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**Climate Change effects on the River Discharge in Bulgaria**

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The following contribution discusses the impact of future climate change under IPCC scenarios RCP4.5 and RCP8.5 on hydrological regimes in plain catchments up to 650 m high and in mountain areas of Bulgaria. The hydrological simulation models (TUWmodel) are calibrated on recorded data and 'forced' in the selected scenarios with precipitation and air temperature data from ALADIN 5.2, a local version of the French global atmospheric model ARPEGE, downscaled to a grid of 12 km. Simulations for the future periods 2013-2042, 2021-2050 and 2071-2100 are compared to the flows in the reference period 1976-2005. The trading space for time approach is also used in parallel. The survey covers watersheds to 83 hydro-metric stations on the territory of Bulgaria. Regionalisation of the results is applied to the ungauged catchments.

Results indicate increased seasonality of flows with noticeably drier summers and increase of river discharge in winter. In most of the cases the analysis of extreme events suggests significant increases in the frequency of both high- and low-flow events. The change in the extreme runoff with a large repetition period required for the design of flood protection structures and systems has been investigated in regions with different mechanisms for flood generation. With the push of RCP4.5 or RCP8.5 scenarios the significant increase in flood peaks is observed in most of the river basins. There is a general trend of decreasing runoff with a 95% probability of exceedance.

## 1. Introduction

The study of climate change effects on the river discharge has both operational and theoretical reasons. This survey is motivated by the former: for design applications (of spillways, culverts etc.), forecasting applications (flood warning, hydropower operation) and catchment management applications. It was known that the assessment of runoff change by the climate change will face difficulties concerning with:

- quality and quantity of accessible climatological and hydrological information from ground measurements in watersheds of Bulgaria;
- many existing ungauged catchments etc.

The difficulties were overcome through calibration of the conceptual hydrological models on runoff data from ground measurements as well as through regionalization the results were applied in ungauged watersheds.

Climate change effects on the river discharge were surveyed in parallel with methods, which differ in data and hypotheses. The scenario analysis is applied through the TUWmodel and the "Trading Space for Time" method is also used for checking purposes.

## 2. Data and Method

The hydrological simulation models (TUWmodel) are calibrated on recorded data and 'forced' in the RCP4.5 and RCP8.5 scenarios with precipitation and air temperature data from ALADIN 5.2,

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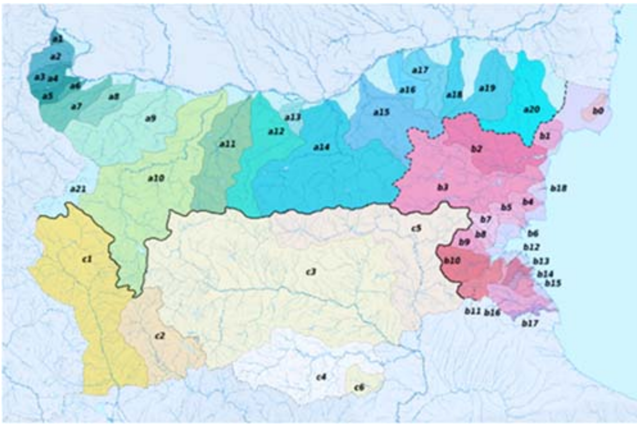
downscaled to a grid of 12 km. Simulations for the future periods (2013-2042, 2021-2050 and 2071-2100) are compared to the flows in the reference period 1976-2005. The survey covers watersheds to 83 hydrometric stations on the territory of Bulgaria.

This study was carried out in Bulgaria using:

- Ground measurements of precipitation (P), temperature (T) and discharge (Q) for the periods 1976 to 1980 and 2000 to 2005,
- ALADIN reanalyzed data (P, T) for the reference period (1976 - 2005) , ERA-Interim;
- ALADIN data for future periods (P, T),
- Hydro1K digital elevation model, Solar index (SI)



River catchments in Bulgaria

The **Runoff TUWien Model (in R)** used in this paper is a semi-distributed conceptual rainfall-runoff model, following the structure of the HBV model. The potential evapotranspiration is calculated with the Blaney-Criddle method modified by Schroedter. Calibration and testing of the adapted hydrological model is made for the main river basins in the country. According to the database, created on historic meteorological and hydrological information in the reference period 1976-2005, the calibration is done in for the first 5ys of the Reference period 1976-1980 with ground data. For validation (testing) of the models the last 6ys of the Reference period are used (2000-2005).

After simulation in the Reference period the model creates daily discharge time series and a projection is translated to future periods with the ALADIN data from the climate projections.

Trends in the impact of climate change on the runoff regime are derived with the **Delta Change Approach** based on rainfall-runoff simulations. In this Approach, simulations for future periods are compared to the simulations in a historical reference period. The changes on climate scenarios RCP4.5 and RCP8.5 are estimated in such future periods (2013 – 2042, 2021 – 2050 and 2071–2100), compared to the reference period (1976 – 2005).

Before the change in the annual runoff distribution was evaluated and analyzed, a general check of the forecast quality was performed through a comparison between the change in average annual runoff using the TUW model and the Trading space for time approach.

**The Trading space for time approach** is applied based on the **model of Turc** [3], which considers long-term (average perennial) runoff values (R, mm) on the base of average perennial runoff values in mm and an index of potential evapotranspiration EPI.

$$R = P.\left[1 - \frac{EPI}{(c.EPI^n + p^n)^{1/n}}\right]$$

where *c* and *n* are parameters of the model. The formula is for precipitation greater than the evapotranspiration, as follows:

$$P > EPI(1-c)^{(1/n)}$$

The index of potential evapotranspiration EPI is in function of T - average perennial value of average annual temperatures. The function is:

$$EPI = a_1 + a_2.T + a_3.T^3$$

where $a_1$, $a_2$ and $a_3$ are regional parameters.

In case of missing enough data, Turc proposes the next values:

$$c = 0.9, n = 2, a_1 = 300, a_2 = 25, a_3 = 0.05$$

As a result of the Turc model calibration for Austria [1] the parameters have been specified, as follow:

$$c = 0.9, n = 1.732, a_1 = 376, a_2 = 30, a_3 = 0.05$$

In [4] for regions in Turkey, the parameters have been defined as follows:

c=0.65, n=2, a1 = 601, a2 = 25, a3 = 0.05.

The calibration of the Turc model for Bulgaria has been made based on ground data for 11 watersheds in North and South Bulgaria in the first 5ys of the Reference period 1976-1980 and the parameters are specified, as follows:

c=0.9, n=2, $a_1$ = 400, $a_2$ = 25, $a_3$ = 0.05.

Through a comparison between the average perennial runoff, defined by the Turc model, and the measured average perennial runoff it has been established that the low flows are overestimated, but, in general, average perennial values of the average annual discharges, predicted with the Turc model, are close to the measured and, according to the purpose of this survey, the model is credible as it takes in account the regional characteristics.

**Regionalisation** of the results is applied using a rough solution for ungauged catchments. It's known, that the main challenge with rainfall-runoff modelling in ungauged catchments is the lack of local runoff data that could be used for calibrating model parameters. A number of methods of transferring the parameters are described [2], and generally the first step is to calibrate the catchment model to the runoff records of the gauged catchments and then in different ways to find the model parameters in the ungauged catchment of interest. A rough solution here is based on a **cluster analysis**, where catchments are grouped, so all catchments in a group are similar to one another with respect to climate and soil setting. The conclusions concerning the number of clusters and their membership are reached through a GIS analysis beginning with the number of groups according to the Climate Atlas of Bulgaria by the Bulgarian Academy of Science, where the climate separation of the territory of Bulgaria is very detailed – in climatology regions, sub-regions and climate areas. The soil map of Bulgaria from the National Soil Survey (http://nationalsoils.com) with seven regions of soil types in the country is also taken into account.

The number of groups is adjusted by an overlay of catchment's borders and using the rule that at least one catchment station with a calibrated model is to be included. The selection of hydrometric stations (an outlet points of catchments), included in the regionalization procedure, is made based on the following circumstances:

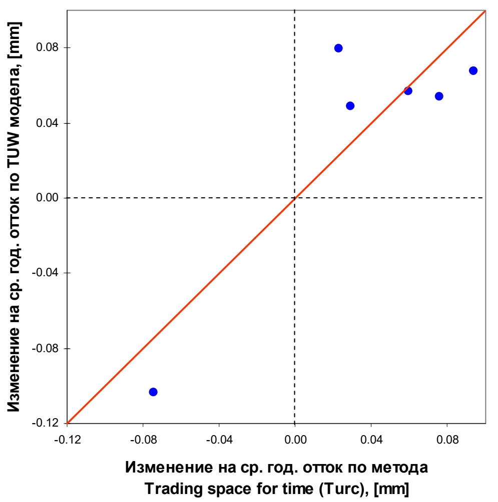
- regions with significant changes in the runoff as a result of dams building are excluded;
- Nash efficiency and Volume error are to be evaluated highly at the check points as results of the models' calibration and validation;
- The prediction on the TUW rainfall-runoff model is to be confirmed by the Turc model.

**3.Results**

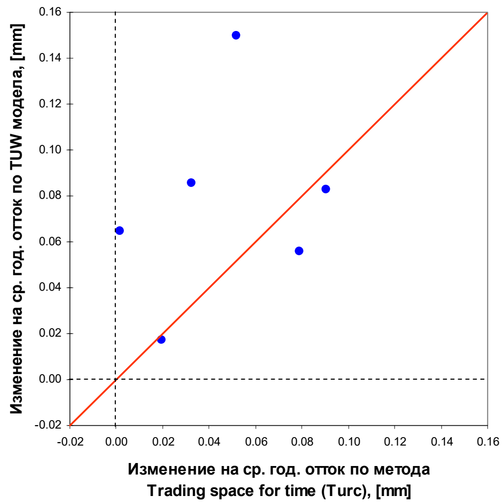
Despite difficulties concerning limited hydrological and meteorological data and information about land use, the hydrological models are calibrated on runoff data from ground measurements and regionalization is applied to ungauged catchments as well. The trading space for time approach is used to estimate and verify the quality of the forecast for average perennial runoff - the approach allows the detection of stations with significant uncertainty in the forecast, despite good statistical estimates of the TUW models. The checks are based on regional specificities and perhaps reveal at the same time uncertainty of the climate scenarios but also the impact of the short series of data available from the ground measurements at our disposal.

Examples of confirmed forecasts for a change to average perennial runoff, mm

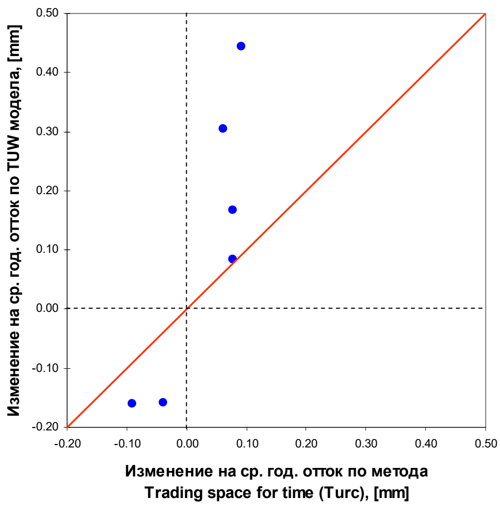
TUW model vs.Turc



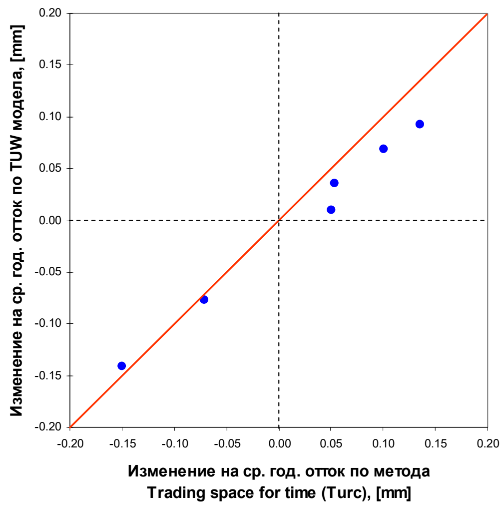

Station Veliko Turnovo– Danube River BD




Station Cherni Osam– Danube River BD




Station Gramatikovo -Black Sea BD




Station Grozdovo - Black Sea BD

The above described cluster analyses for regionalization and climate change prediction in ungauged watersheds with respect to climate and soil setting showed as a result 32 homogeneous zones /groups of catchments on the territory of the country, illustrated in the figure on right.

Using regionalization the climate change effect on the **Average Annual Runoff** as a result of simulation in both climate scenarios RCP4.5 and RCP8.5 showed overall following results:

Northern Bulgaria

North of the Balkan Mountains runoff is not expected to decrease according to scenarios 4.5 and 8.5, with the exception of the north-eastern part, where in scenario 8.5 a 5% decrease is expected.

Long term prognoses for the 2071 – 2100 period for both scenarios show a 5% runoff decrease in the northern plains of Bulgaria, with a 20% decrease in the north-eastern part. The mountainous regions of the Balkan Mountains show resilience to climate change and the mean annual runoff there shows no trends towards decreasing.

Southern Bulgaria

South of the Balkan Mountains the short- and mid-term prognoses for scenarios 4.5 and 8.5 show no significant trends for the mean annual runoff.

Prognoses for the 2071 – 2100 period clearly show a trend towards a reduction of the mean annual runoff, approximately 5% overall, pronounced much more strongly in the mid- and lower parts of the Tundja basin and the Black Sea coast – approximately 15%.

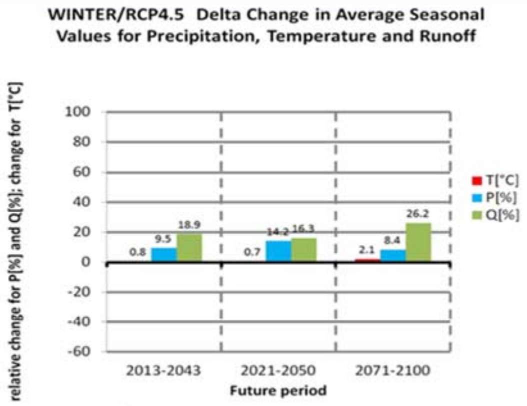
An assessment of the change in **Seasonality** of river flow for the three timeframes is made. Results show clearly expressed seasonality of flows, with noticeably drier summers and increase of river discharge in winter.

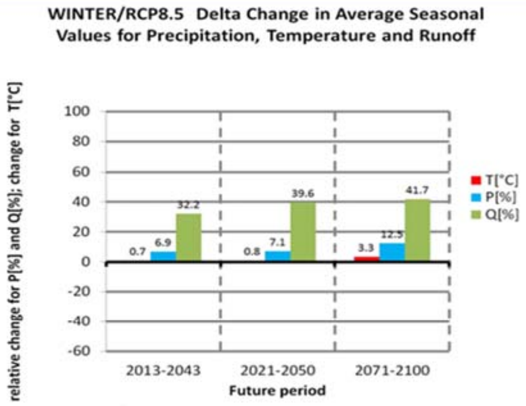
Overall, winter runoff in Bulgaria trends towards increasing according to both scenarios. The most prominent exception in this regard is the north-eastern part of Bulgaria, where the trend shows no change in the short- and mid-term and a 15% reduction in the 2071 – 2100 period.

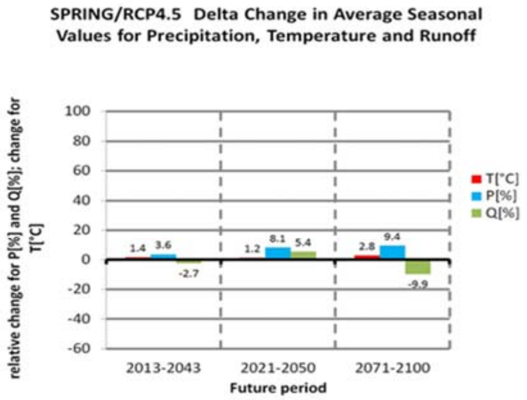
Summer runoff prognoses for both scenarios show a clear trend towards reduction, most clearly pronounced in the mountainous areas and the Black Sea coast.

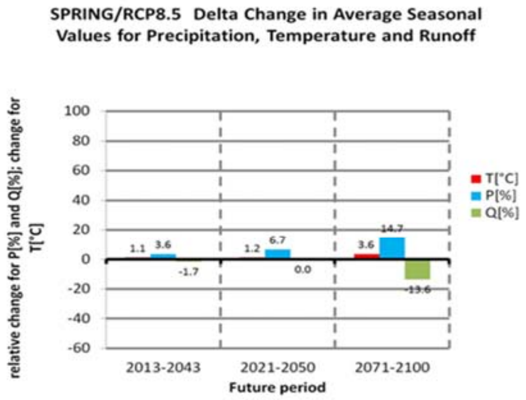
For example, the change in seasonal values is shown at Station Falkovets, Nord-Western Bulgaria.

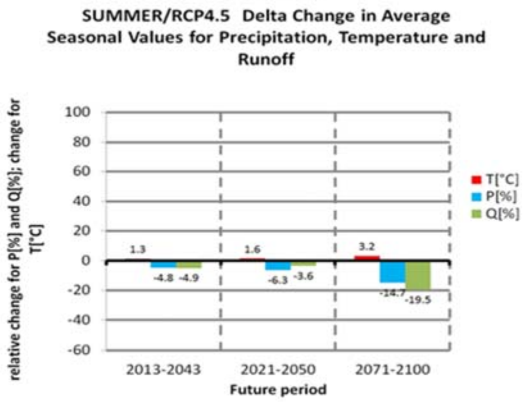
Station Falkovets - Danube River BD

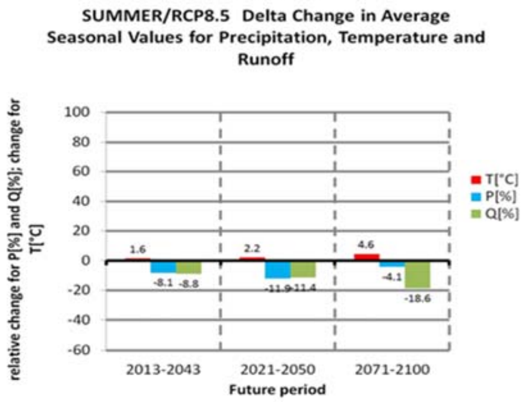


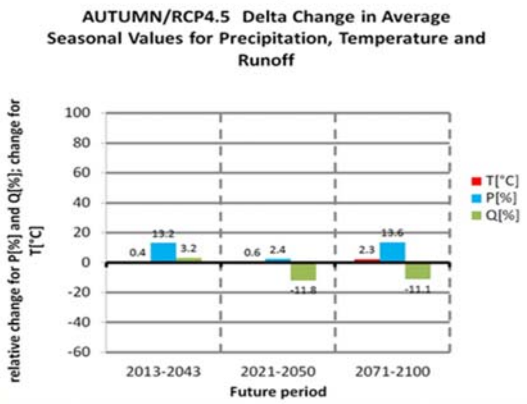



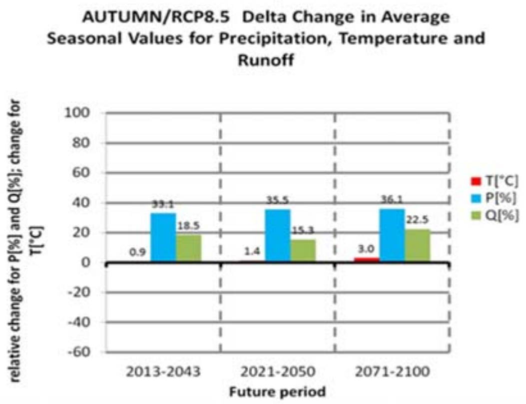



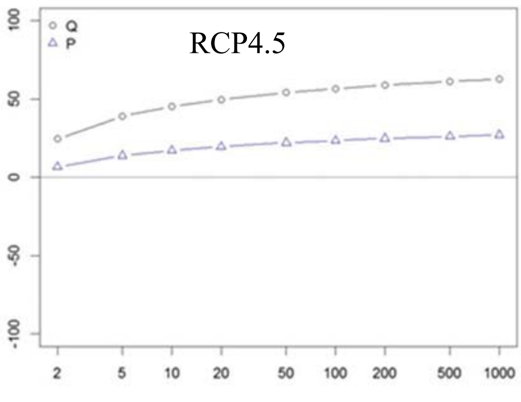



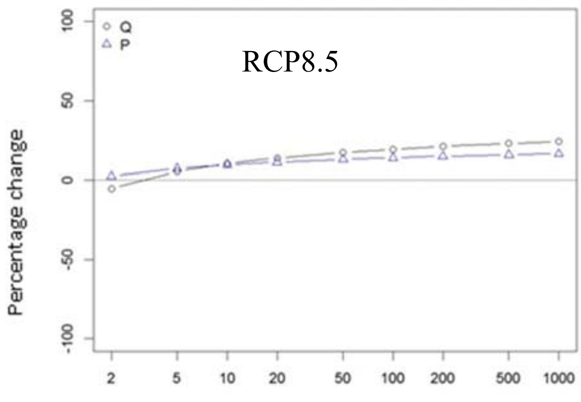



In most of the cases the analysis of extreme events suggests significant increases in the frequency of both high- and low-flow events. With the push of RCP4.5 or RCP8.5 scenarios the significant increase in flood peaks is observed in most of the river basins. Floods show a clear tendency towards increasing in Southern Bulgaria. Regions, most threatened by this tendency are along the rivers Struma, Mesta, Dospat and the higher parts of the Arda river and its tributaries.



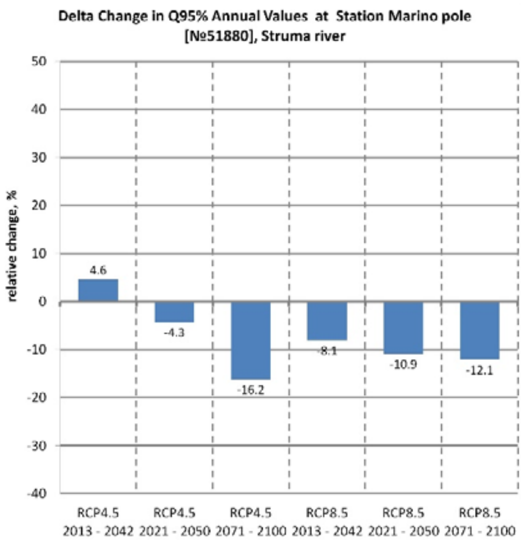




HM Station Taran - RCP4.5 and RCP8.5 for the period 2013 - 2042: Relative change in% of extreme rainfall and runoff at the respective repetition frequency

Low waters

Low flows are analysed based on the mean q95 of the daily runoff. The change in low waters overall is approximately +/- 5%, with a clear tendency towards reduction in north-eastern Bulgaria etc.

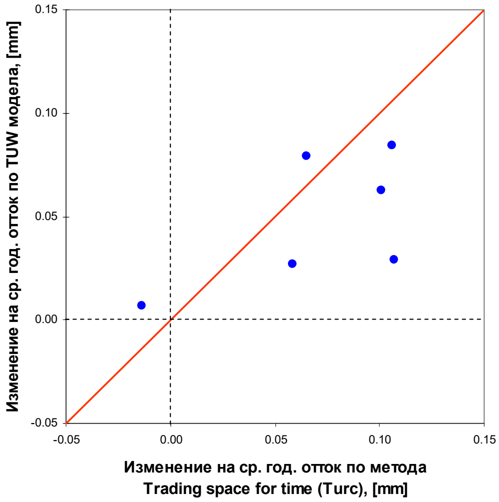
The figure shows the predicted changes in the low waters q95 in the West Aegean region – HMStation Marino Pole.



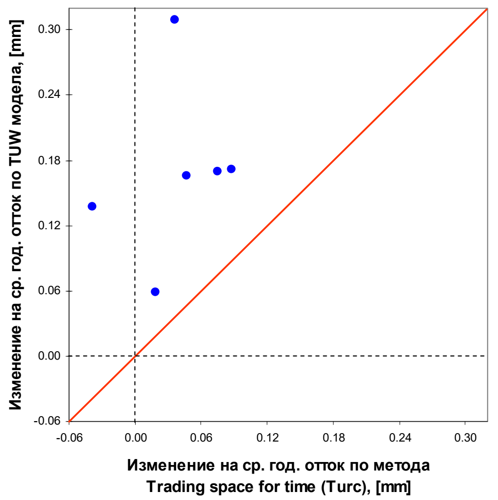

## 4. Discussion and Conclusions

The Trading space for time approach is used here for assessment and check of the prediction accuracy of the TUW model, searching for gauges with significant uncertainty of the forecast. Checks show some results that await their explanation. For example, many gauges on altitude of about 500 m, most of them in the Danube basin, have no verification of the long-term prognoses on scenario RCP4.5. It is necessary to follow the survey seeking explanations and interpretations of scenarios, within which spatial and temporal conditions show considerable uncertainty.

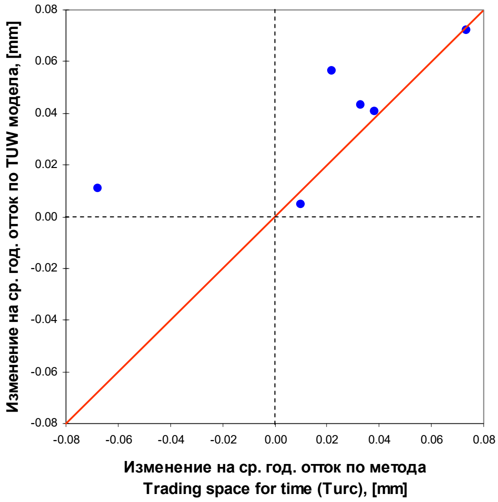
Examples of confirmed forecasts for a change to average perennial runoff, mm
except RCP4.5 (2071 - 2100) where the forecast is not confirmed



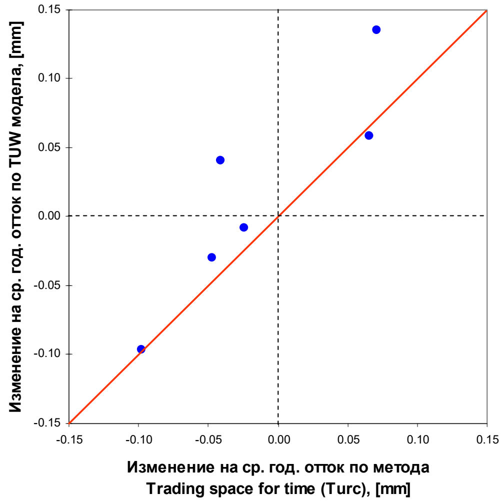

Station Stoyanovo - Danube River BD




Station Lovech - Danube River BD




Station Dusevitsa - Danube River BD




Station Taran -East Aegean RBD

The cluster analysis, made in the survey, steps on a generalized and rough approach (as fast first step analysis), which groups basins with respect to climate and soil setting and allows interpolation of the results from the observed and modelled watersheds to the whole territory of the county. The regionalization of hydrological specifics is not included in the clustering at this stage of the survey, but it sets up a basis for discussion and creation of ideas for its improvement concerning grouping watersheds with respect to, for example, size, shape, slope, land cover, etc. depending on the purpose of the study.

There is no doubt, that the climate change effect vs. land use change impact on the river discharge is an important study on the way to try to understand the phenomenon. This provokes thoughts about the possibility of expanding the current study to a stage, where the effect of land use changes in Bulgaria could be analysed in the reference period 1976-2005 by comparison of the intensive agriculture period (1950-1990) with the period of agriculture decay (1990-2005). Calibration and validation of hydrological models with ground data for such separated periods with different land use perhaps can give some answers on its effect on the river discharge. Specific information about the land use changes in each catchment is yet to be collected and analysed. Details about the effect of one kind of land use instead of another could be searched on local level in a detailed survey of a watershed.

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