Lomonosov Moscow State University

WATER REGIME TRANSFORMATION UNDER THE INFLUENCE OF CHANGING CLIMATE ON THE EUROPEAN PART OF RUSSIA

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Problem statement

Number of dangerous hydro meteorological events in Russia according to ROSHYDROMET-WDC
Motivation

Changes in river runoff are needed to be identified by components and seasons to understand mechanisms and main drivers.

Main questions:

1) How the runoff redistributed within the hydrological year?

2) What is the main reason for water loss increase during spring?

3) Does the transformation of seasonal flood wave compensate by low flow period?

4) What are the main drivers of the water regime transformation during last 35 years?
State-of-the Art: seasonal flood wave transformation

STUDY AREA:

1. Volga river basin $F=1360000 \text{ km}^2$
2. Don river basin $F=422000 \text{ km}^2$
3. N.Dvina river basin $F=357000 \text{ km}^2$
4. Pechora river basin $F=322000 \text{ km}^2$
5. Neva river basin $F=281000 \text{ km}^2$
6. Kuban river basin $F=58000 \text{ km}^2$
7. Terek river basin $F=43000 \text{ km}^2$

- Well-pronounced seasonal flood wave (> 50 % of runoff)
- Stable summer-autumn low flow period
- Autumn occasional flood period

East-European type of water regime and hydrograph separation according to Kudelin (1973)

More than 300 hydrological gauging stations in total for 1880-2011
Changes in annual flow and contribution of the precipitation to it

Annual flow changes 1978-2010 VS 1945-1977

Contribution of the precipitation in annual flow changes

\[ R = P \cdot \exp(-PET/P) \]
\[ \frac{dR}{dP} = (1 + 1/P) \cdot \exp(-PET/P) \]
\[ \Delta R_p \approx \Delta P \cdot \frac{dR}{dP} \]
\[ \Delta R_{PET} \approx \Delta PET \cdot \frac{dR}{dPET} \]

Contribution P = \[
\frac{\left| \Delta R_p \right|}{\left( \left| \Delta R_p \right| + \left| \Delta R_{PET} \right| \right)} \times 100\%
\]
Seasonal flood wave transformation

Typical hydrographs for Oka river

1976

1997

Averaged annual hydrographs for river Don – Kazanskaya

Extremely low and early seasonal flood waves

Higher low flow during winter and summer
Assumed mechanisms

Atmospheric circulation above the European part of Russia in winter

Van Lon et al., 2015

Synthetic time-series according to different hydrological Drought type

Frolova et al., 2016
Changes in low flow and it’s reasons

Changes in winter low flow

Changes in summer low flow

Correlation between winter and summer
Changes in precipitation of warm period
Changes in precipitation of cold period
Changes in number of the day with precipitation (summer)  

Changes in maximum daily precipitation (summer)
Changes in intensity and precipitation type

Less gradient due to more intensive warming in Arctic

Less West-East transfer

“Block effect”

Chernokulskiy et al., 2017
Changes in evaporation capacity (PET)

PET = 0.0009384 \cdot H_0 \cdot (T_{\text{mean}} + 17.8) \cdot (T_{\text{max}}-T_{\text{min}})^{0.5}


Observed evaporation capacity (1) and humidity deficit (2) by Sperantskaya, 2016

1, mm

2, mB
Winter P and PET correlation with NOA and AO

Month with maximum moisture content:
- No Data
- March
- March-April
- April
- May

NAO

Winter P

PET

Month with a maximum moisture content

AO
Hydrograph separation: Kudelin’s scheme (1963)
Study methods and Data: general idea

GrWat software – algorithm for hydrograph separation based on daily data grapho-analitical and complex parallel analyses

19 parameters, that are calibrated to match the hydrograph separation according to Kudelin scheme

Example of rain-flood wave separation from melt-water seasonal flood wave with different grad1 values

R-script block:
- input data checking,
- time-series period clarifying
- missing values replace
- virtual time-series of T, P creating

FORTRAN block:
- Identifying seasonal boarders
- Seasonal flow characteristics calculating
- Genetic types separation

R-script block:
- Interpretation of the results
- Graph output report
- Complicated cases report

3 Inside programs – calculating algorithms for
- Summer - autumn and winter low flow period
- Minimum low flow 5, 10, 30- days min discharge

Input data: daily discharge. txt
19 parameters
Pre-calculation
Hydrological years separation
Seasonal flood separation
Ground water component separation
Occasional floods separation
Study methods and Data: calibration parameters

DATES
- Mome
- polmon(1)
- polmon(2)

GRADIENTS
- grad
- grad1
- kdQgr1
- polgrad(1)
- polgrad(2)
- SignDelta
- SignDelta1

CRITICAL DURATIONS
- polkol(1)
- polkol(2)
- polkol(3)
- prodspada

SYNOPTIC CHARACTERISTICS
- nPav
- Pcr
- Tcr1
- Tcr2
- Tzam
Study methods and Data: seasonal flood wave

The great deal – declination phase of the seasonal flood wave

Example of rain-flood wave separation from melt-water seasonal flood wave with different grad1 values

Incorrect separation with any parameters, inaccuracy ≈ 20 %

For Vyatka–Vyatskie Polyani: 15 from 75 years
Recession curve as an instrument for occasional flood separation

**Recession curve** - represents decline of the basin water supply, includes river network capacity, sub-surface and ground water capacity

M. Gregor, P. Malik, 2012

Toebes, 1969

FIG. 1

\[ q_t = a + (q_0 - a)k^t \]

\[ q_t = \frac{q_0}{1 + (1 + c)^{-t}} \]

TOBES, 1969

Boutaghane, 2012

**Recession curve**

**Flow (m³/s)**

\( K_1 = 0.88 \)

\( K_2 = 0.49 \)

\( K_3 = 0.94 \)

Boutaghane, 2012

**Relative time [days]**

\( K_1 = 0.65 \)

\( K_2 = 0.92 \)

\( K_3 = 0.99 \)
Thaws – Rain event separation
Study methods and Data

Combine Discharge data with Meteo Data

- Daily NOAA-CIRES 20th Century Reanalysis V2

Single flood wave separation criteria \( q > q_{kp} \)

- \( q(90%) < q_{kp} < q(50%) \), 10 – 50% of peaks – not significant;
- \( q_{kp} < Q_{\text{max}}(95%) \) all annual max > \( q_{kp} \);
- \( Q_{cp}(70%) < q_{kp} < Q_{cp}(30%) \), \( q_{kp} \) close to \( Q_{cp} \);
- \( q_{kp} > q_0 (5%) \), \( q_{kp} \) is higher than local min (95% probability)
World wide practice

**BFI+**

[Graph showing hydrograph separation in BFI+ with Local Minimum Method]

**FlowComp**

[Graph showing hydrograph separation in FlowComp]

Drawn up three sub-regime (surface, subsurface, groundwater) **FlowComp**

http://hydrooffice.org, (M. Gregor, 2013)
RC - software

Combined graph of discharge and precipitation

Preliminary results

East-European type of water regime changed to West-European with wet and warm winter

- High ground water component
- Deficit of Melt water During spring
- Early start of the low flow period
- Not very deep but very long deficit
- Rain water isn’t effective
Thank you for your attention !!!

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Preliminary results

• Decrease in Seasonal flood volume and increase in occasional. (а, b)

• Drops in the rate of maximum annual discharge to maximum discharge during winter (б)

• Increase in duration of the deficit period

• Increase in number of the flood waves

• Shift to the earlier dates the start of the seasonal flood
Problem statement: Don basin drought 2007 - ... ???

Annual runoff value of the Don in the Tsimlyansk HPS:
1 – annual runoff 50 % probability; 2 – annual runoff 75 % probability; 3 – annual runoff 90 % probability; 4 – extremely low flow years; 5 – extremely low flow time-series

Fito-plankton concentration on the Don river VS runoff

Long-term oscillation of the inflow to the reservoir (1) and water level in the Tsimlyanskoe reservoir (2)

Algal bloom in Tsimlianskoie water reservoir

Total volume of the runoff deficit 40.4 km$^3$

The longest hydrological drought during the period of the measurements
Problem statement: North Dvina flooding 16.04 - ...
2016 ???

Crushed by flakes and flooded houses near by Velikiy Ustug, 16.04.2016

Total flooded area >10,000 hectares.
1350 houses, 5000 inhabitants

The main cause of the flood: Winter break-up during extreme thaw