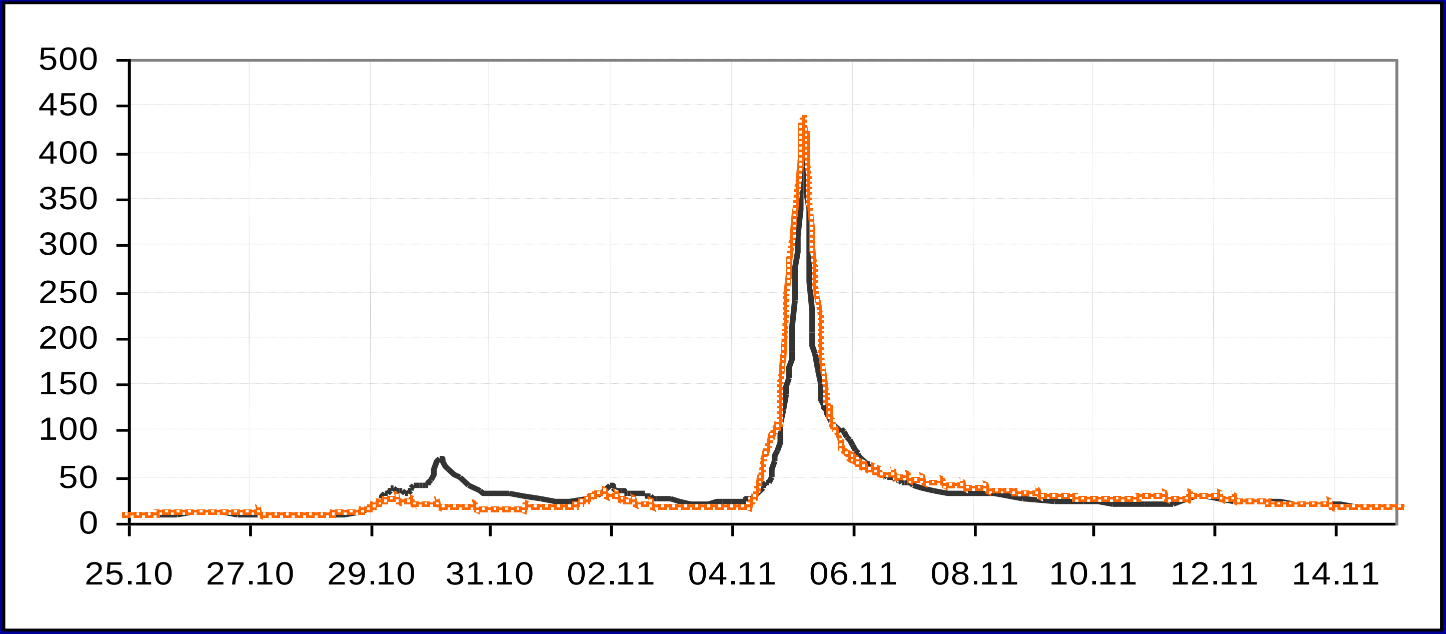
GIS maps for Turya Watershed (tribuatary of Uzh River)– input for TOPKAPI model.

Maps: Elevations, Aspects, Slopes, Channels



Результати моделювання водозбору р.Тур”я (головна притока р.Уж). Повінь 1998 року.

Results of simulations for Turya River Watershed. Flood Event of November of 1998



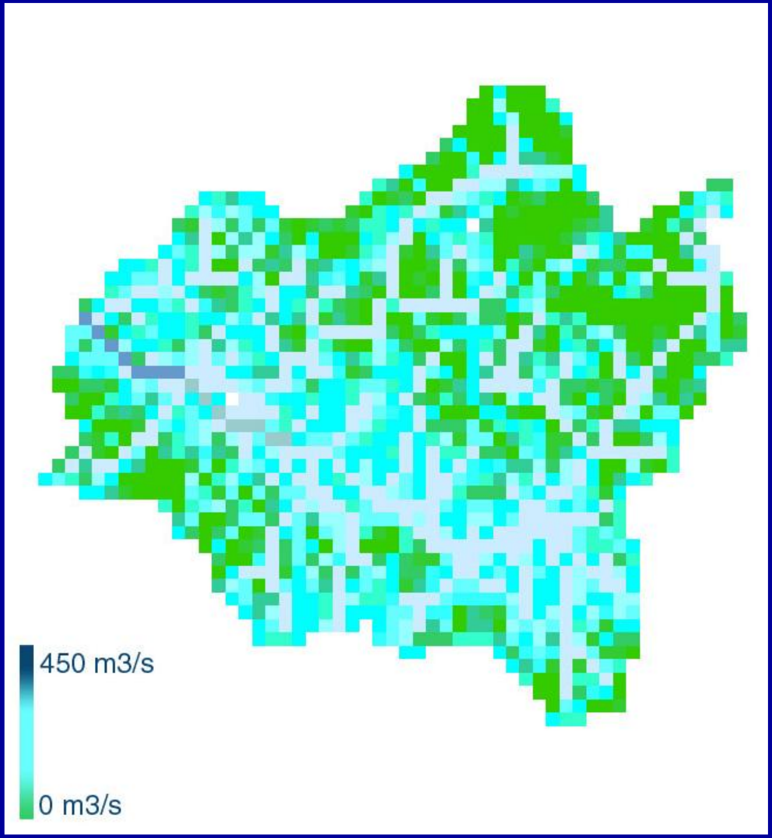
Фактичні та виміряні витрати води, Сімер, р.Тур”я

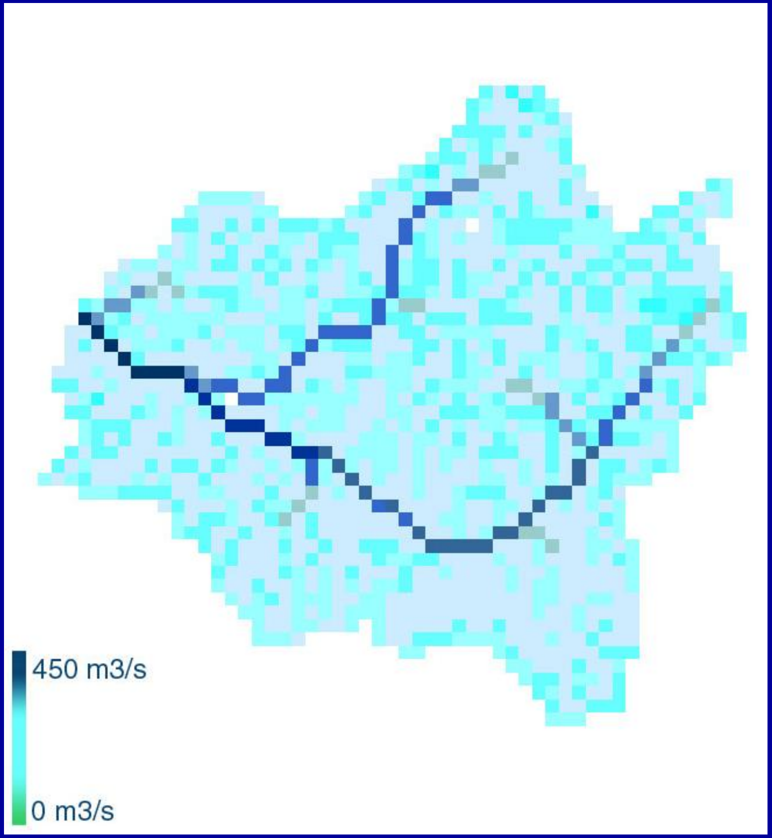
Чорна лінія – виміри, Червона лінія – розрахунок

Simulated and observed runoff for outlet point Simer, Turya river.

Black line – observed discharge, Red line - simulated

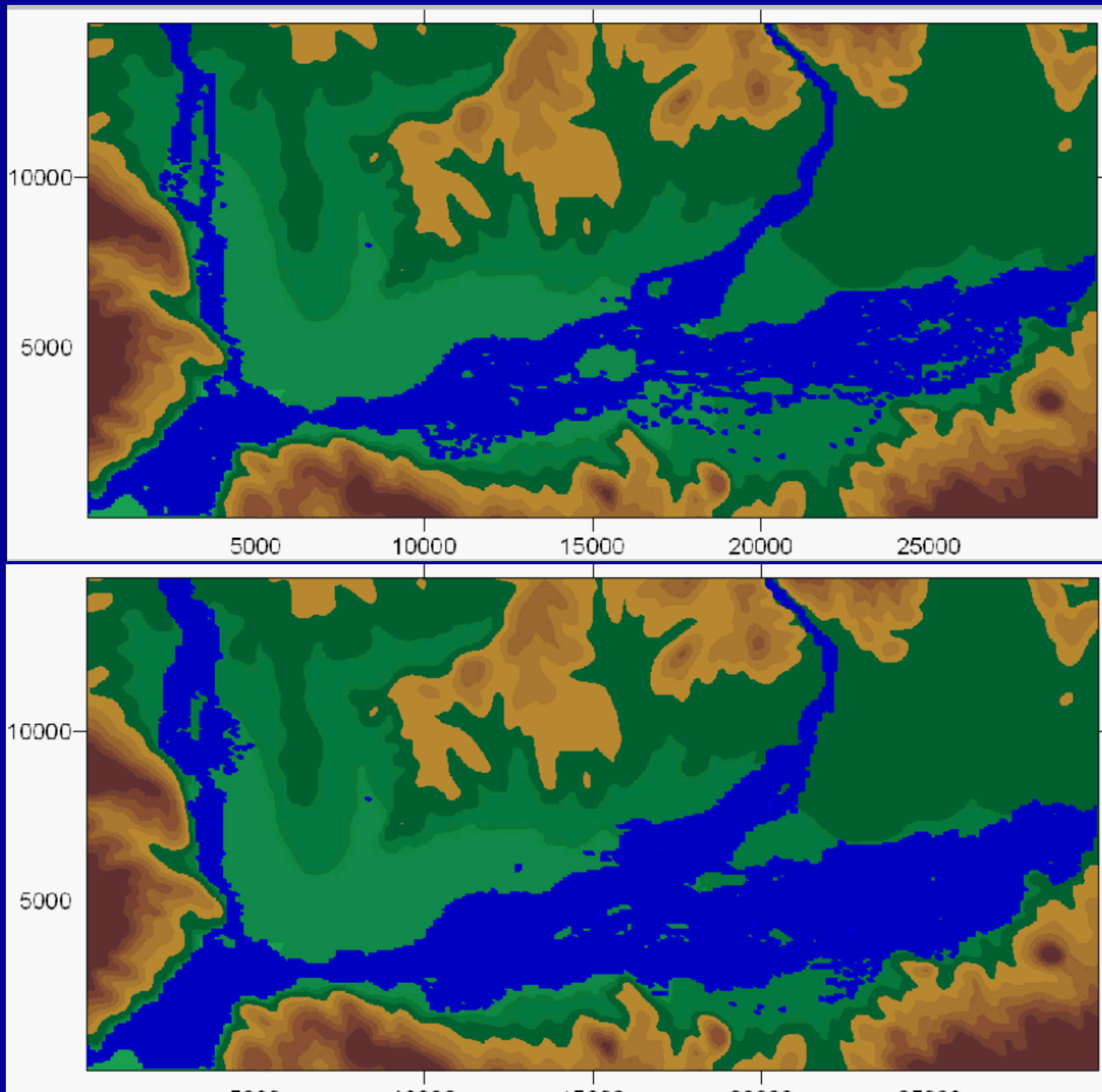
р.Тур”я (головна притока р.Уж). Повінь 1998 року.
Turya river case study.
Flood event of autumn 1998.

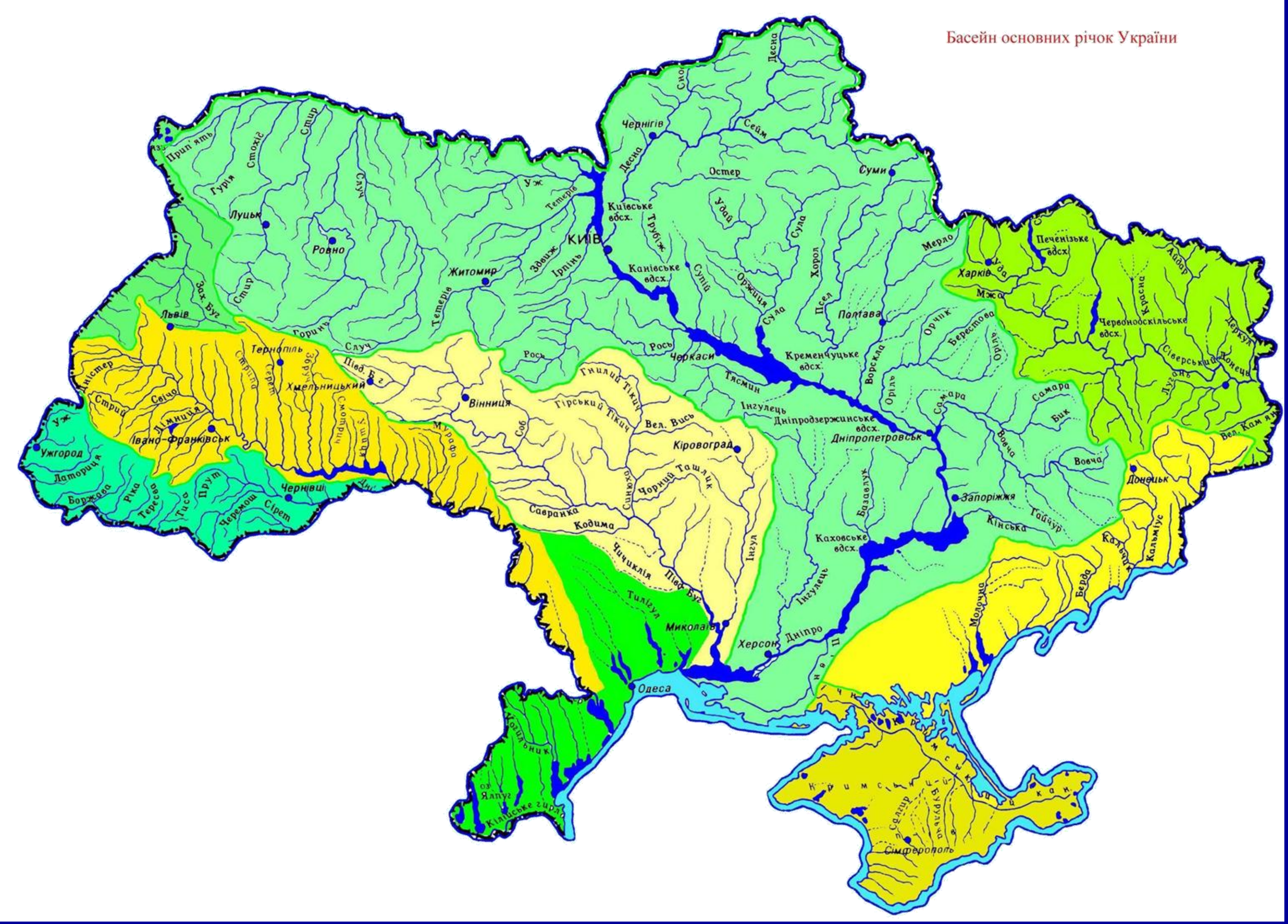




Розподіл витрат під час повені в басейні річки Тур”я
Distribution of discharges during flash flood on Turya river basin.
Зліва, Left - 04.11.1998 07:00. Зправа, Right - 05.11.1998 07:00

2D model COASTOX – IMMSP floodplain inundation Tisza River at city Khust





➪ Dnipro	F=504 000 km^2	L=2201 km
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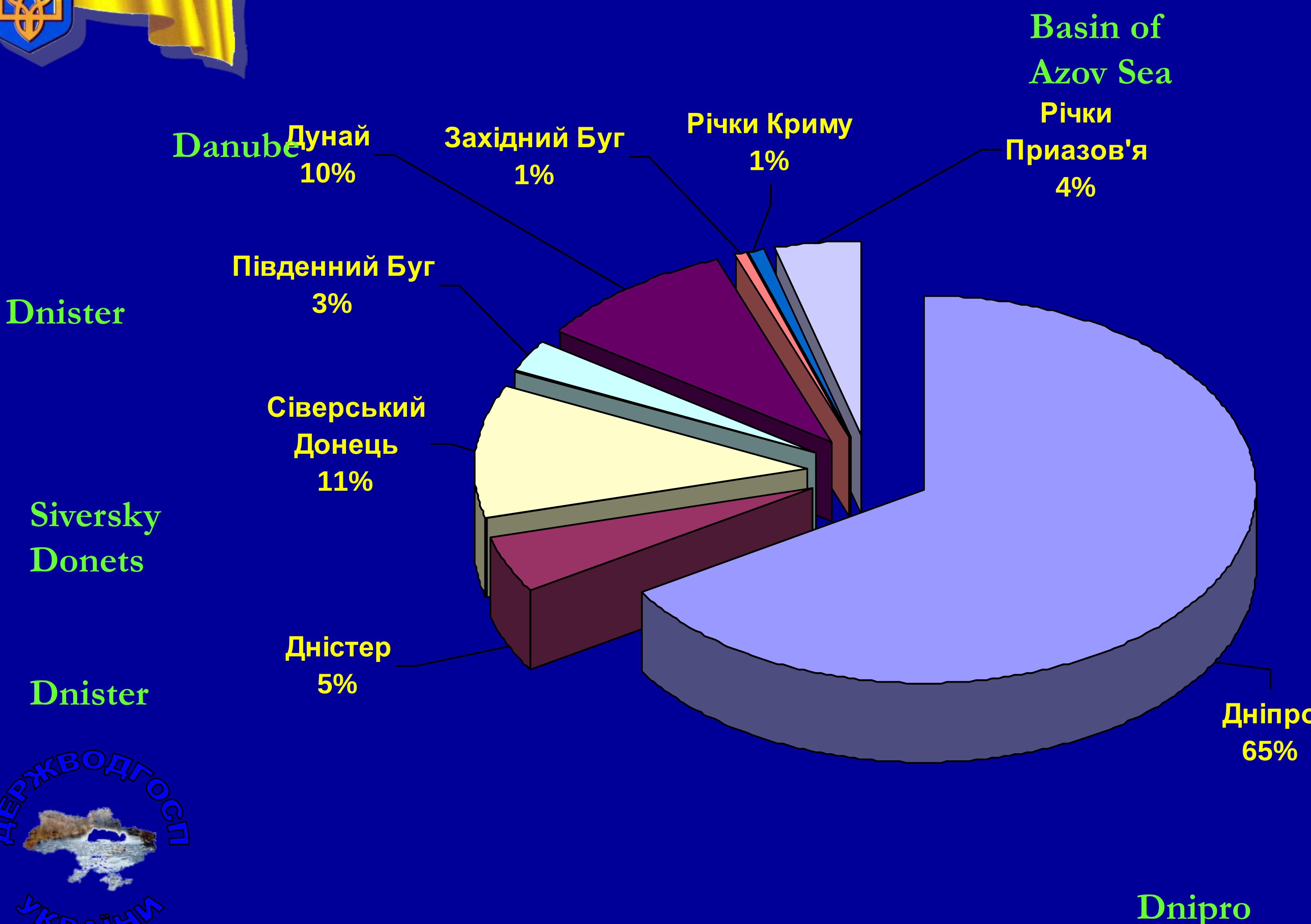
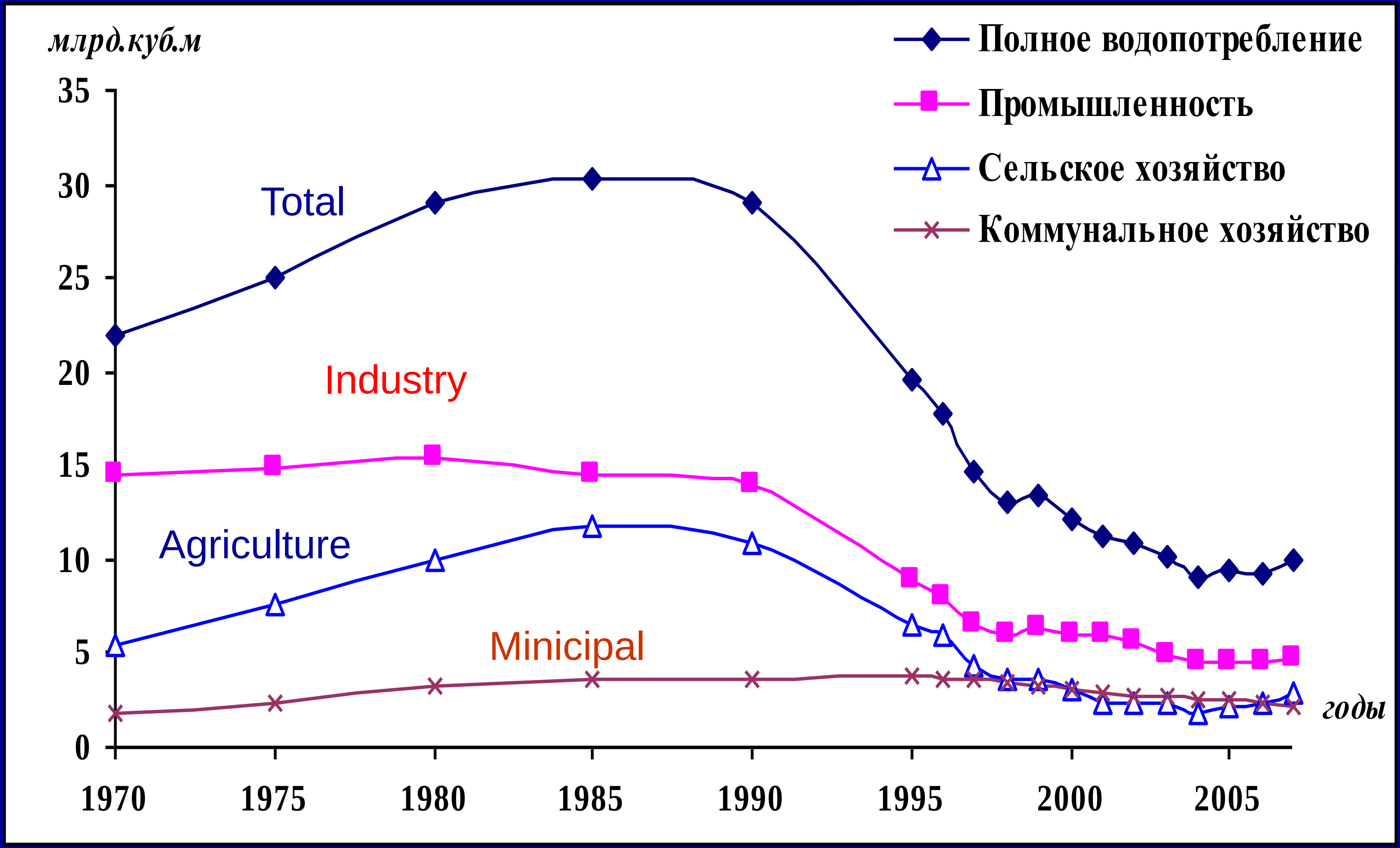
➪ Tissa	F=153 000 km^2	L=966 km

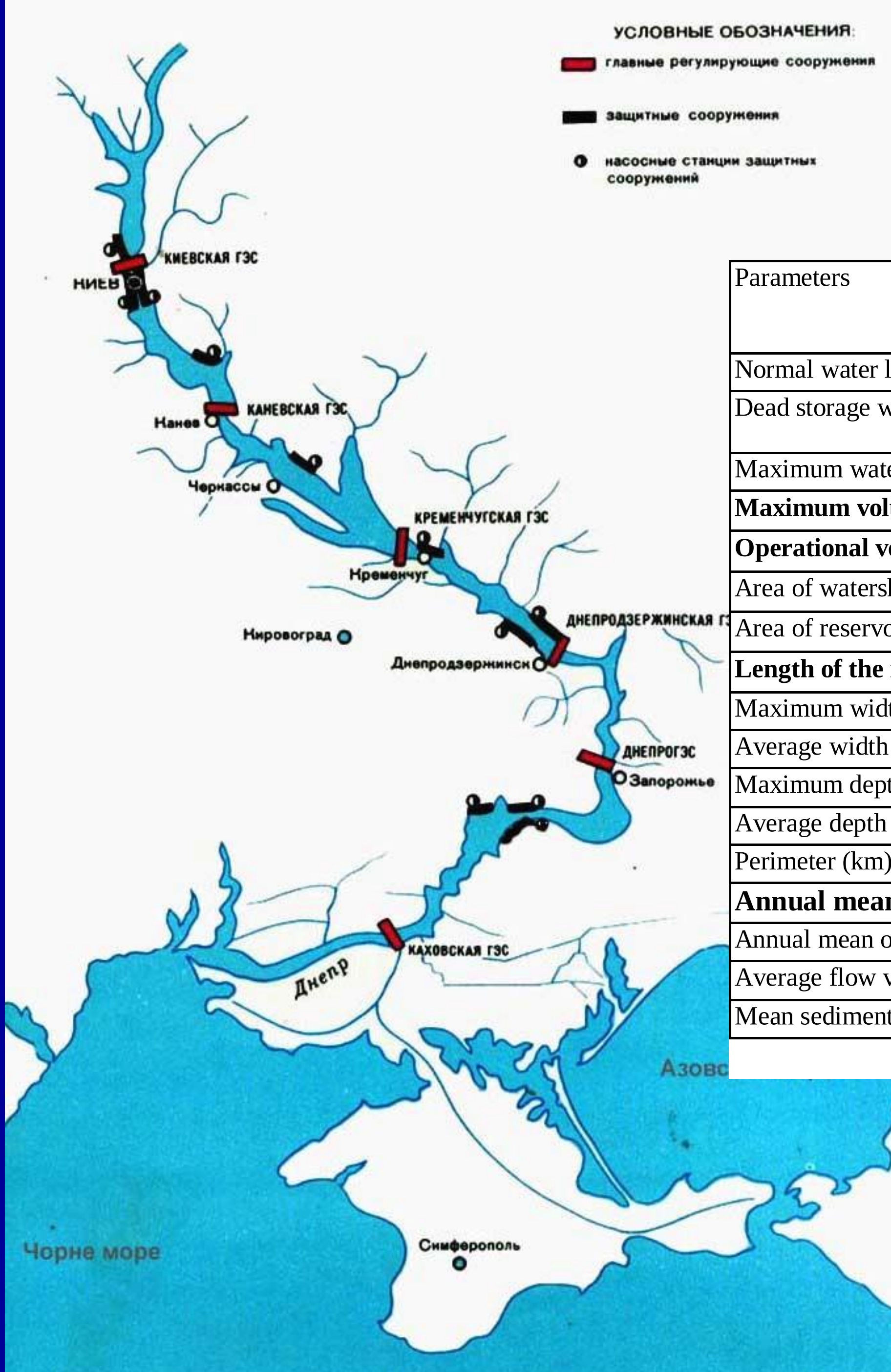
Water use allocation between the river basins



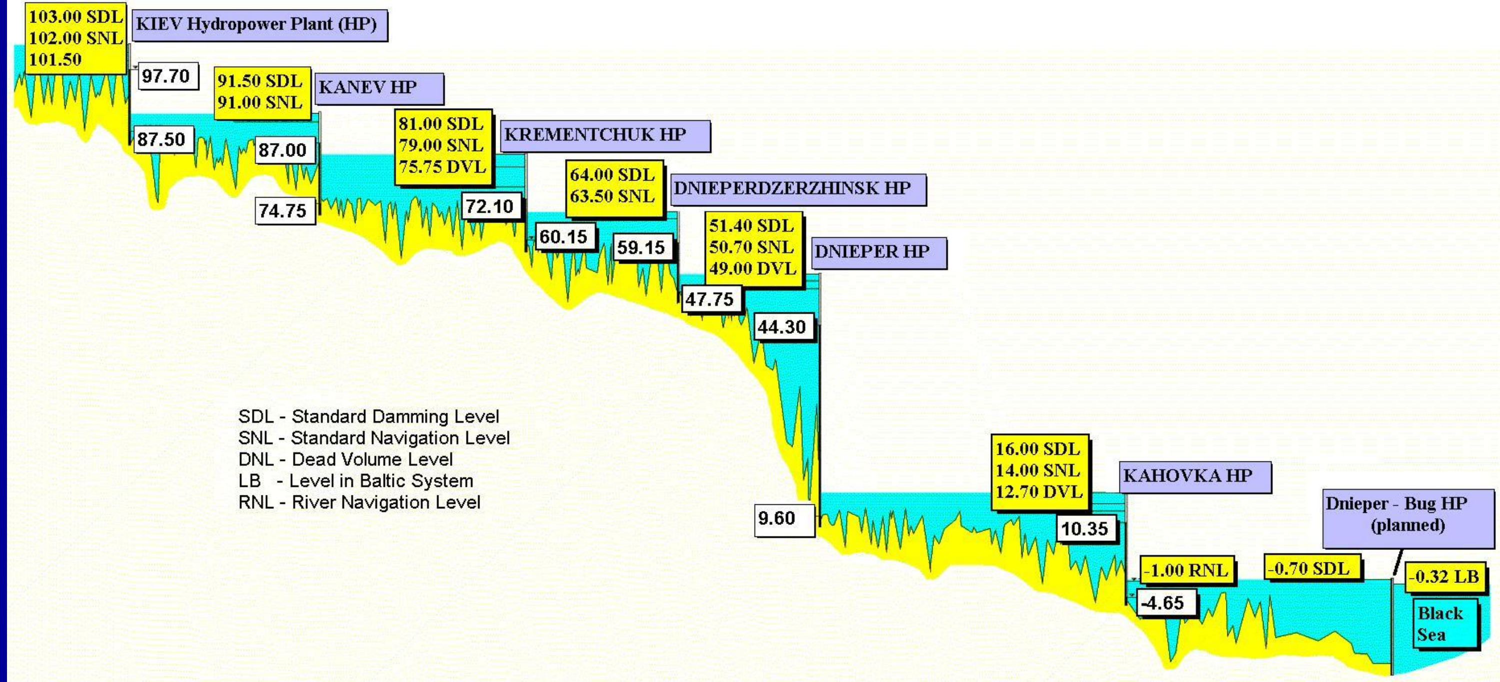
Потребление пресной воды в Украине за 1970-2007 гг.

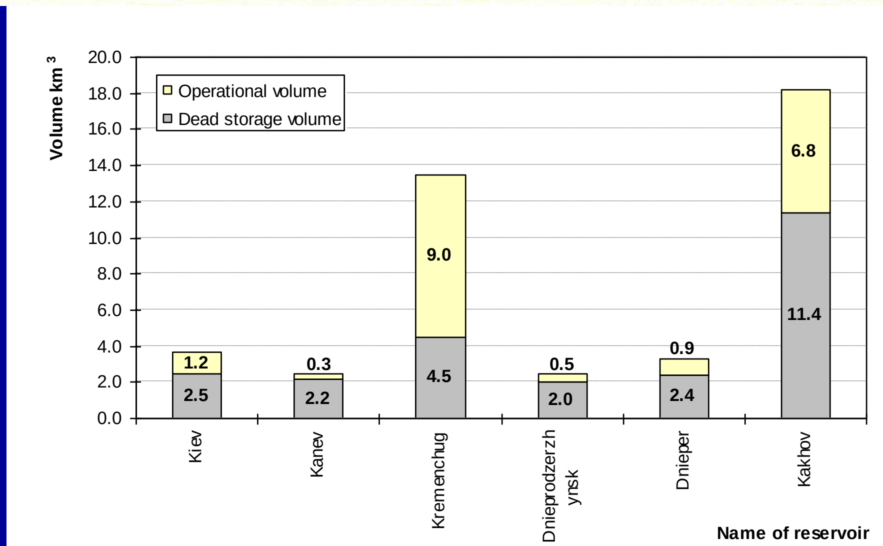
Fresh water use in Ukraine 1970-2007



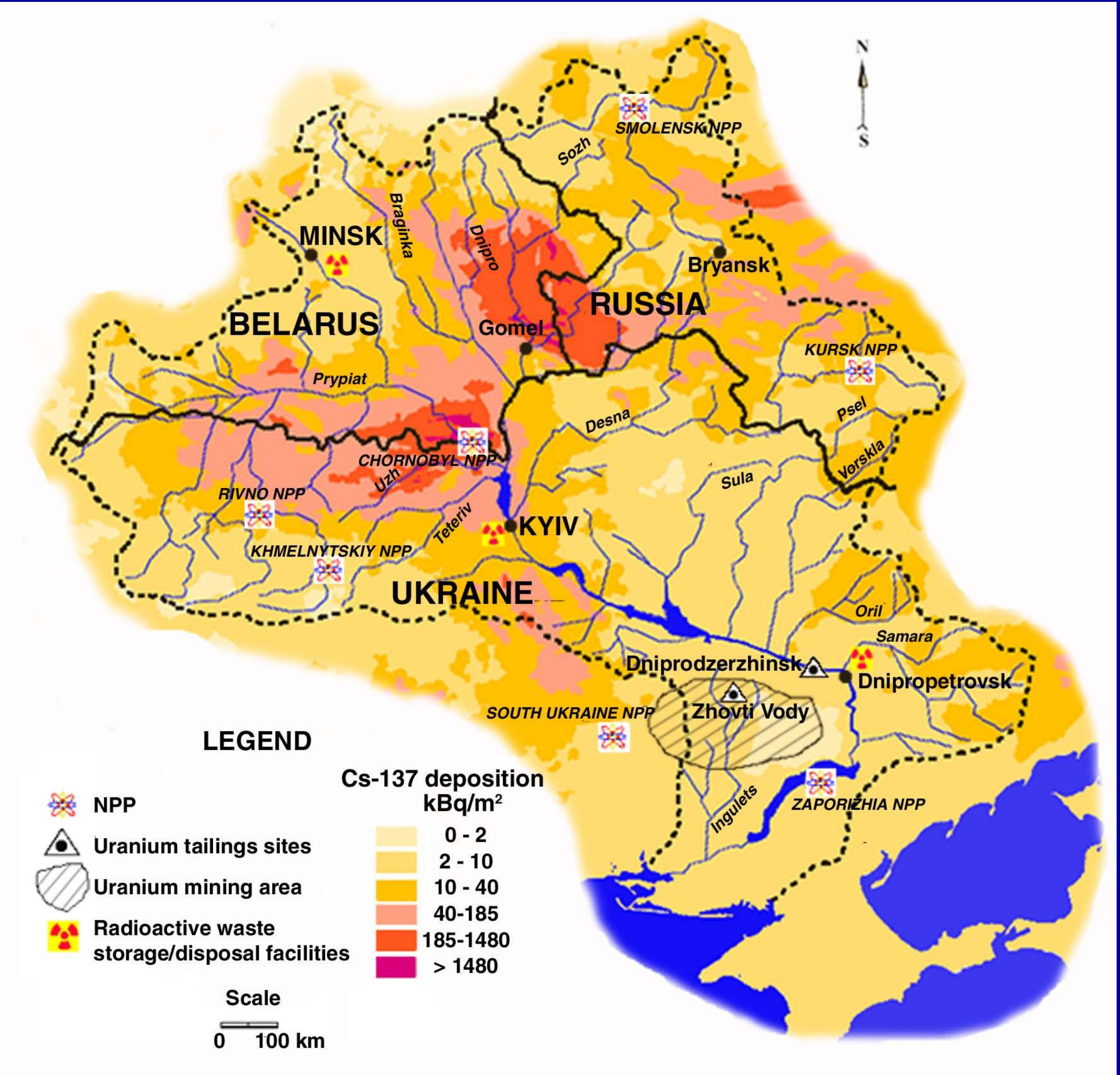


Parameters	Kiev	Kanev	Kremenchug	Dnieprodzerzhinsk	Zaporozhie	Kakho
Normal water level (m a.s.l.)	103.0	91.5	81.0	64.0	51.4	16.0
Dead storage water level (m a.s.l)	101.5	91.5	75.75	63.0	48.5	12.7
Maximum water level (m a.s.l.)	104.1	92.7	82.4	66.0	51.4	18.0
Maximum volume (km^3)	**3.7**	**2.5**	**13.5**	**2.5**	**3.3**	**18.2**
Operational volume (km^3)	**1.2**	**0.3**	**9.0**	**0.5**	**0.9**	**6.8**
Area of watershed (1000 km^2)	239	336	383	425	463	482
Area of reservoir for normal water level (km^2)	922	675	2250	567	410	2150
Length of the reservoir (km^2)	**110**	**123**	**149**	**114**	**129**	**230**
Maximum width (km)	12.0	8.0	28.0	8.0	7.0	25.0
Average width (km)	8.4	5.5	15.1	5.1	3.2	9.3
Maximum depth (m)	14.5	21.0	20.0	16.0	53.0	24.0
Average depth (m)	4.0	3.9	6.0	4.3	8.0	8.5
Perimeter (km)	520	510	800	358	250	900
Annual mean outflow (m^3/s)	**1050**	**1390**	**1510**	**1640**	**1650**	**1650**
Annual mean outflow volume (km^3/year)	33.1	43.9	47.8	52.	52.2	52.2
Average flow velocity (cm/sec)	3.0	7.6	2.0	7.1	6.4	1.6
Mean sedimentation rate (cm/year)	0.70	2.00	0.94	0.98	1.37	0.80





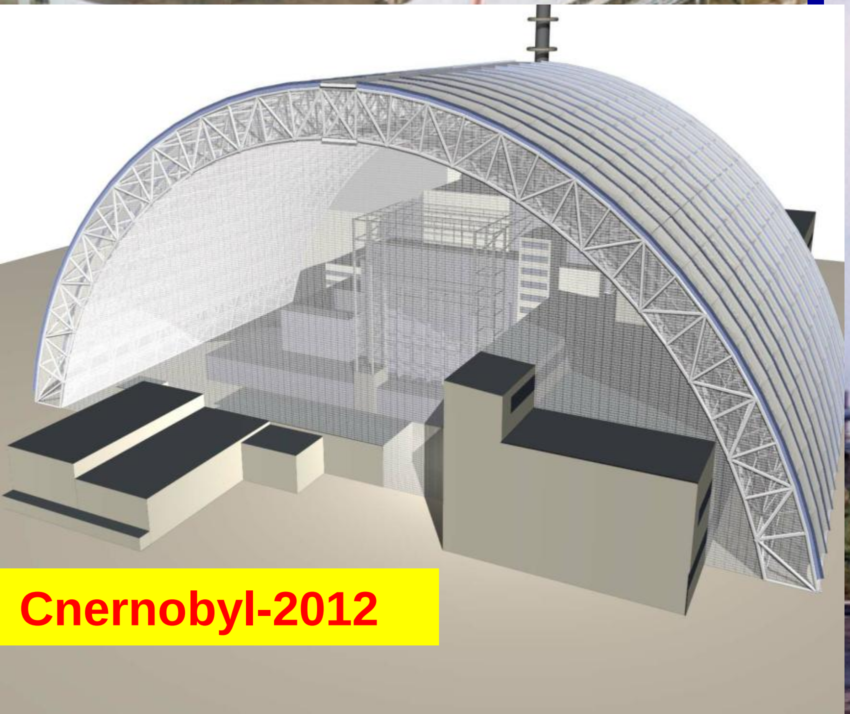
Operational and dead storage volume of the Dnieper reservoirs


N
S
SMOLENSK NPP
Sozh
MINSK
Braginka
Dnipro
Bryansk
RUSSIA
BELARUS
Gomel
KURSK NPP
Prypiat
Desna
Psel
CHORNOBYL NPP
Vorskla
Uzh
Sula
RIVNO NPP
Teteriv
KYIV
KHMELNYTSKIY NPP
UKRAINE
Oril
Samara
Dniprodzerzhinsk
Dnipropetrovsk
SOUTH UKRAINE NPP
Zhovti Vody
LEGEND
Cs-137 deposition
kBq/m²
NPP
Uranium tailings sites
Uranium mining area
Radioactive waste
storage/disposal facilities
0 - 2
2 - 10
10 - 40
40-185
185-1480
> 1480
Ingulets
ZAPORIZHIA NPP
Scale
0 100 km

Cnernobyl-1986:

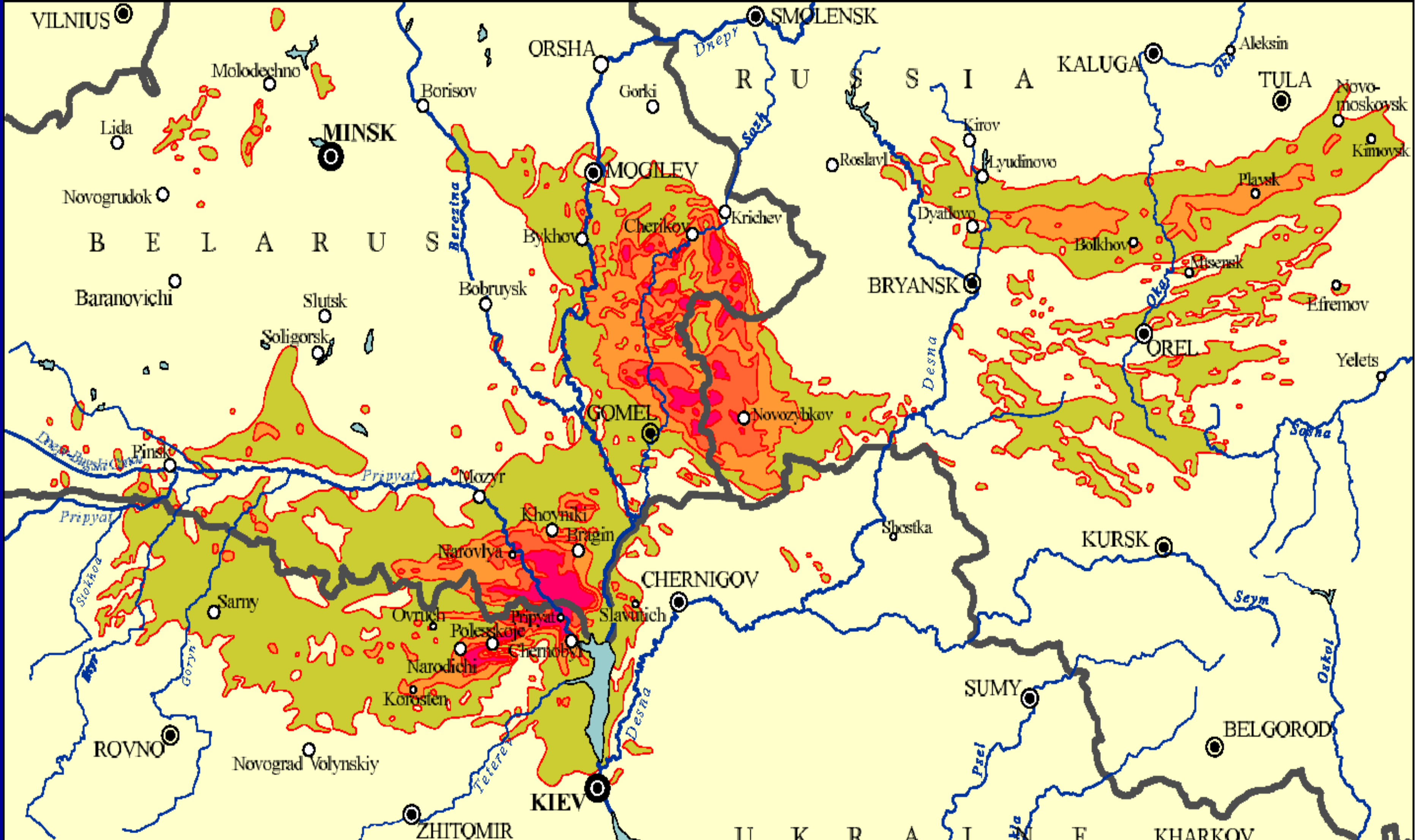
Mathematical Modeling of Environmental Processes, Model Based Decision Support Systems -

The R&D were intensified since 1986 due to the NASU deep involvement into scientific support of the mitigation of the consequences of the Chernobyl Accident



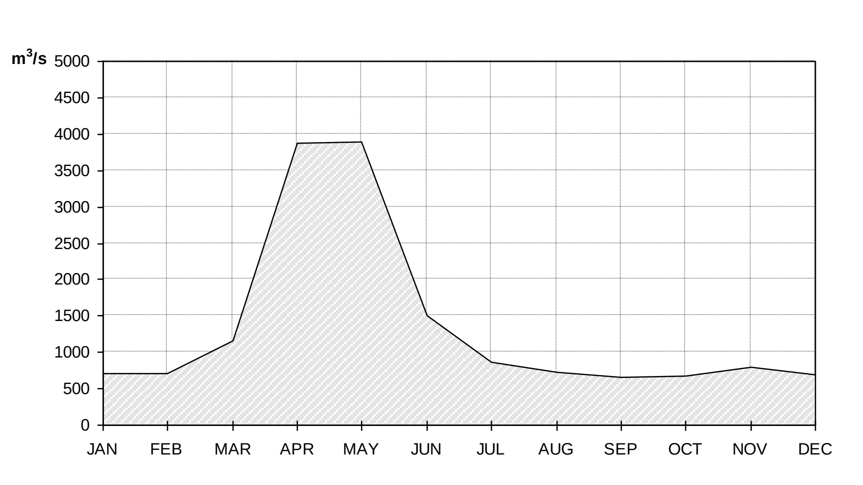
Cnernobyl-2012

Cnernobyl-1997:



Model/data based Decision Support Systems for water bodies protection and minimization of the radionuclide transfer through the Pripyat- Dnieper river- reservoir system has been developed in 1986-1999 and updated after 2000

Map of Post- accidental Fallout of Cs-137 in Dnieper-Pripyat Basin



Average hydrograph at Kiev station (1881-1964)

The maximum daily flood at Kiev station during the 1881-1974 period was 23 100 m3/s at 2nd May 1931.

The maximum daily discharge measured at the Lotsmano-Kamenka station was 25 100 m3/s on 9th May. The years with second and third largest flood values for the Kiev series were respectively in 1970 with maximum daily discharge of 18 500 m3/s and in 1917 with discharge 17 500 m3/

The largest flood in 1931 was caused by combination of several factors: saturation of the soil during the autumn, accumulation of large snow amount during winter, rainfall during and to the end of melting period and high melting temperatures.

Decision making procedures on Dnipro reservoir management (2)

The Commission defines:

- sizes and intensity of the cascade reservoirs depletion before the beginning of spring and during the period of freezing-over,
- order of cascade water filling before the spring flood,
- restrictions of water discharge and its variations by ecological criteria,
- control the amount of high discharge passing through the cascade for prevention of undesirable flooding etc.

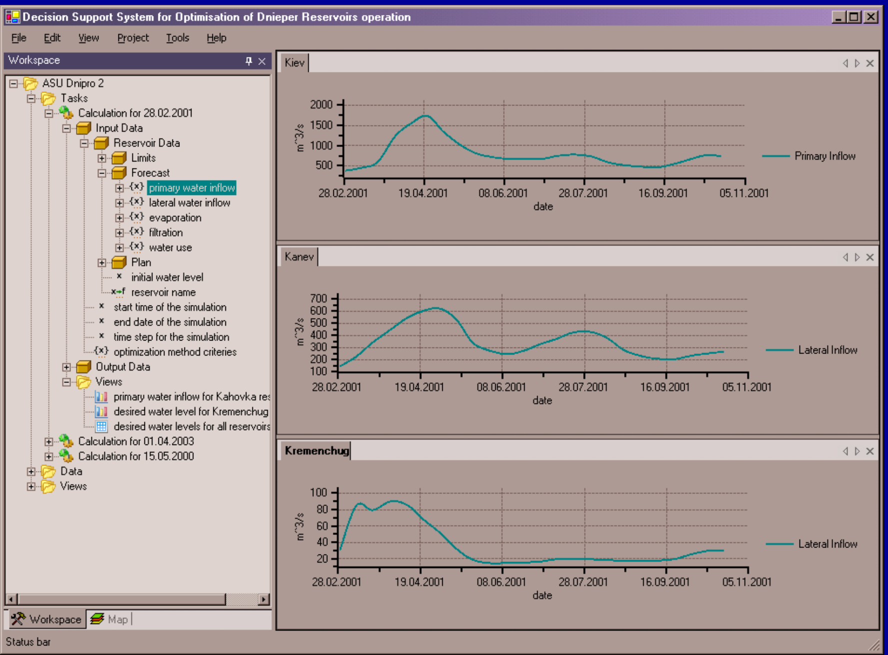
In this decisions the Commission uses the forecasts of the inflow to the reservoirs described in the section 3.2 above and the results of the optimization of the reservoir operations calculated by the balance model ASUD (Automatic System of Dnieper Management) developed by the SCUWM in Soviet time and more modern system ASUD2 developed by IPMMS last decade in the frame of the international and national projects.

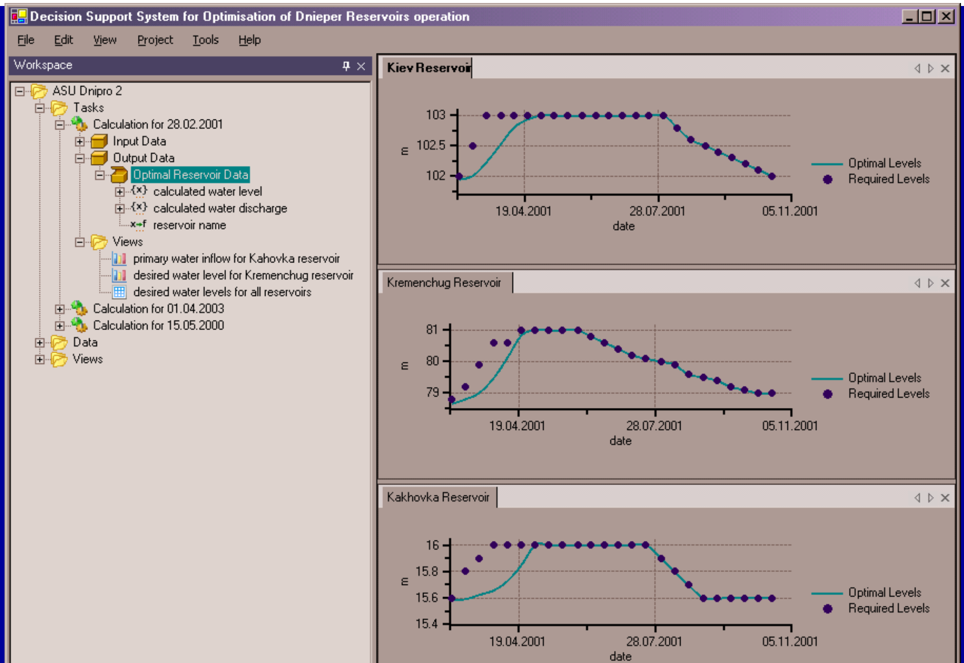
ASUD-2 optimization system based on the box models

ASUD-2 system developed by IMMSP in the frame of SIDA, 2003 and nationals projects has extended old ASUD system by using new technologies and possibilities to use multy-criteria optimization, including into the target functions not only water discharge/level. but also water quality parameters (Irits et al., 2003, Shatokhin et al, 2008).

ASUD2 includes multicriteria optimization engine that drives the reservoir water balance models and box models of water quality based in the equations of the US EPA WASP Model. The Integrated Database IDB-ASUD2 supplies the information such as state of the all reservoirs, hydrological observations and predictions, water demands, measured water quality parameters.

Optimization engine of ASUD2 is based on DONLP2 nonlinear programming procedure (Spellucci, 1998) included into www.nettlib.org library.
The system programmed on the basis of the object oriented approach (.Net, c# technologies) integrates the optimization module with the Integrated Date Base (IDB) and GIS module.

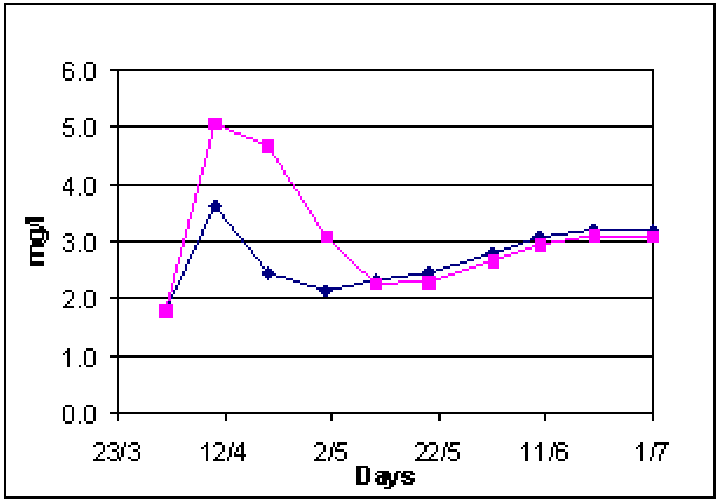




ASUD2 includes multicriteria optimization engine that drives the reservoir water balance models and box models of water quality based in the equations of the US EPA WASP Model. The Integrated Database, demonstrating graphics of inflow , the result of optimization on the criteria, minimizing the distance between the planned and actual water levels, the discharges from HPP in the simulated mode.

ASUD2 uses the information such as state of the all reservoirs, hydrological observations and predictions, water demands, measured water quality parameters.

The main water use optimization criteria are minimizing of the distance to the planned levels, smoothing of the oscillation of the water discharges from HPP, etc. The minimization of BOD and maximization of DO are established as criteria for the water quality optimization. For two operational modes of Kremenchug reservoir the difference in the CBOD concentration in downstream Dneprodzerzhinsk and Dniprocvske Resrvoirs is presented in Fig. 3.



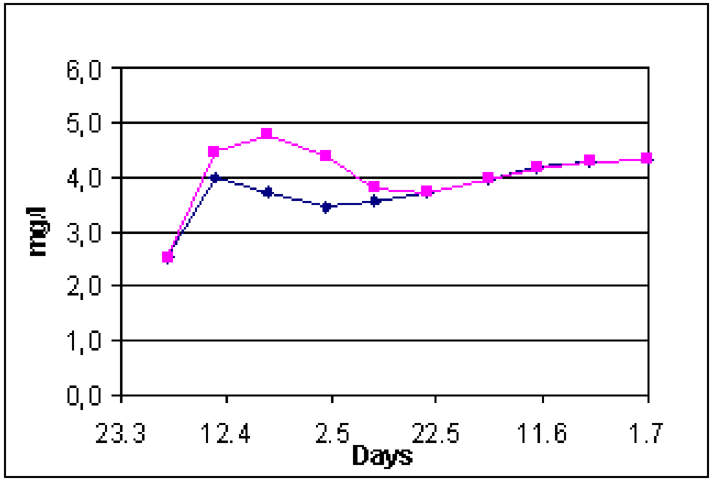
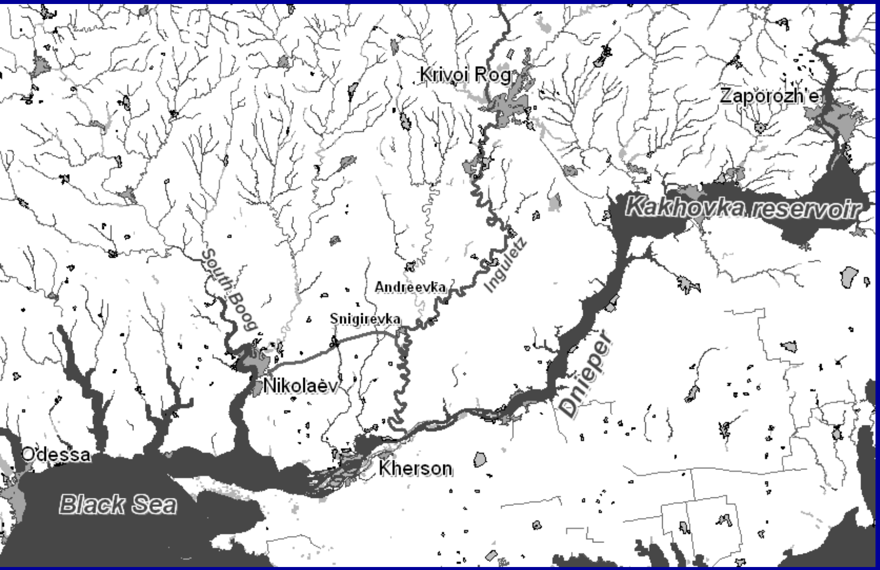
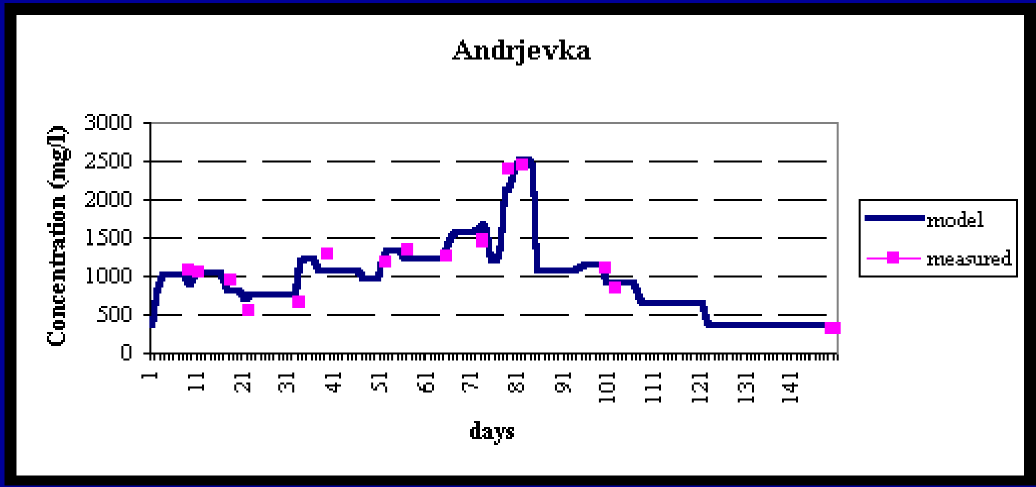
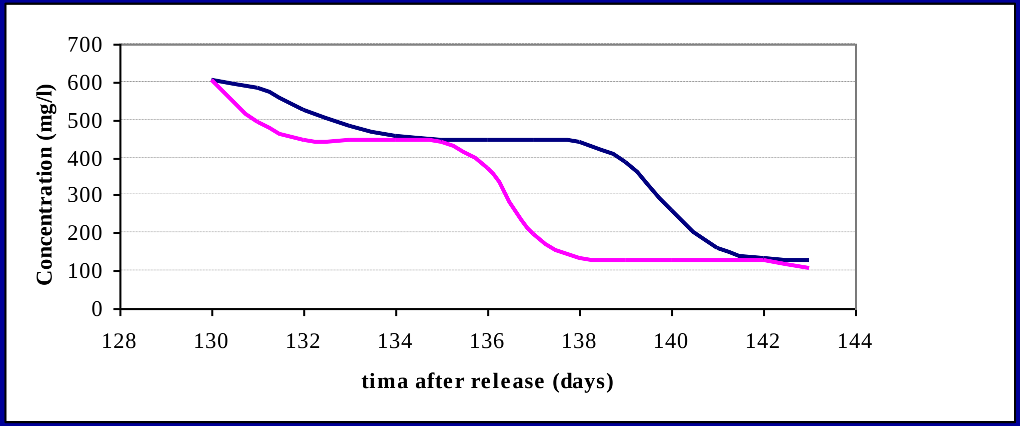


Fig. 5.2 Dniper Reservoir Cascade Simulated CBOD in . Dneprodzerzhinsk reservoir (Mishurin Rog) and Dneprovski reservoir (Nicolskoe) for two the different operational modes of the Kremenchug reservoir for the same hydrological conditions of year 1984).

One dimensional model f water dynamics and water quality of Dnipro reservoir cascade and its tributary – Ingulets river







Simulated and measured concentration of chlorides in the Ingulets at .Andrjevka (269 km from the river mouth) since 9 December 1997 (a) and chlorides concentration in Ingulez upstream the river mouth under two scenarios of the water discharges through the Kakhovka dam (b).

Flood forecasting – key problem for Dnipro reservoirs management and flood protection

Spring 2010 flood forecasting – implementation of IMMS/UCEWP shallow water equations 2D model on unstructured grid: COASTOX-UN

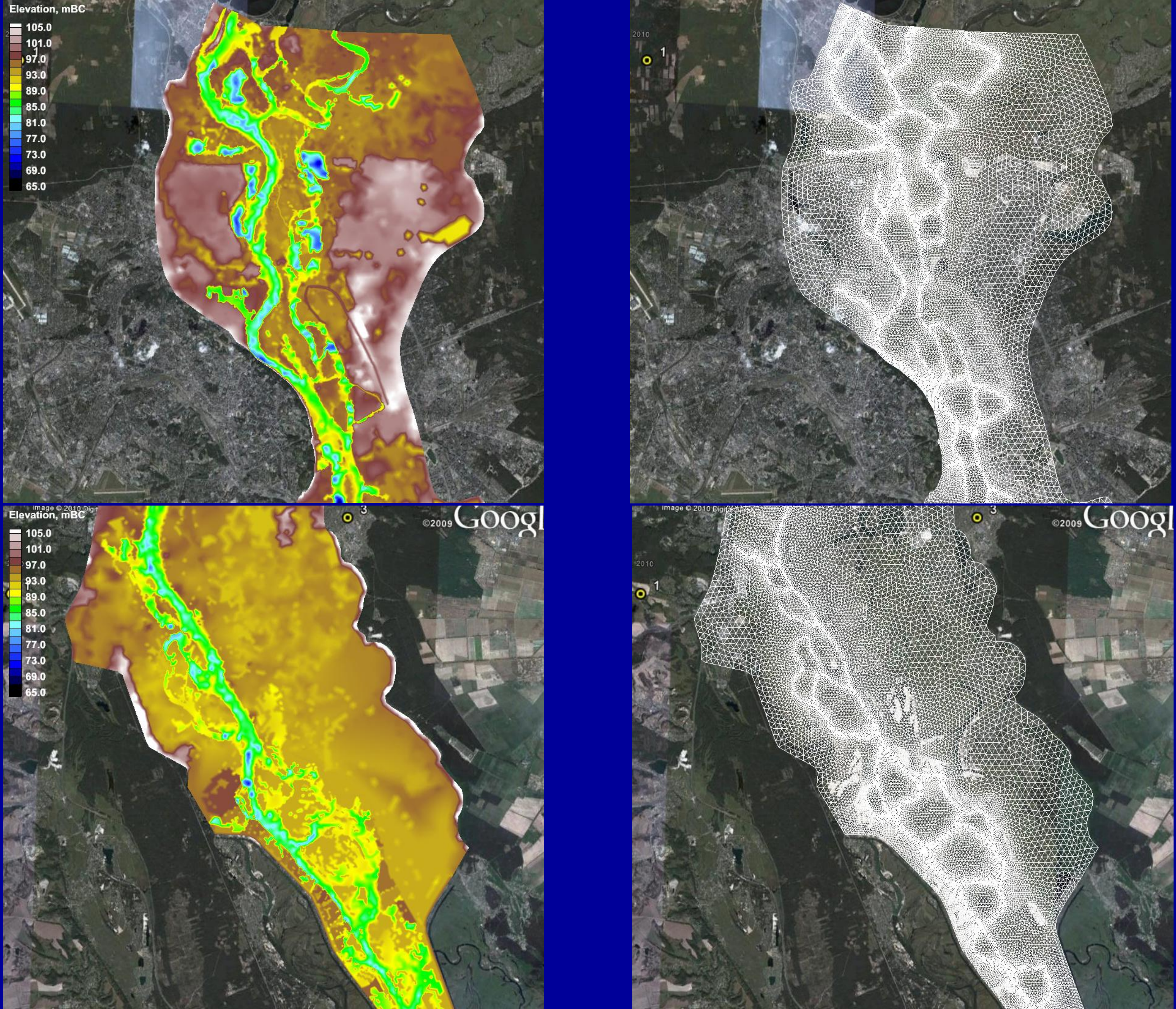
Analog of ADCIRC (USA) and MIKE-21 FM (Denmark) models

COASTOX UN : more robust algorithms for wetting –drying than in world known brand models ADCIRC and MIKE21-FM

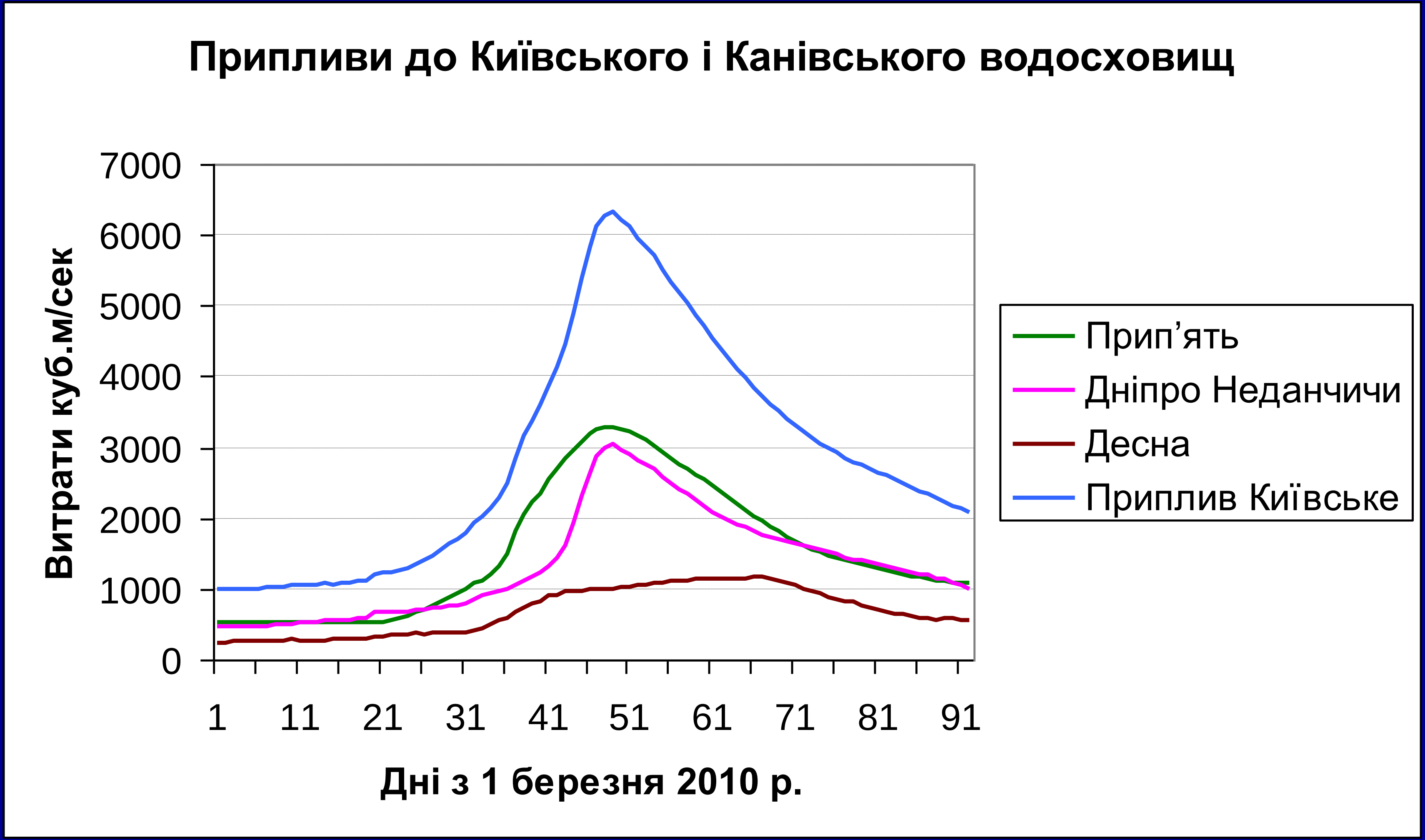
Maximum Floods at Kiev

Год Year	Максимальный расход воды, куб.м/сек Q cub m/sec	Максимальный уровень воды от 0 поста Киев, м Level at Kiev Water Gage above its datum	Максимальный уровень воды в БС, м Water Surface Elevation above sea datum
1931	23100	10.73	97.73
1970	18500	9.80	96.80
1979	10500	8.39	95.39
2004	5100	6.50	93.50

February 2010 – rumors that flood will be higher then in 1979


Elevation, mBC
105.0
101.0
97.0
93.0
89.0
85.0
81.0
77.0
73.0
69.0
65.0
1
Elevation, mBC
105.0
101.0
97.0
93.0
89.0
85.0
81.0
77.0
73.0
69.0
65.0
3
©2009
1
3
©2009

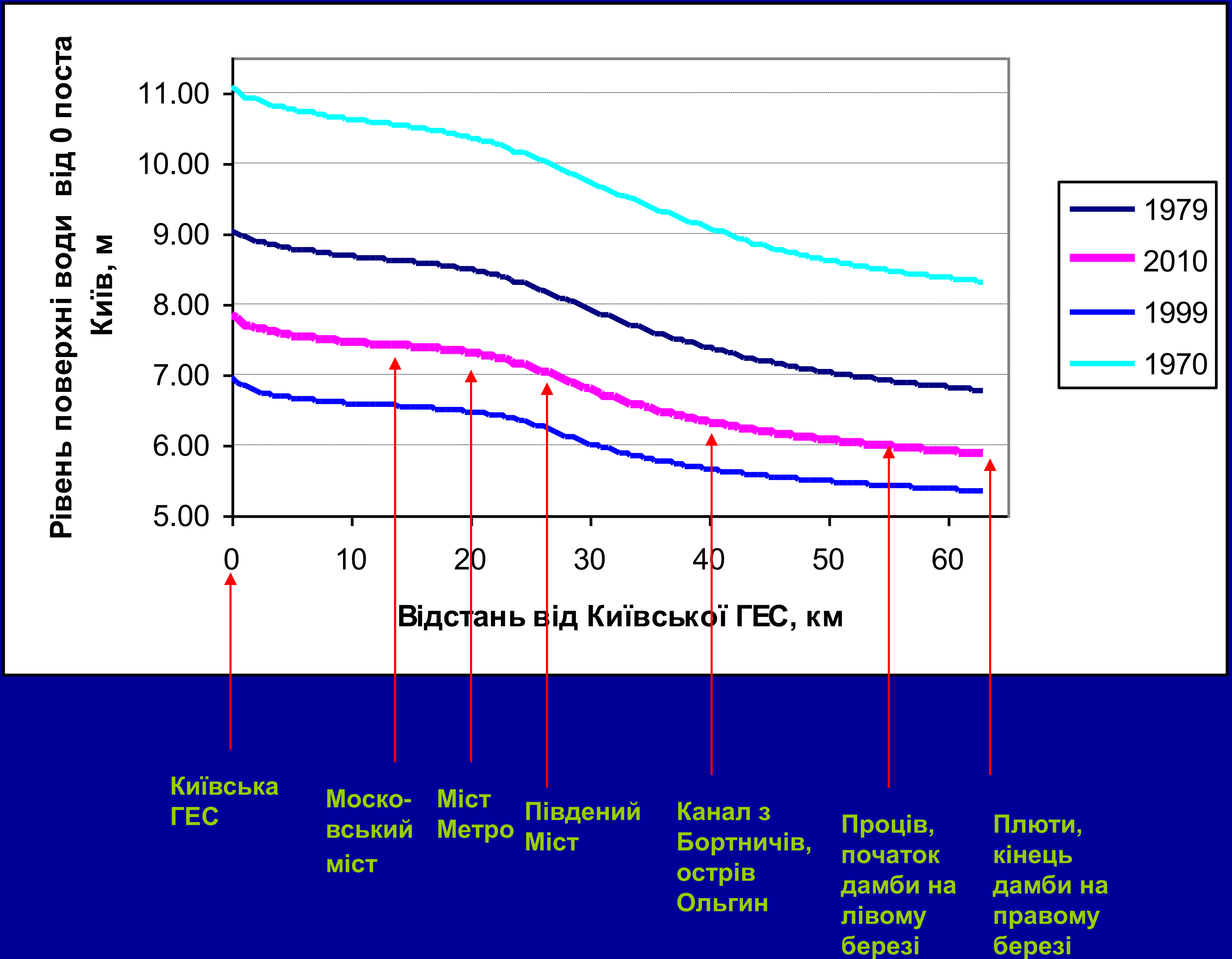
Калібрування 1D моделі: Виміряні та розраховані рівні води (мБС) на гс Київ у 2004 році в залежності від кількості днів від початку року.



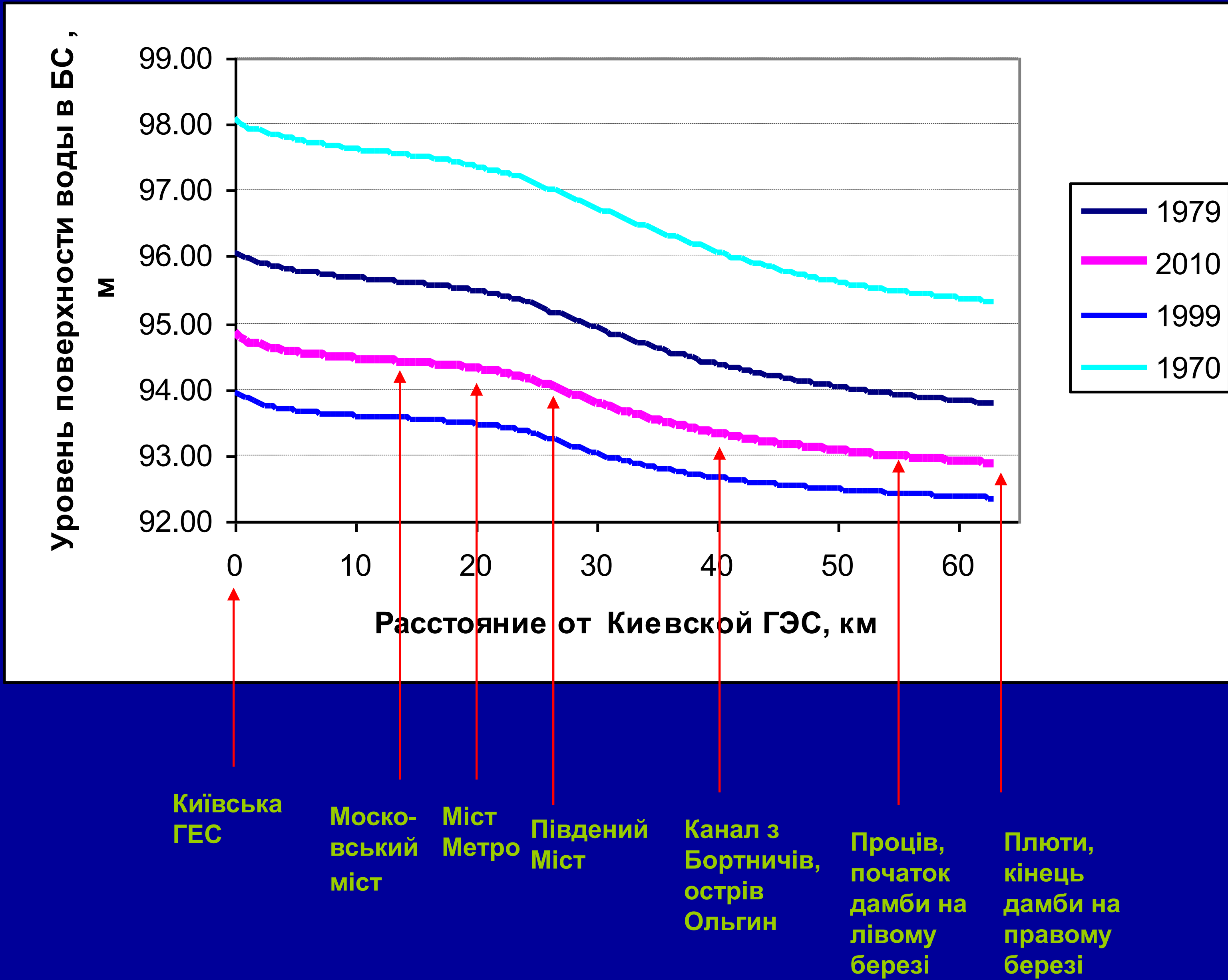
Сценарій 2010 р. - модифіковані аналоги припливів

Scenario of water inflow forecast from March, 1 2010

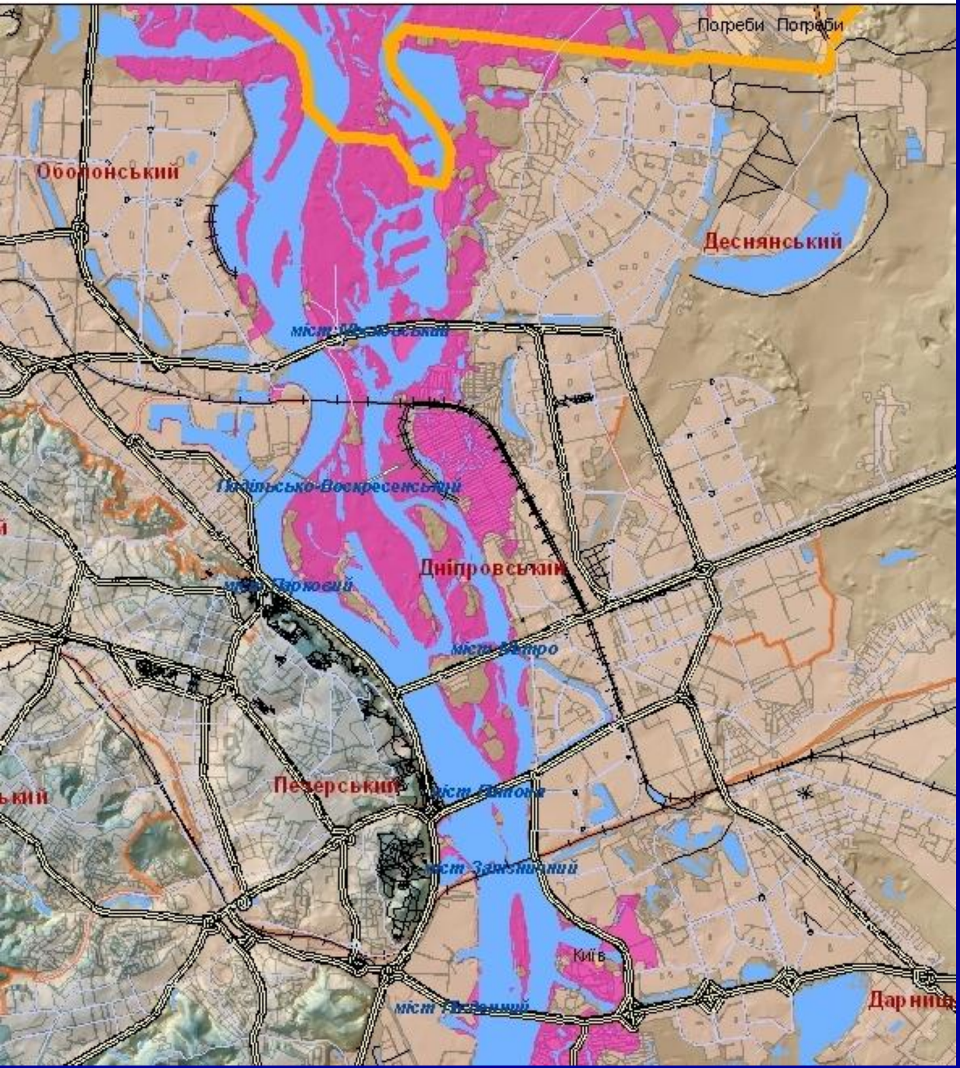
Результати 1D моделювання



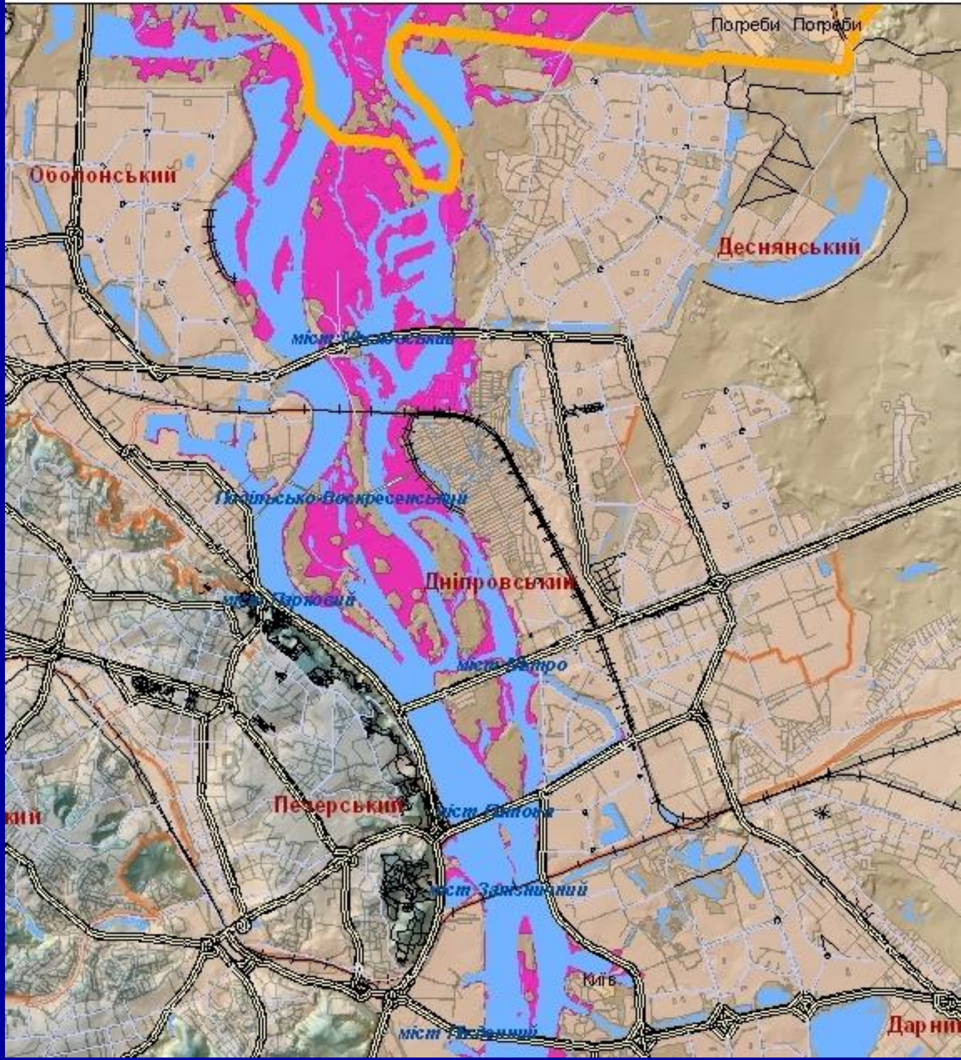
Результати 1D моделювання



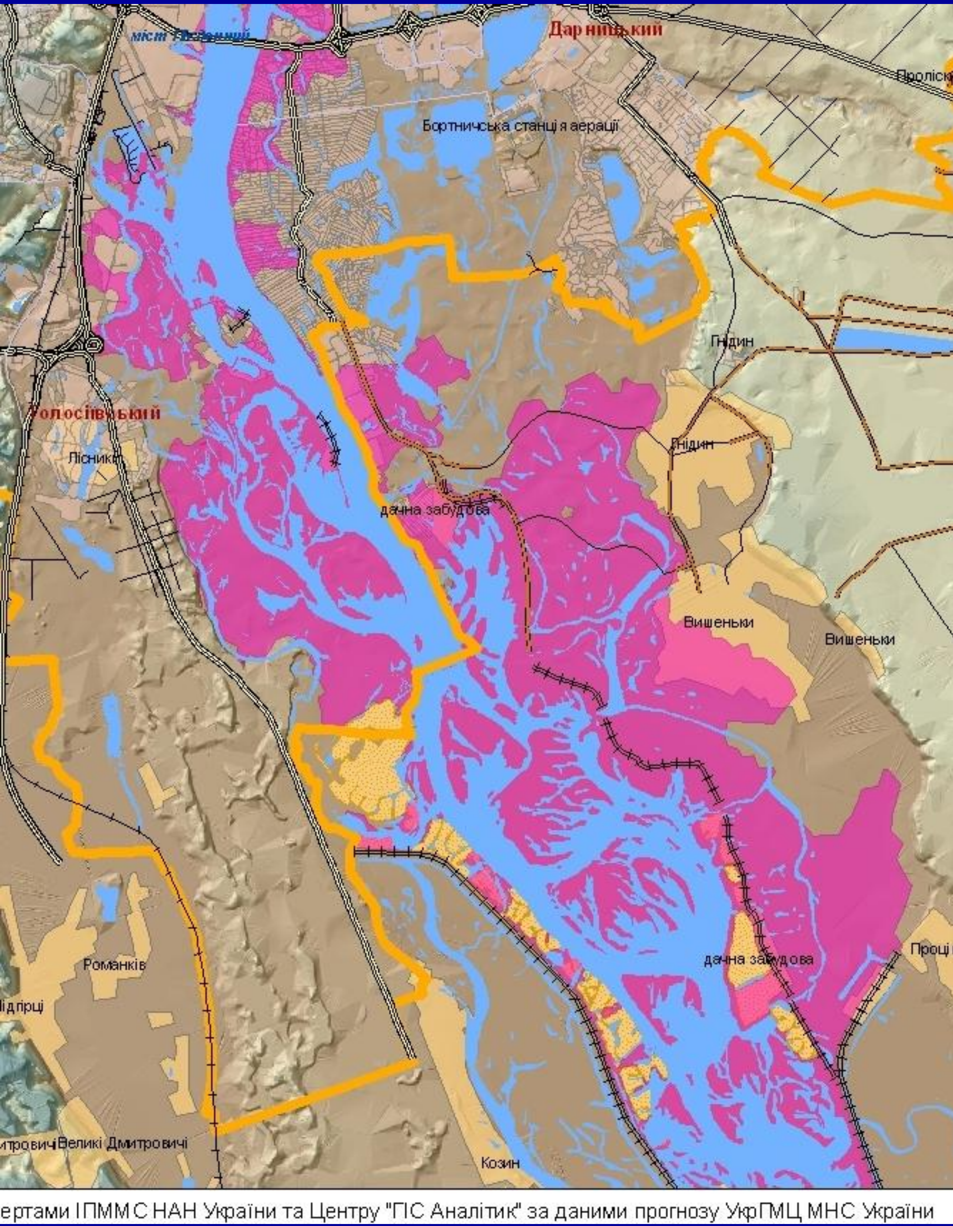
Прогноз затоплення заплави р. Дніпро в межах м. Києва за сценарієм розвитку весняного водопілля 1979 р.

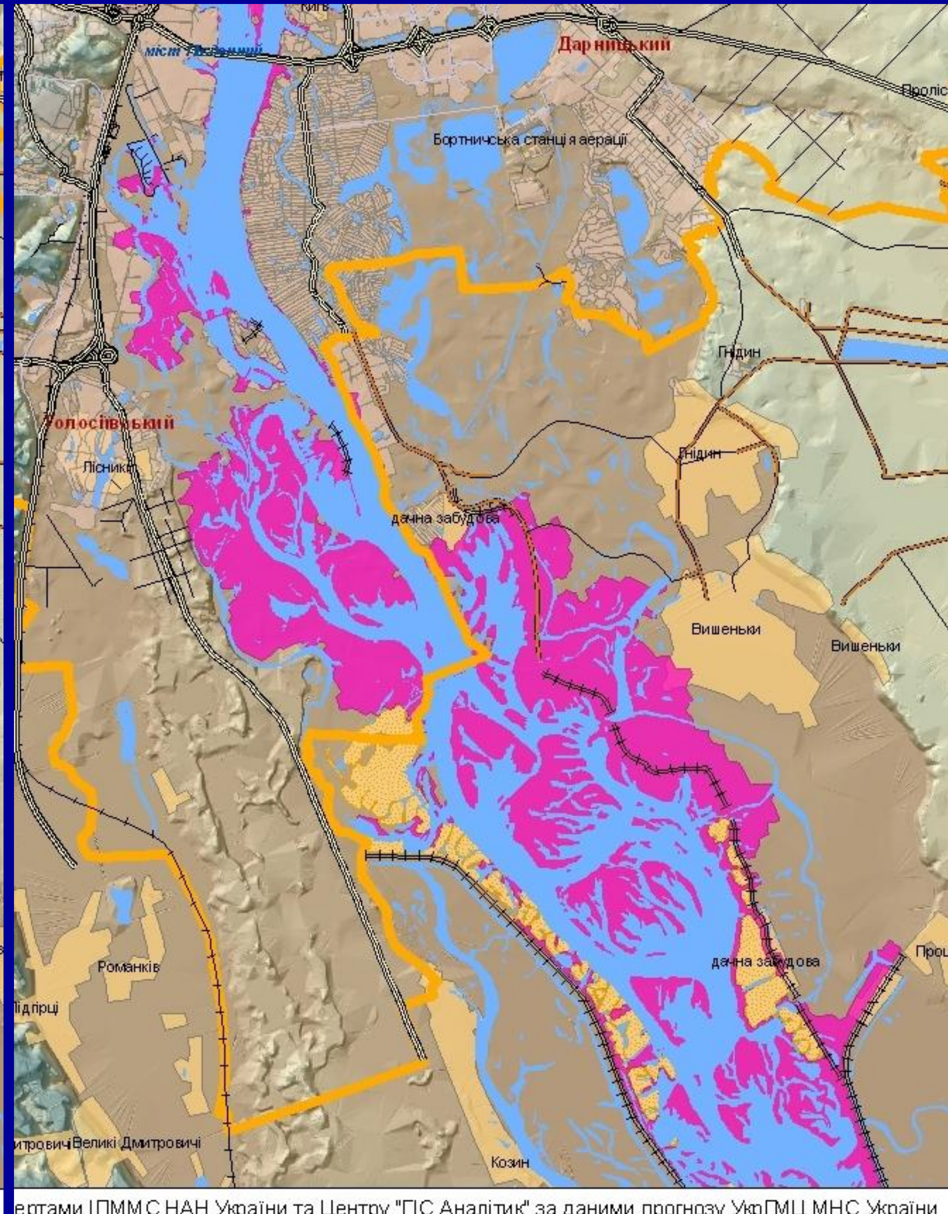


Прогноз затоплення заплави р. Дніпро в межах м. Києва за даними розвитку весняного водопілля 2010 р.

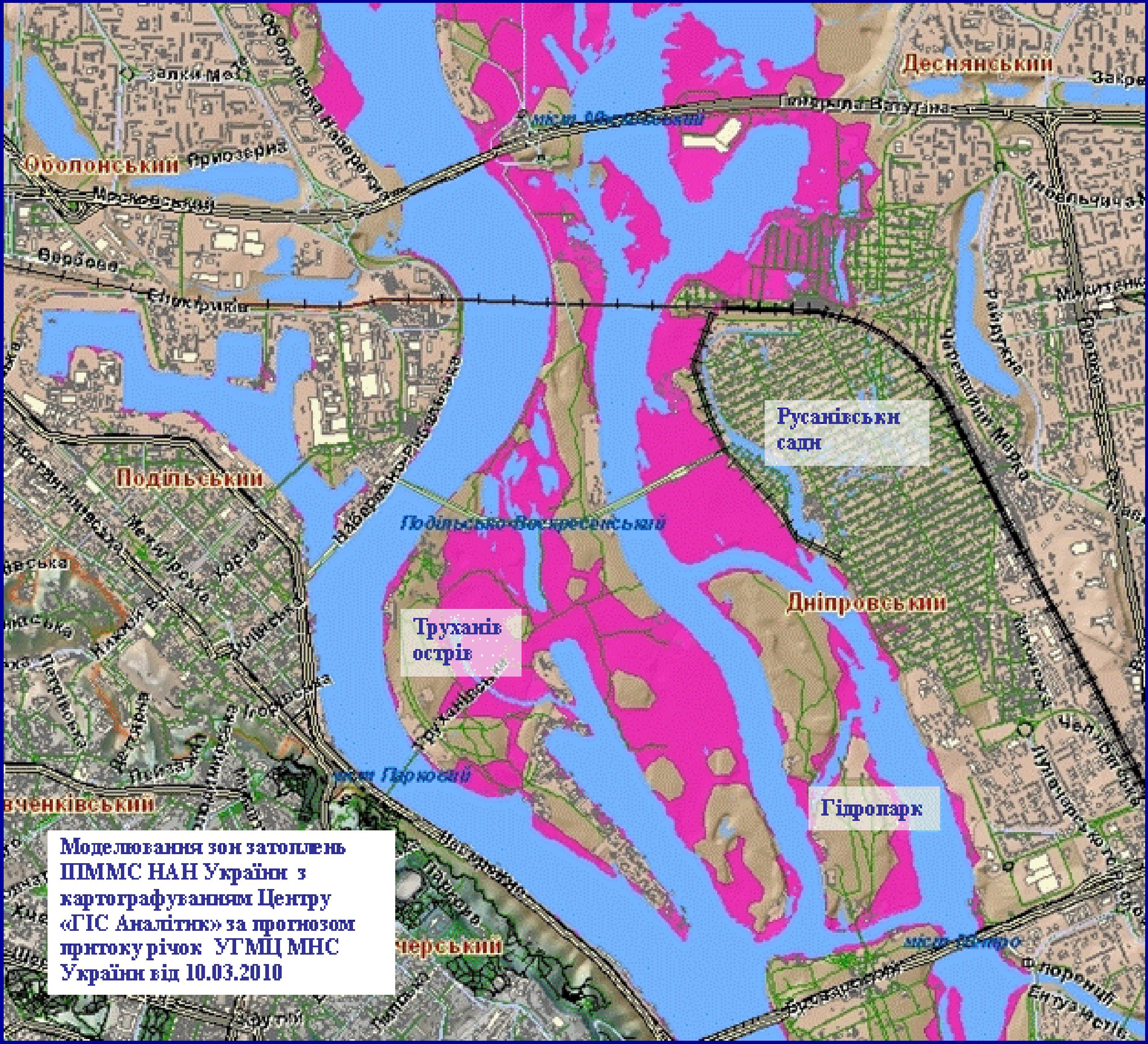


Порівняння зон затоплення у максимум повені за прогнозом на 2010 р. (справа) з зонами максимальних затоплень для сценарію водності 1979 р. (зліва) – ділянка від устя Десни до Південного мосту.

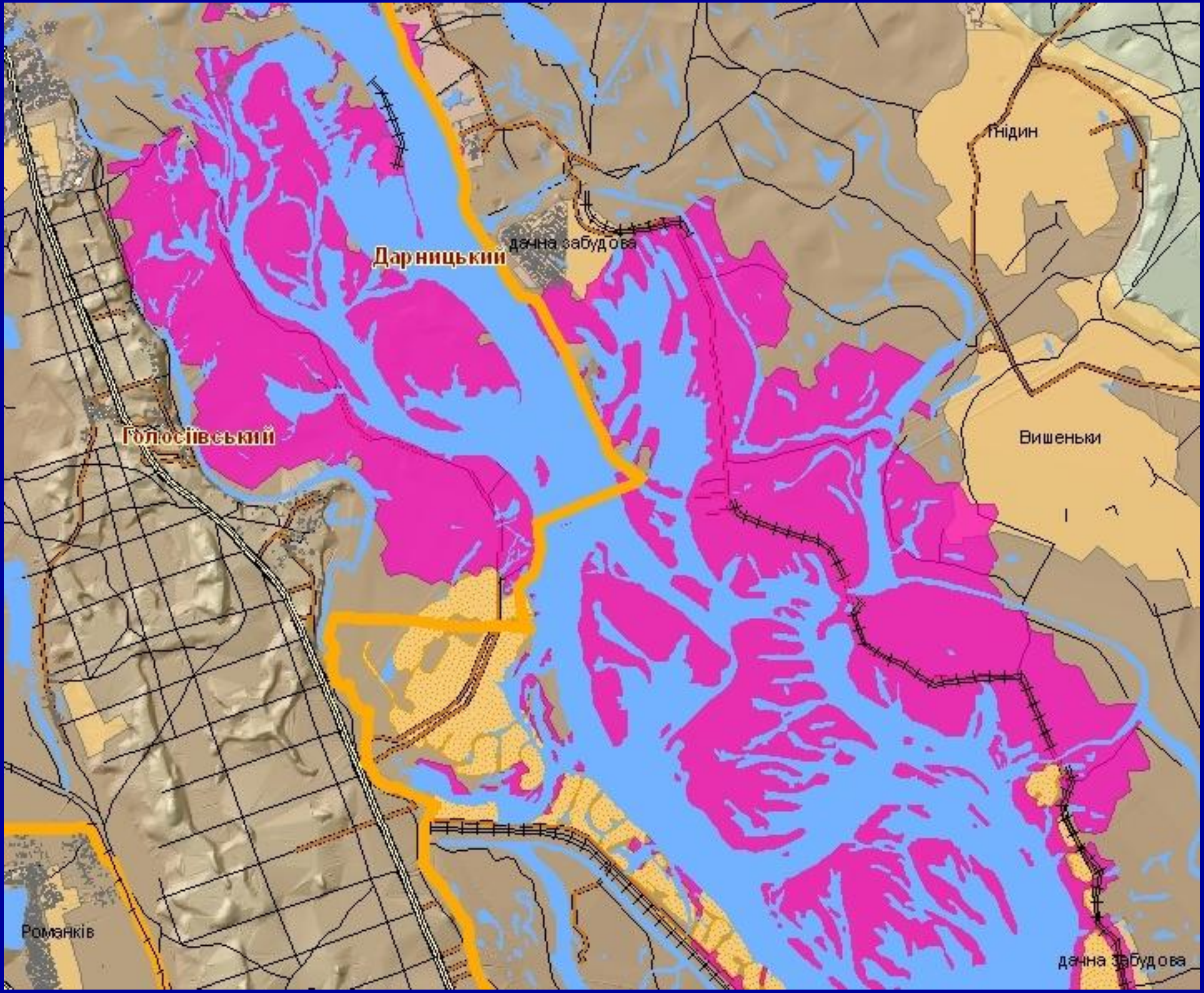




Порівняння зон затоплення у максимум повені за прогнозом на 2010 р. (справа) з зонами максимальних затоплень для сценарію водності 1979 р. (зліва) – ділянка від Південного мосту до Козина.



Деталізація зон затоплень в районі м. Києва в період максимума прогнозуємого водопілля 2010 р. - район Труханова острова.



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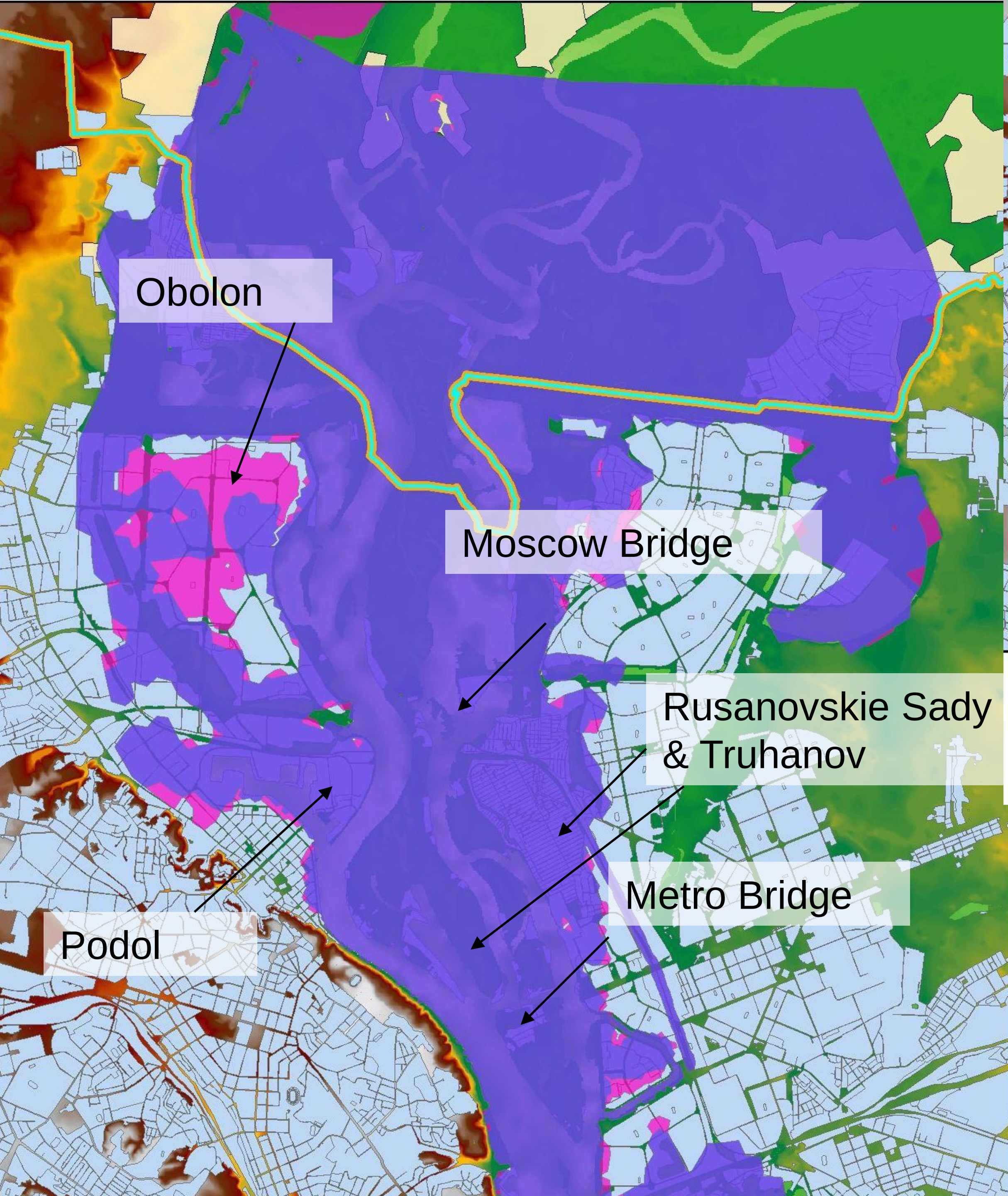
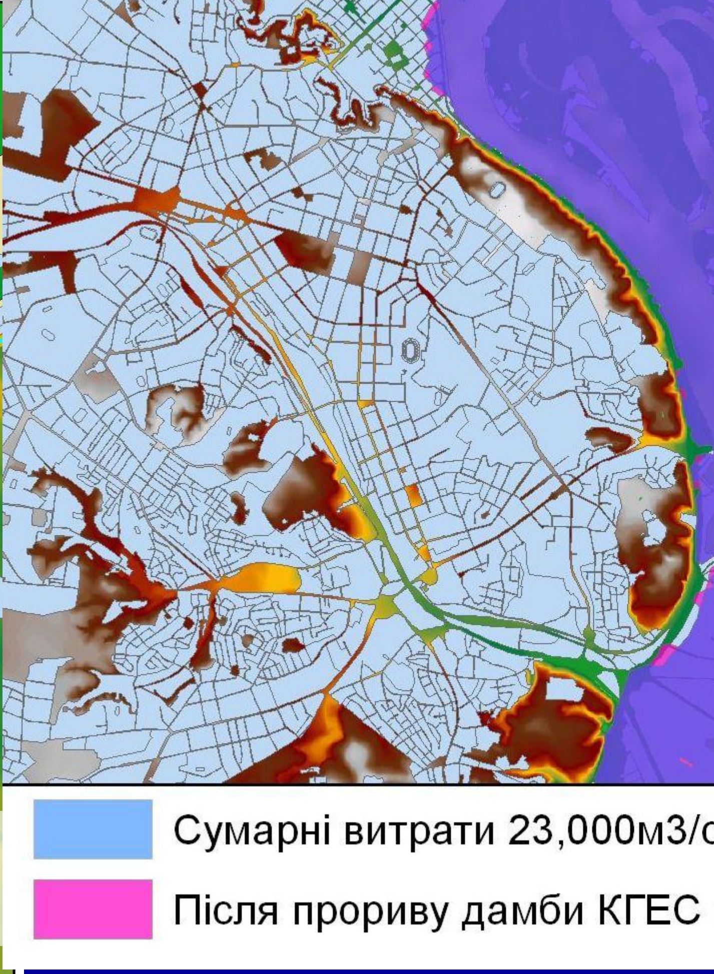
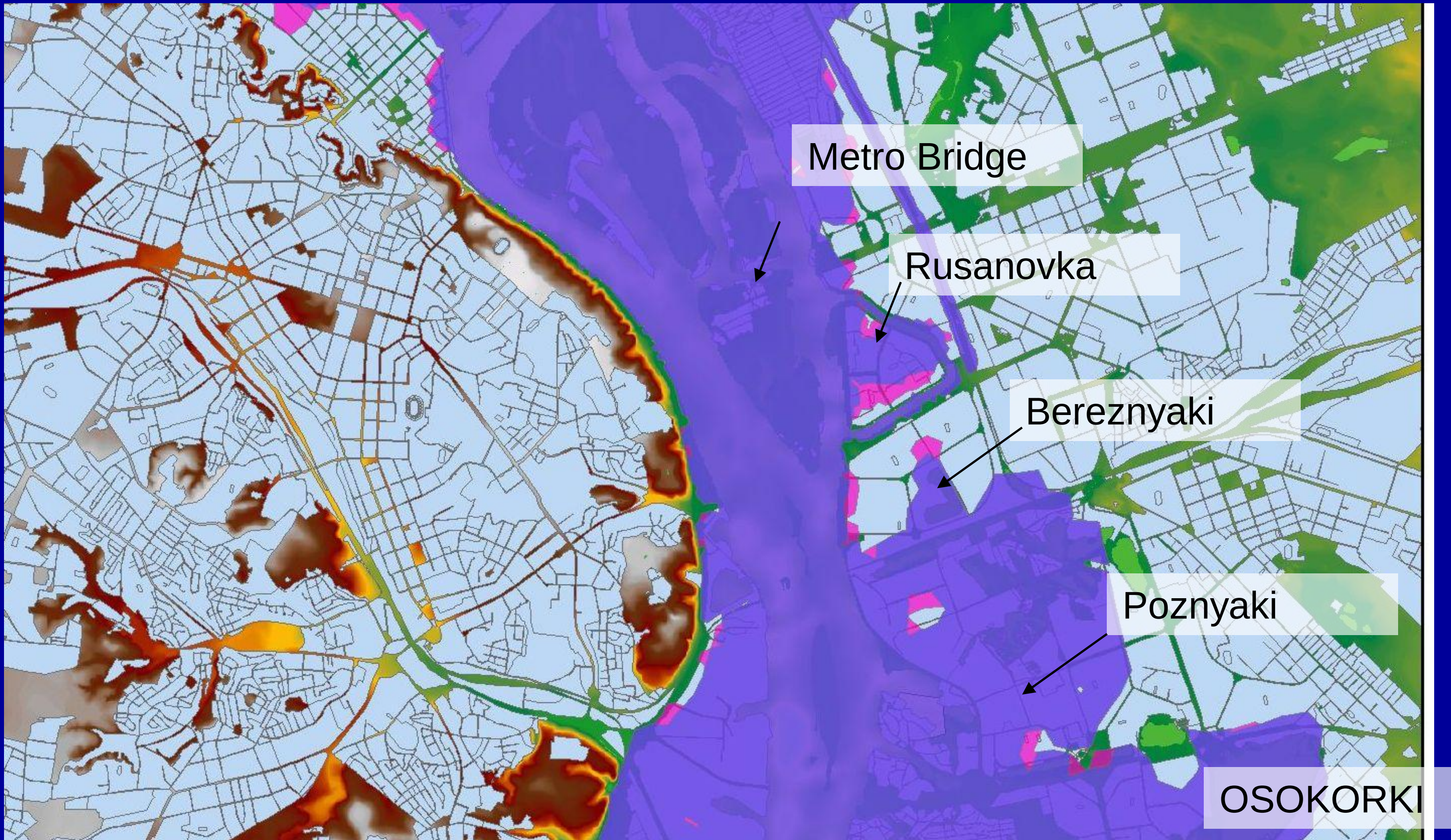




Spring Flood of year 1931

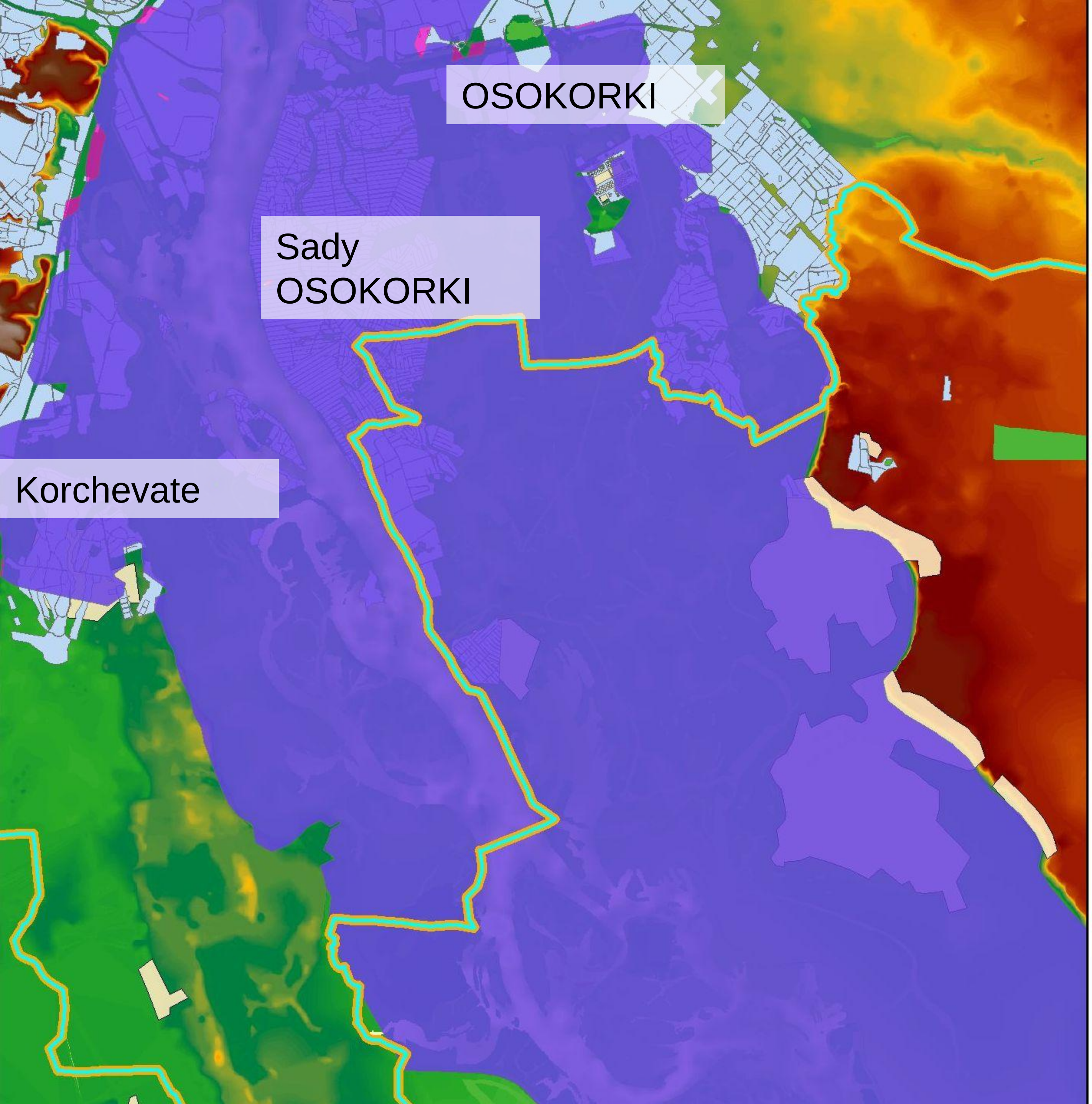
Kiev HPP dam break

Breach -400 m during this flood



Сумарні витрати 23,000м3/с

Після прориву дамби КГЕС шириною 400м


OSOKORKI
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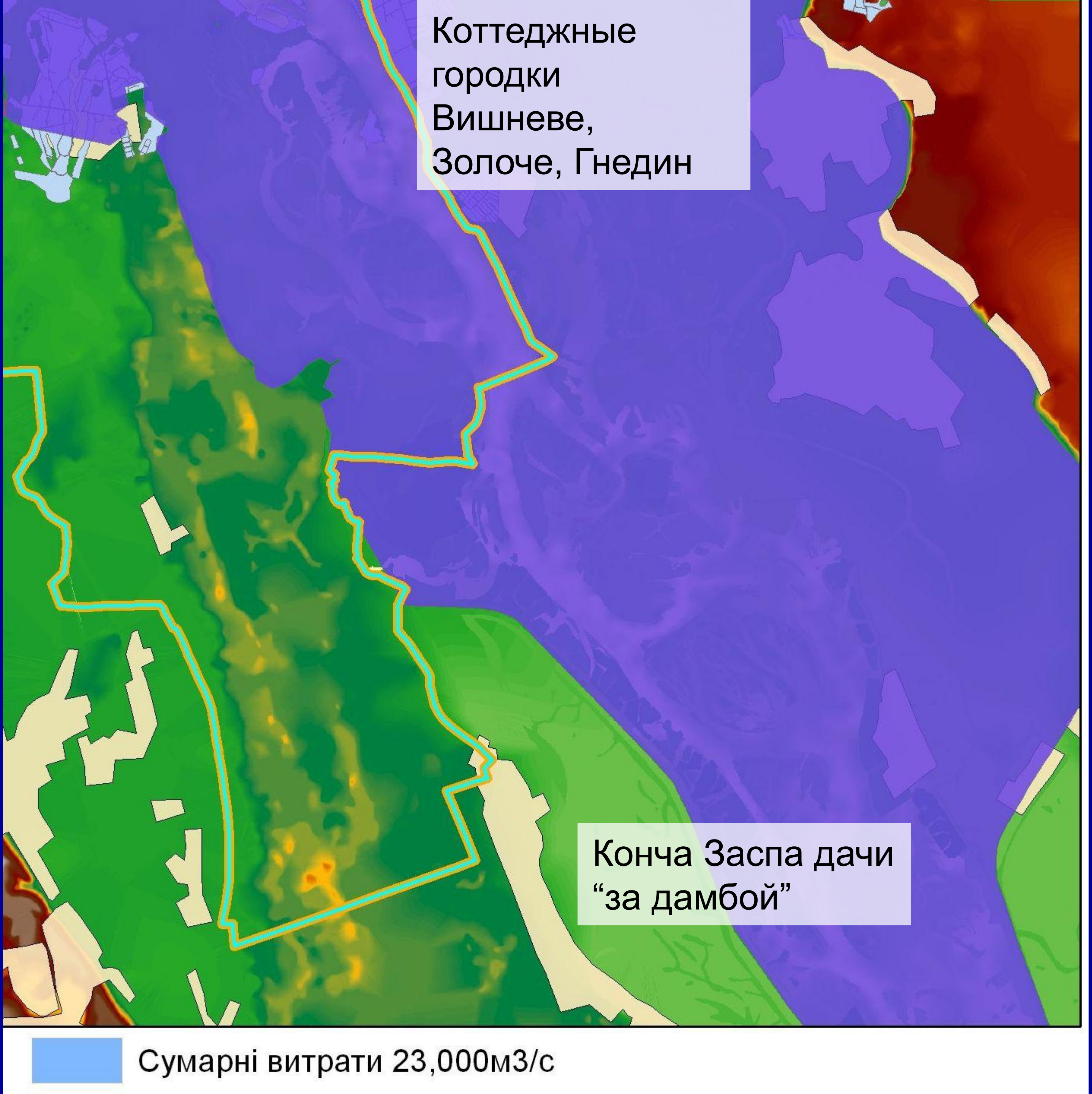
Korchevate


Коттеджные
городки
Вишневе,
Золоче, Гнедин
Конча Заспа дачи
“за дамбой”
Сумарні витрати 23,000м3/с

Climate change projections

Two projects in cooperation with NAS U.S.- US Army Corps of Engineers

Granted: “Formulating and evaluating water resources adaptation options to climate change uncertainty in the Carpathian Region” granted by the Civilian Research Development Foundation USA , CRDF, will start December 2010

coordinators Dr Ivan Kovalets- Dr Eugene Stakhiv

Planning today NAS Ukraine/UktHMC/Vodgosp- NAS USA – RosHydromet- BellHydromet Project

“ Quantitative and qualitative aspects of Dnieper water management under uncertainties of regional climate changes: watershed runoff, the cascades of Dnieper reservoirs, estuary, coastal areas of Black Sea

CRDF Project Method of meteorological downscaling of climate change scenarios

- WRF nonhydrostatic mesoscale model driven by initial and boundary conditions coming from Coupled Global Climate Models (CGCMs) – as was also used for downscalling of CGCM scenarios in many works (Lo, et.al., J. Geophys. Res., 2008, Flaounas, et.al., 2008. Climate Dynam., Caldwell, et.al., 2009. Climatic Change).
- 3-km grid resolution around area of interest – Carpathian part of Ukraine
- Spectral nudging in upper part of the domain as available in WRF
- Split of multy-year run into sequence of independent 1-month runs (as suggested by work of Lo, et.al. Geophys. Res., 2008 and many others) allows for effective use of available grid infrastructure.

Evaluation of downscalling methodology

•30-year simulation 1960-1990 will be performed on the basis of NCEP reanalisys data and comparison of NCEP reanalysis and downscaled results with climate statistics of available station data as presented by Climatic Registry of Ukraine (Central Geophysics Observatory, 2006) in order to clarify added value of regional-scale downscalling and validate the chosen methodology

•Sensitivity studies with respect to chosen Planetary Boundary Layer (PBL) and microphysics parameterization schemes and other details will be performed

Evaluation of CGCM scenarios

- Among several available CGCM models (NCAR-CCSM3, GFDL-CM2.1, and other) the best one will be chosen on the basis of evaluation of retrospective forecasts for the region of study
- Downscalling of the several scenarios (A2, B1, A1B according to IPCC) as calculated by the selected CGCM model will be performed with WRF

Hydrological projections

Hindcasting of runoff in Carpathian watersheds using TOPKAPI (VIC?) and 1D Rivtox model

Hydrological projections fir the downscaled climate change scenarios