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ESTIMATION OF MAXIMUM WATER FLOW IN CASE OF INSUFFICIENT DATA OF HYDROMETRIC OBSERVATIONS ON THE EXAMPLE OF THE SIRET RIVER BASIN

Abstract: *Catastrophic flood hydrograph components are formed depending on spatial variation and seasoning of meteorological elements. However, from year to year, the role of anthropogenic factors becomes more and more substantial, and the latter significantly effect on the duration of flood passage. The time series of maximal flow rates within natural-economic basin system of the Siret River were considered in the present work, which, with the use of the rivers-analogues, allowed for specification of said rates' values at 1% provision probability. In comparison to previous publications, too generalized data were highlighted in more detail, thus adding to differentiation of maximal flow rates distribution. The maximal flow rates were put to prolonged series of observation, and the obtained values were compared to those in previous publications by other authors who made use of significantly shorter series within the territory of the study. The results allowed for the assertion that the maximal flow rates essentially decreased in all observation sites at 1% excess probability. The biggest value of maximal flow rate at 1% excess probability was characteristic for the Siret River-Town of Storozhynets, while the lowest – for the Mykhydra River-Village of Lypovany.*

Key words: *maximal flow, prolonged series, drain module*

Formulation of the problem. Estimation of the parameters of big floods is among the most important and complicated tasks within the problem of runoff calculations, since the dimensions of culverts in bridges, railroads, roads,

appurtenances, etc, directly depend on computed values of the biggest water flow. Underestimation of predicted values of maximal water expense would lead to damages and destructions, whereas overestimation – to significant increase of building costs. Hydro-ecological safety problems within the territory are connected with both natural factors and anthropogenic loads. River basins undergo different types of nature use, which, in combination with natural factors affects the rivers' hydrological regimes. The problem of study of the effects of economic activity on the parameters of the stream runoff becomes more and more important in the last years. Anthropogenic load on the rivers' hydrological regimes is the leading cause of the sharp worsening of ecological situation in many regions.

Formation of catastrophic flood hydrograph components depends on spatial variable and seasoning of meteorological elements. Year by year, the role of anthropogenic factors becomes more and more substantial. It is most vividly actual in conditions of global warming when the course and the character of distribution of major meteorological elements is distorted, especially in the context of interrelation between the formation of regional hydrographic network and open water regime, and the climatic conditions.

The last qualitative systemic generalizations of hydrologic information for a long-term period were conducted and standardized over 30-40 years ago. That is, the hydro-meteorological observations of that time interval are not sufficiently used in construction design on regional rivers. Development and improvement of the methods to define principal predicted behavior of floods by way of geographic argumentation of calculated parameters distribution in the model of maximal flow rates seems to be an essentially important task [Review of Risk Based Prioritization, 2004, Swain R.E., Bowles D., and Ostenaa D., 1998].

The choice of the object of study – natural-economic system of the Siret River basin – was conditioned by its specific geo-spatial disposition (belonging to the Carpathian Mountainous Country, trans-border position), complexity of the hydrographic network and landscape structure, longtime history of settlement and

assimilation, and significant present-day level of anthropogenic development [Berezka I.S., Chernega P.I., Yavkin V.G., 2011].

Analysis of recent research and publications. Development of railway building in the mid-nineteenth century raised the necessity of calculations for water-conveying constructions in places where the numerous elements of hydrographic network were crossing the ways. Such tasks were specifically difficult in situation with the Carpathian rivers.

On the territories that belonged to Austro-Hungarian Empire they were guided by the Kostlin's Specification of Sites and Artificial Constructions by Basin Area (Vienna, 1868). According to these standards, the rainfall flood's maximal expense was defined depending on the area, length and longitudinal profile of the reception basin, and the specific discharge parameter.

The period of Austro-Hungarian ruling in Bukovyna was remarkable for the series of natural science works, in particular, V. Conrad's essay in Bukovynian climatology. C. Bratescu's research into geomorphology of the Siret's valley (1925) laid foundation to studies of the whole Siret River system [Bratescu C., 1928]. The period of intense study of the Siret basin's nature fell on the early 1950s.

The late 1970s and the beginning of the 1980s coincided in the world practice with powerful efforts to help develop recommendations for calculation of maximal flow rates of given annual frequency within the river reception basins with none hydrometric observations [Aron G., Kibler F.,1979, Cohen O., Ben-Zvi A., 1979].

The 1870s gave start to first hydro-meteorological observations in the basin of the Siret. It was in the Austro-Hungarian period that the network of hydrological stations was at its peak of development. Simultaneously, similar trend was gathering momentum in Europe. International cooperation between Hungary, Poland, Rumania, Ukraine, Czech Republic and Slovakia under the patronage of UNESCO in the Hydrology of the Carpathians, a complex scientific problem (1972-1978) was a powerful boost to geographical research in the area of engineering calculation of the Carpathian rivers' maximal flow rates.

In some latest publications their authors disclosed regional particularities of flood passage frequency [Atiem, I.A., Harmanciolu, N.B., 2006, Douglas E. M., Vogel R. M., Kroll C. N., 2000, Svensson C., Kundzewicz Z. W., 2004] and established regional statistical distributions using spatial nearness of the basins [Kuk-Hyun Ahn, Richard Palmer, 2016] and obtaining hydrologically homogeneous plots [Atiem, I.A., Harmanciolu, N.B., 2006]. Some works were devoted to the analysis and application of the relief's digital models [Jena, P.P., Panigrahi, B. & Chatterjee, C., 2016]; modeling and predicting the passage of maximal water expense; floods prevention in the EC countries and ways to adequately respond [Parker, D., Fordham, M., 1996]; methods to reduce risks of flood passage and overcome consequences [Kellens, W., Vanneuville, W., Verfaillie, E. et al., 2013, Soleimani-Alyar, M., Ghaffari-Hadigheh, A. Sadeghi, F., 2016]. It is important to note the changes in the approaches from flood fighting to maximal water expense passage risks assessment [Burn, D. H., 1990, Ellouze, M., Abida, H., 2008].

Methodical adjustments to and spatial (trans-border) coordination of given-provision maximal runoff statistical parameters were conducted within the territory of study which allowed for mapping of distribution of related parameters of maximal runoff prediction models in the Carpathians. On the territory of Ukraine, these were the mountainous basins of the Tysa, Prut, Siret and Dniester [Yavkin V. G., 2005, Yavkin V.G., Melnik A.A., 2012].

Highlighting previously unresolved parts of a common problem. The present work aims at assessment and analysis of maximal flow rates at 1% excess probability in natural-economic system of the basin of the Upper Siret, with the use of prolonged observation series obtained from rivers-analogues.

Presenting main material. The analysis of the curves of maximal water expense provisions for Ukrainian rivers was taken from reference books published in 1966-1971 and used by hydrologists, hydro-designers, etc through this present day.

Existing in a common system of Earth's nature evolution, the process of temporal changeability of hydro-meteorological components manifests some cyclicism in the values of maximal annual water expenses (repetition of catastrophic floods).

The analysis of long-time temporal series regarding the maximal runoff of Ukrainian rivers points to the fact that beginning from 1980s there appeared indications of temporal trend with polar signs, that is, there was increase or decrease of maximal water expense, especially as pertaining to the area of remote probabilities [Melnik A.A., Tsependa M.V., Tsependa M.M., 2015, Yavkin V.G., Melnik A.A., 2012].

The increase of the duration of observation series today requires re-calculation, generalization and expert assessment of the parameters of hydrological characteristics. It is only two active hydrological observation stations today within the territory of study (Siret River-Town of Storozhynets, Siret River-Village of Dolishniy Shepit), which is totally insufficient to help map the distribution of maximal flow rates. That was why, for the purpose of geographical generalization of the parameters of statistical distributions in the absence of station observations, it was decided to prolong the temporal series for the stations with insufficient interval of regular observations by way of the basins-analogues.

Annual values taken from 4 control sections of the Siret and its tributaries, namely, the Siret River-Town of Storozhynets, Siret River-Village of Lopushna, Mykhydra River-Village of Lypovany, Small Siret River-Village of Verkhni Petrivtsi were used for the analysis of maximal flood runoff observations. The present-day normative documents regarding calculations of probable values of maximal runoff offer the parameters of the prediction model containing generalized hydro-meteorological information of up to and including 1975. By way of analog approach, we have prolonged the observation series to 2009 or 2014. The areas of the river basins up to observation station within the territory of study vary from 144 km^2 to 672 km^2. The duration of observation period in the last three stations was insufficient since said periods were not representative. That was why hydrological characteristics under the present study have been reduced to the data taken from the long-term period of observations of the rivers-analogues. Observations of the majority of reception basins cover the period of 1953-2014 with the total period of observations amounting to 62-64 years. Choosing the station-analogue, it was majorly necessary that the synchronicity in fluctuations of river runoff was available. Quantitatively, such synchronicity is defined through r_{xy}, the

coefficient of pair correlation between the maximal runoff in the given river station and the station-analogue, with $r_{xy} \geq 0,7\text{-}0,8$, while r_{xy} should relate to average square error as $r_{xy}/\sigma_r \geq 2$. The value of relative average square error should not exceed 10%.

The rated hydrological characteristics are defined through homogeneous hydrological series. Their (characteristics) homogeneity is assessed proceeding from the genetic analysis of river runoff formation conditions by way of establishment of the causes that result in heterogeneity of observations' initial data. When quantitative assessment of observation data homogeneity is required, the statistical criteria of homogeneity of average values and dispersions are applied with consideration of intro-series and inter-series correlation relationships. To establish the values that sharply diverge from general totality of maximal values, we have conducted the assessment of homogeneity of empirical distributions and stationary state of temporal series' basic parameters. For that purpose, we have applied the sharply divergent readings of extreme values in the empirical distribution: the Smirnov-Grubbs and Disckson's criteria, specific for being developed for conditions of normal symmetric law of distribution of general totality and absence of auto-correlation. With that, the value of critical point depends on the target level of significance, selection scope, coefficients of auto-correlation and asymmetry. In the course of study, the level of significance was assigned to be 5%, which, according to theory of mathematical statistics, corresponds to acceptance of zero hypothesis of homogeneity with probability amounting to 95%.

The analysis of the results of maximal water expense within the series showed that the hypothesis of homogeneity can be applied for all reception basins. To flatten and extrapolate the empirical curves of distribution of annual excess probabilities, the three-parameter gamma density at any proportion of C_S / C_V, and the grapho-analytical method were applied. Parameters of analytical distribution curves – normal $\overline{Q}$, coefficient of variation and proportion C_S / C_V were defined way of the maximum likelihood method. Plotting the curves of provision, we have made use of semiologarithmic paper provided for by the Stok Stat software. For the purposes of comparison, we have plotted the empirical and analytical curves on logarithmic paper,

which showed similar results. The best coincidence of empirical and theoretical curves was observed when the grapho-analytical method with the use of three data points – $X_{5\%}$, $X_{50\%}$, $X_{95\%}$, - of the empirical curve was applied.

To characterize the maximal runoff, we have used the values of the module of 1% excess probability reduced to a 200 km^2 area. This was done to help estimate the maximal runoff horizontally, since the maximal water expenses undergo reduction in terms of area.

Keeping to requirements of engineering hydrology regarding calculation of catastrophic floods of certain probability, we suggested the following parameter values for the Upper Siret basin in the aforesaid model. Prolongation of temporal series of observations allow for suggestion of new parameter values in the prediction model of maximal runoff. The rate of the degree of reduction within the basin is 0,25 on the average, which denies the values of previous estimations, namely, P.M. Liutyk's (1983) - 0.40, V.I. Vyshnevskyy's (1999) – 0.29. Such divergences in n would essentially effect on calculation values of maximal runoff in small reception basins, that is, they would contribute to overestimation water maximal expenses. Besides, the questions regarding the approaches to generalization of the M_{200} - reduced module within the territory are not yet elaborated both scientifically and methodically.

The selects of adaptation of maximal flow rates distribution functions showed significant divergences in the area of low frequencies (1-5%). In particular, the values ranged from 0,4 to 1,58 within the Mykhydra River-Village of Lypovany in 1963. In 1970s, when the use of three-parameter gamma-distribution with additional grapho-analytical approximation was methodically substantiated and practically tested, the divergences essentially lowered and the values of maximal flow rates by way of several experiments was proved to amount to 1,55 m^3/sec km^2 on the average. The values of maximal flow rates at 1% excess probability when the prolonged observation series were applied, decrease in all hydrological stations. The highest flow rate values at 1% excess probability was characteristic for the Siret River-Town of Storozhynets – 1,65 m^3/sec km^2, while the least - for the Mykhydra River-Village of Lypovany – 0,9 m^3/sec km^2.

Guided by P.F. Vyshnevskyy's studies, we have compared the map schemes of distribution of maximal flow rates within the territory of study at 1% excess

probability as per calculations before 1977. The analysis showed that with the prolonged observation series, the values decreased in all stations. Along with this, according to P.F. Vyshnevskyy, the highest flow rate values at 1% excess probability was characteristic for the Siret River-Village of Lopushna – 2,28 m^3/sec km^2, while the least – for the Mykhydra River-Village of Lypovany – 1,45 m^3/sec km^2.

Conclusions. The series prolongation allowed for specification of the maximal modules of predicted provisions in the region, and, in comparison to previous publications, for particularization of too generalized data, thus facilitating the differentiation of maximal runoff distribution.

With application of the prolonged observation series, the maximal flow rates at 1% excess probability significantly decreased within all observation stations. The highest values of the maximal flow rate at 1% excess probability were characteristic for the Siret River-Town of Storozhynets (1,65 m^3/sec km^2) station, and the least – for the Mykhydra River-Village of Lypovany (0,9 m^3/sec km^2).

Comparison of the values of maximal flow rates to those presented in previous publications showed that said values decreased in all stations when prolonged observation series were applied. Along with this, according to P.F. Vyshnevskyy, the highest flow rate value at 1% excess probability was characteristic for the Siret River-Village of Lopushna– 2,28 m^3/sec km^2, while the least – for the Mykhydra River-Village of Lypovany – 1,45 m^3/sec km^2.

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А.А. Мельник, І.С. Березка, В.Г. Явкін Оцінка максимальних витрат води при недостатності даних гідрометричних спостережень на прикладі басейну річки Сірет

Анотація. Формування складових гідрографа катастрофічного паводка залежить від просторової варіації та часової мінливості метеорологічних елементів. Проте роль антропогенних чинників з кожним роком стає вагомішою, що позначається на тривалості проходження паводку. В роботі розглянуто часові ряди

максимальних модулів стоку води в природно-господарській басейновій системі річки Сірет, що дозволило уточнити їх показники при 1%-й ймовірності забезпечення з використанням річок-аналогів. Деталізовано, порівняно з попередніми публікаціями, занадто генералізовані дані, що сприяло диференціації розподілу максимального стоку води. Проведено порівняння величин максимальних модулів стоку води визначених за подовженими рядами спостережень з попередніми показниками досліджень інших авторів та значно коротшими рядами спостережень для території досліджень. Отримані результати дозволяють стверджувати, що максимальний модуль стоку води 1%-ї ймовірності перевищення суттєво знижується на всіх пунктах спостережень.

Ключові слова: максимальна витрата, подовження рядів, модуль стоку.

Оценка максимальных расходов воды при недостаточности данных гидрометрических наблюдений на примере реки Сирет

Аннотация. Формирование составляющих гидрографа катастрофического паводка зависит от пространственной вариации и временной изменчивости метеорологических элементов. Однако роль антропогенных факторов с каждым годом становится более весомой, что сказывается на продолжительности прохождения паводка. В работе рассмотрены временные ряды максимальных модулей стока воды в природно-хозяйственной бассейновой системе реки Сирет, что позволило уточнить их показатели при 1%-й вероятности обеспечения с использованием рек-аналогов.

Детализировано по сравнению с предыдущими публикациями, слишком генерализированные данные, что способствовало дифференциации распределения максимального стока воды.

Проведено сравнение величин максимальных модулей стока воды определенных по удлиненным рядам наблюдений с показателями исследований других авторов. Что позволяет утверждать - максимальный модуль стока воды 1%-ной вероятности превышения существенно снижается на всех пунктах наблюдений.

Ключевые слова: максимальный расход, удлинение рядов, модуль стока.