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New verification of the groundwater and tectonic processes possible impact on a series of recent catastrophic floods and debris flows (2011-2017)

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Traditionally torrential rains are considered as the main factor of flood/debris emergence. But with some examples of disastrous floods in absolutely different regions of the world the rough estimation of the water balance results in necessity to suggest a correct alternative hypothesis. In fact, the simplest model (taking into account precipitation, evaporation and soil permeability) clearly points out the significant discrepancy for several events between potentially accumulated and observed water masses. This observation pushes the idea that precipitation is necessary but not often sufficient factor for disastrous flood emergence and for the water flow budget. Thus, other available water source, i.e. groundwater, cannot be ignored. We discuss existing problems and basic principles for the concept, the evaluation of the sources and amounts for catastrophic floods, comparison of observations and measurements flood characteristics by analysis, as an example, for certain recent events over the world, in particular for 2011-2017 disastrous floods in Louisiana, Mississippi-river, Colorado-river (USA) et.al. The key part of the concept is connected with the impact of fractured bedrock, as the natural transport ways for groundwater contribution, on the water balance in the 3D-system of the river basin. Finally, we consider a possible role of tectonic stresses in the earth's crust on dynamics of the groundwater basin functioning. The analysis of its state for identification of significant factors in the formation of the water balance in mountain ranges shows that there are some controversial issues and policy challenges for forecasting of catastrophic/historical water events.

catastrophic floods, groundwater, tectonic processes

Новые данные влияния подземных вод и тектонических процессов на ряд недавних катастрофических наводнений и селей (2011-2017 годы)

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Традиционно проливные дожди считаются основным фактором возникновения катастрофических наводнений и селей. Однако, во многих случаях этих катастрофических явлений, происходящих в разных регионах мира, даже простая оценка водного баланса приводит к необходимости более глубокого анализа возможных причин появления больших водных масс в рамках некоторого альтернативного подхода. Действительно, общепринятая модель (с учетом осадков, испарения и проницаемости почв) часто указывает на существенное несоответствие для ряда этих событий между потенциально ожидаемыми и наблюдаемыми водными массами. Поэтому необходимо проанализировать другие возможные источники их возникновения с учетом реального бюджета распространяющихся потоков. Речь идет о выходящих на поверхность подземных водах. Мы обсуждаем существующие проблемы и базовые принципы данной концепции на основе анализа, например, некоторых недавних катастрофических наводнений, произошедших в 2011-2017 годах в штате Луизиана (США) в речном бассейне р. Миссисипи, на реке Колорадо (США) и др. Ключевая часть концепции связана с наличием системы трещин в горных породах как естественных путей транспортировки подземных вод на поверхность, обеспечивающих их вклад в общий водный баланс в единой 3D-системе речного бассейна. Резкая перестройка топологии такой трещиноватости, приводящая к выходу подземных вод, может быть связана с тектоническими напряжениями в земной коре в естественной динамике функционирования подземного водного бассейна, в т.ч. и в условиях землетрясений, даже происходящих на достаточном удалении от катастрофического события. Рассмотрение значимых факторов для механизма формирования общего водного баланса в речном бассейне при катастрофических/исторических водных событиях, которое проведено в настоящей статье, позволяет более точно решать задачи прогнозирования для данных явлений.

катастрофические наводнения, подземные воды, тектонические процессы

Introduction

The principal goal of present paper is to discuss the existing uncertainty and discrepancy for the flood/debris water balance estimation in the area under heavy rain. The problem between, on the one hand, the theoretical approach and reasonable database due to rainfall going from atmosphere, and, on the other hand, the real surface water flow parameters practically measured by some methods and/or fixed by eye-witness is under study [*Trifonova et al. 2014*].

In [*Trifonova et al., 2016*] we discussed basic principles for the concept, including the evaluation of the sources and water budget for catastrophic floods in comparison of observed and measured flood characteristics, for 2015 disastrous floods in Louisiana, June 7-20, USA, and in Assam, August 22 – September 8, India, as examples. The simplest and conventional model for our water balance estimation has included certainly such main elements as precipitation, evaporation, soil permeability, calculated water mass, observed water mass.

The analysis and estimations, performed by us, show the greater (up to 75%) water mass discharge observed during the events than it could be expected from the rainfall process only in the area under study. The fact gives us the founding to take into account the groundwater possible contribution to the event [*Trifonova et al., 2015, Trifonova et al., 2015*].

The key part of the concept is determined by impact of fractured bedrock, as the natural transport/transit ways for groundwater/surface water, in the water balance for the river basin unified 3D-system [*Trifonova et. al. 2008*]. We consider also possible role of tectonic stresses in the Earth's crust in the groundwater basin functioning in dynamics [*Koneshov et. al., 2017*]. The reasons for that are, first, the pressure field variation in groundwater basin and, second, the modification of the crack-net itself by different factors occurring both suddenly and/or smoothly.

Current problems and basic principles for the concept

Both the interaction process and the water exchange between the groundwater and surface water are very principal for flood development. But even using many hydrological gauging stations for data collection and global early flood warning technologies (taking into account the space and/or radar monitoring) there is a big discrepancy between different models and real events, especially for a historical flash flood, e.g. [*Revilla-Romero et al., 2015*]. In fact, for real water events they obtained (by hydrograph) that a peak flow of the flood occurs sometimes earlier than rainfall fields became maximum. Moreover, it has not been observed a direct correlation between precipitation and the groundwater dynamics during the storm events for both dry and wet seasons [*Efstratiadis A., et. al. 2014*]. The conclusion from this study has a general meaning because the response of surface water and groundwater to meteorological factors are often not obvious.

The numerical analysis model

We now determine budget of water pressure in aquifers required for groundwater exit on the Earth surface.

In accordance with observable catastrophic water flash discharge in the Krimsk-city event (July 07, 2012, Russia) we did following estimations (Fig. 1).

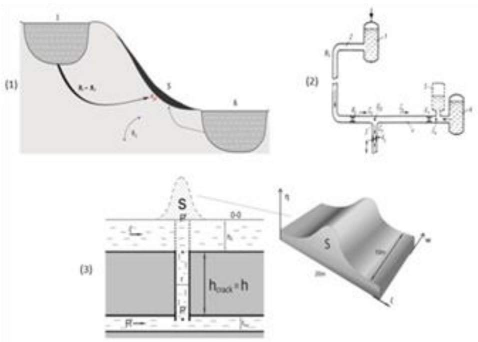

Fig. 1. Model of the fluid system and conditions of influence of deep (underground/ground) water on the formation of surface water flows: simple hydrodynamic (1) and equivalent hydraulic (2) schemes for a potentially dangerous areas; (3) the key parameters for calculation procedure to have a water exit phenomenon on the land surface (as a soliton object – S). All used parameters are clear from the picture

Our analysis shows that when $h_{river} \equiv h_0 = 5$ m, R = 0.54 m and for two values for definition of the aquifer depth (by the crack transportation system) $h_{crack} = 12$ m (groundwater) and $h_{crack} = 150$ m (deep horizon/artesian groundwater), we have the values in groundwater horizon $P_2' = 64$ and 79 atm, respectively (P_{atm} taken as 1 atm).

Although these estimates are quite rough, because they contain many assumptions and idealizations (cf. [*Trifonova et al., 2014, Trifonova et al., 2015*]), but, however, they allow to establish the procedure of estimating the required pressure in the aquifer for the expected/observable mass of water/debris flow on surface from groundwater with the chosen parameters.

The approach results in reasonable model for nonlinear trigger process of the catastrophic water event with some principal aspects, e.g. development in time of a catastrophic water travelling front on surface. We carried out some universal computer simulation for the process. The picture gives multiple solitary destructive wave propagation during the catastrophic event [*Trifonova et al., 2014*].

The conclusion from our study: the trigger mechanism (scenario 1) of a catastrophic event (occurred for the designated conditions) is realized at values $P_{flash} \geq P_d' \sim 64$ atm or 79 atm.

As to spreading flood in terms of smooth replenishment of groundwater (scenario 2) for already formed a high water level (after his release and/or due to the accumulation of water masses from other sources, such as rainwater, into the channel/riverbed), the dynamics of its development can also be determined through additional recharge from groundwater reservoirs (localized in certain spatially-distributed areas over the riverbed).

These two scenarios probably may be associated, consequently, with the Krimsk-city flash flood event, July 06-07, 2012 (Russia) and with the Amur river long flood event, Aug.-Sept, 2013 (Russia/China).

We also carried out a modelling for duration of the water event in aspect of the question: which time is necessary for a water flow propagation along the river channel (cf. [*Trifonova et. al. 2014*]). Our results (in frame of the simulation model for water breakthrough) show that the process is developing very fast without a long time water standing in the area under flood even for a quite topography of surface land (e.g. Middle Russian Plane). The parameters of our analysis in dynamics by computer simulation for the event are used: momentary breaking down of artificial water reservoir with water body $\sim 5\cdot 106$ m^3 and square water mirror $\sim 1.5\ 106$ m^2 with water depth (in reservoir immediately near the dam border) ~15m. These conditions take place for a real water object in Vladimir region (Russia) on the river Sodyshka. The principal conclusion is that we have, in fact, a short time period event (but being complex with multiple local maximums of water front flow), and all consequences of the flood transit process (both a water running and a flood period) occur during the 8-16 hours only with a small area of spate in a wide well-developed river valley basin.

Thus, a long time flood, especially in mountain river basin, requires a more correct analysis, and cannot probably be explained without extra water sources being a groundwater exit on surface. In fact, e.g. in Moscow on June-July 2017 the extremely heavy rain occurs (historical for 150 years), but no flood is developed. Principal, that these fantastic water masses disappear during 1-2 hours over the river basin area without any long time consequences.

Monitoring of both water mass in artesian wells and surface water/river discharge

The coupling of groundwater and flood event is probably evident from the correlation between the level of water in artesian wells and the flood period development. In fact, according to the data [www. usgs.gov] our consideration shows that a sufficient correlation for discussed coupling is closed to 100 % with delay time ~ 13 days between water state in wells and flood event on surface for the distance difference ~ 200km (has been recognized by existing of measured station dislocations). For quiet period (no flood) there are the natural cycles in time for coupling of water level in wells and the river discharge process (we determined the correlations ~ 75 %) – see division 2 below.

In this aspect we can introduce, as examples, two very principal facts, unfortunately, being out of the analysis in literature, but strongly supporting the groundwater impact on flood process.

First, for a Krimsk event, the Neberdzhay reservoir (water body $7\cdot 106$ m^3, above the Krimsk-sity) absolutely disappeared in next year without any water accident on surface, that may be associated with process of passing away the water mass from the land to groundwater horizon being vacant after previous catastrophic flood.

Second, two items for the Amur-river flood took place by the same reason, when (i) the water level in Lena-river was dramatically degraded simultaneously (in frame of conception for unified (space scale ~ 2000 km) groundwater basin for two great rivers) and (ii) the catastrophic fire accidents occurred in few months later on the territory being before as the Amur flood-river area. In this year (2017) probably by same reason we have a catastrophic fire problem in Europe after earlier flood seasons in previous years (the biggest one in 2013 – see Fig. 7 below in division 3).

Analysis for historical flood in Mississippi River basin (on May 2011)

General information and approach

When we are talking about surface and groundwater interaction, and as result the contribution of this factor to catastrophic floods, it is necessary to recognize the correlation between several processes.

The principal of their:

(1) river-discharge (the data was taken from [https://waterdata.usgs.gov/nwis/sw]);

(2) precipitation level (the data was taken from [www.ncdc.noaa.gov/cdo-web/]);

(3) artesian water level in wells in some localized river basin areas (the data was taken from [https://waterdata.usgs.gov/nwis/gw]).

Especially, we must make a monitoring of their variations before, during and after the catastrophic water event in association with statistical data on the subject over nearby years. Next position, is to find out the reasons/mechanisms of such variations, and to determine the conditions when not only precipitation is a dominant factor in water balance estimation for the flood. Our hypothesis is that seismic activity may be important for the case under some specific conditions (see division 3 below).

We carried out an analysis on basis of this concept in Mississippi-river basin for the area in which necessary open access database was existed in both space and time (see Fig.2).

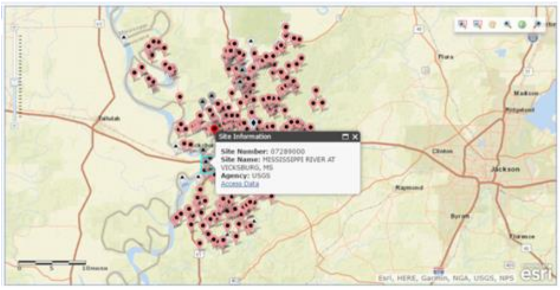

Fig.2. Displacement of artesian wells in the Mississippi River basin region near the catastrophic flood area on May, 2011.

Preliminary results obtained by us are following.

1. In quiet period (2014-2015) correlation coefficient K_{13} between two factors (1) and (3) is K_{13} = - 0.74 (anti-correlation process) that means that increase/decrease of river discharge is due to decrease/increase of the artesian water level. These natural cycles in time are reasonable for the river basin area functioning in equilibrium state.

2. When the flood occurred (April-June, 2011) $K_{13} \sim$ - 0.50 for the measurements made «day by day». But with a shift over days in 13 days (before the different event day occurrence) we had for distance $\sim$ 200 km (according to station source localization of database collection) practically absolute correlation: $K_{13} \sim$ - 0.994, i.e. artesian water obviously results in the surface water discharge increase (the details see below in Table 2 and Fig.4).

Further, we will concentrate on this last event.

Let's now compare development of two factors (1) and (2) from January 1, 2011 to December 31, 2011. For correlation coefficient K_{12} («day by day») we had unexpected very small value $K_{12} \sim$ 0.011 (maximal discharge period was during the May, and exceeded the level, e.g. on February, in 7 times). As to correlation coefficient K_{23} its value was small as well, $K_{23} \approx$ 0.060, but the level of groundwater didn't sufficiently vary during the whole of 2011 in contrast with precipitation intensity (for the same observed area of approximation). It means that precipitation doesn't directly impact immediately (we forget here about the different localization of the stations for the areas under measurements). To adjust the day shift parameter for the correlation coefficient improve we can increase and reach its values for two discussed cases, however not more than value $\sim$ 0.7.

But all these conclusions are relatively problematic because, first, strongly depend on the averaging scale for available database. Second, the discharge parameter is determined not only by water mass itself but the velocity of flow in general. Third, the correlations between different processes strongly depend on the temporal shift in days for their (both natural and for modelling) when the events occur, and the comparison has made for observable and calculated subjects. Forth, the dislocation of the stations being a resource of the database cannot be controlled in the same areas under study.

More detailed consideration for historical flood (on May, 2011) in the area of Mississippi-river reduces to following.

The available dependences (over certain years) based on the data for groundwater (artesian wells) [*https://waterdata.usgs.gov/nwis/gw*] and river-discharge [https://waterdata.usgs.gov/nwis/sw] are shown in Fig. 3.

Geographic coordinates of information retrieval/measurements are following: for discharge in fixed area (a) station: NAD83 Warren County, Mississippi Latitude/Longitude: 32°18'54"/90°54'21"; for groundwater in two dislocated areas (b) station: Elliott 4 NW, Mississippi Latitude/Longitude: 33°41'57"/89°45'46" and (c) station: Orleans Parish, Louisiana Latitude/Longitude: 29°56'52"/90°02'01".

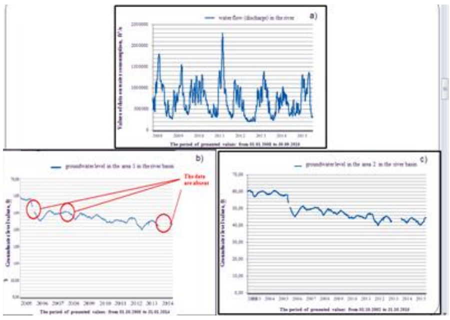

Fig. 3. Statistical data processing averaging over the days but for different years: daily statistics based on data for the level of groundwater in the two Mississippi-river basin areas (1 and 2).

As you can see, during the flood period (May, 2011) the groundwater level can decrease (Fig. 3, c) and increase (Fig. 3, b). Both these opposite cases may be reasonable due to, first, spatial and temporal delay because of different dislocation areas for observation stations and, second, concrete 3D-crack structure variation of the river basin in dynamics (by impact of different external factors) for water transit in such channels of the river basin.

A modeling procedure

The fragment of data for precipitation level and other parameters (being important for the analysis in general) are presented in Table 1 (from March 01 to June 30, 2011).

We used the basis parameters for statistical processing of the data reduced to ordinary characteristics:

(i) the sample standard deviation

$$s_y = \sqrt{\frac{\sum_{i=1}^{n}(y_i-\hat{y})^2}{n-1}}, \quad (1)$$

where n – the sample size; $\hat{y}$ – arithmetic average of a sets of number n, and

(ii) the criterion of observation

$$I_i = \frac{|y_i-y_{i-1}|}{s_y}, \quad (2)$$

where index i indicates the number of observations, and limit value for sample size was determinate by the criterion for required accuracy (probability of first kind error α is accepted as value α = 0.05). A mathematical model for forecasting of floods based on river basin data and has the following results.

Initial data for the mathematical model are: groundwater level, water flow rate and water flow in the Mississippi-river estimated by days with a shift in the dependence on time for the flood period on May, 2011. Determination of the dependence and the calculation results for correlation coefficient K13 are presented in Table 2 and in Fig. 4. They based on data for the Mississippi-river basin with a different shift over days between the groundwater level and the water flow rate (river-discharge) during the flooding on May 2011.

Table 1. Database for principal parameters (maximal flood days: May 16–19, 2011)

Year	Month	Day	Rain (inches)	Snow (inches)	Snow cover (inches)	All precipitation (snow+rain)	Discharge, cub. foots /s.	groundwater, foots
2011	3	1	0	0	0	0	727000	44,95
2011	3	2	0	0	0	0	795000	44,85
2011	3	3	0	0	0	0	852000	44,76
2011	3	4	0	0	0	0	900000	44,66
2011	3	5	0,38	0	0	0,38	947000	44,56
2011	3	6	0,65	0	0	0,65	988000	44,61
2011	3	7	0	0	0	0	1020000	44,62
2011	3	8	0	0	0	0	1050000	44,55
2011	3	9	2,19	0	0	2,19	1100000	44,48
2011	3	10	0,03	0	0	0,03	1140000	44,51
2011	3	11	0	0	0	0	1170000	44,51
2011	3	12	0	0	0	0	1190000	44,53
2011	3	13	0	0	0	0	1210000	44,54
2011	3	14	0	0	0	0	1230000	44,53
2011	3	15	0,81	0	0	0,81	1250000	44,55
2011	3	16	0	0	0	0	1260000	44,57
2011	3	17	0	0	0	0	1280000	44,60
2011	3	18	0	0	0	0	1300000	44,60
2011	3	19	0	0	0	0	1310000	44,62
2011	3	20	0	0	0	0	1330000	44,63
2011	3	21	0	0	0	0	1340000	44,63
2011	3	22	0	0	0	0	1350000	44,60
2011	3	23	0	0	0	0	1370000	44,56
2011	3	24	0	0	0	0	1390000	44,59
2011	3	25	0	0	0	0	1390000	44,58
2011	3	26	0,04	0	0	0,04	1400000	44,54
2011	3	27	0,6	0	0	0,6	1420000	44,54
2011	3	28	0,68	0	0	0,68	1420000	44,54
2011	3	29	0	0	0	0	1410000	44,47
2011	3	30	0,56	0	0	0,56	1410000	44,14
2011	3	31	0,01	0	0	0,01	1410000	44,27
2011	4	1	0,1	0	0	0,1	1400000	44,27
2011	4	2	0	0	0	0	1380000	44,29
2011	4	3	0	0	0	0	1350000	44,26
2011	4	4	0	0	0	0	1320000	44,19
2011	4	5	1,3	0	0	1,3	1310000	44,25
2011	4	6	0	0	0	0	1270000	44,23
2011	4	7	0	0	0	0	1220000	44,20
2011	4	8	0	0	0	0	1170000	44,17
2011	4	9	0	0	0	0	1140000	44,18
2011	4	10	0	0	0	0	1100000	44,18
2011	4	11	0	0	0	0	1060000	44,18
2011	4	12	0,43	0	0	0,43	1030000	44,26
2011	4	13	0	0	0	0	1010000	44,28
2011	4	14	0	0	0	0	991000	44,27
2011	4	15	0,75	0	0	0,75	980000	44,20
2011	4	16		0	0	0	983000	44,30
2011	4	17	0	0	0	0	992000	44,32
2011	4	18	0	0	0	0	1000000	44,27
2011	4	19	0	0	0	0	1010000	44,24
2011	4	20	2,25	0	0	2,25	1020000	44,24
2011	4	21	1,85	0	0	1,85	1050000	44,24
2011	4	22	0,27	0	0	0,27	1090000	44,21
2011	4	23	0	0	0	0	1130000	44,19
2011	4	24	0	0	0	0	1160000	44,17
2011	4	25	0	0	0	0	1200000	44,11
2011	4	26	0	0	0	0	1240000	44,05
2011	4	27	1,27	0	0	1,27	1290000	43,98
2011	4	28	0,68	0	0	0,68	1340000	44,11
2011	4	29	0	0	0	0	1390000	44,13

2011	4	30	0	0	0	0	1440000	44,09
2011	5	1	0	0	0	0	1490000	44,10
2011	5	2	0	0	0	0	1540000	44,07
2011	5	3	1,03	0	0	1,03	1590000	44,11
2011	5	4	0,11	0	0	0,11	1650000	44,10
2011	5	5	0	0	0	0	1700000	44,08
2011	5	6	0	0	0	0	1760000	44,06
2011	5	7	0	0	0	0	1820000	44,07
2011	5	8	0	0	0	0	1890000	44,06
2011	5	9	0	0	0	0	1960000	44,06
2011	5	10	0	0	0	0	2020000	44,12
2011	5	11	0	0	0	0	2080000	44,21
2011	5	12	0	0	0	0	2140000	44,30
2011	5	13	0,7	0	0	0,7	2200000	44,40
2011	5	14	1,15	0	0	1,15	2230000	44,48
2011	5	15	0	0	0	0	2270000	44,54
2011	5	16	0	0	0	0	2290000	44,57
2011	5	17	0	0	0	0	2310000	44,59
2011	5	18	0	0	0	0	2310000	44,61
2011	5	19	0	0	0	0	2280000	44,65
2011	5	20	0	0	0	0	2250000	44,70
2011	5	21	0,03	0	0	0,03	2230000	44,76
2011	5	22	0	0	0	0	2200000	44,83
2011	5	23	0	0	0	0	2150000	44,88
2011	5	24	0	0	0	0	2100000	44,93
2011	5	25	0	0	0	0	2050000	44,96
2011	5	26	1,13	0	0	1,13	2010000	45,00
2011	5	27	0	0	0	0	1970000	45,02
2011	5	28	0	0	0	0	1930000	45,06
2011	5	29	0	0	0	0	1880000	45,12
2011	5	30	0	0	0	0	1830000	45,18
2011	5	31	0	0	0	0	1780000	45,23
2011	6	1	0	0	0	0	1740000	45,27
2011	6	2	0	0	0	0	1690000	45,29
2011	6	3	0	0	0	0	1650000	45,35
2011	6	4	0	0	0	0	1610000	45,42
2011	6	5	0	0	0	0	1580000	45,49
2011	6	6	0	0	0	0	1540000	45,56
2011	6	7	0	0	0	0	1500000	45,64
2011	6	8	0	0	0	0	1470000	45,68
2011	6	9	0	0	0	0	1430000	45,72
2011	6	10	0	0	0	0	1390000	45,76
2011	6	11	0	0	0	0	1350000	45,80
2011	6	12	0	0	0	0	1310000	45,84
2011	6	13	0	0	0	0	1260000	45,88
2011	6	14	0,34	0	0	0,34	1210000	45,91
2011	6	15	0	0	0	0	1170000	45,94
2011	6	16	0	0	0	0	1130000	45,99
2011	6	17	0	0	0	0	1090000	46,02
2011	6	18	0	0	0	0	1040000	46,07
2011	6	19	0	0	0	0	1000000	46,13
2011	6	20	0	0	0	0	962000	46,18
2011	6	21	0	0	0	0	928000	46,24
2011	6	22	0,72	0	0	0,72	906000	46,29
2011	6	23	0,35	0	0	0,35	887000	46,34
2011	6	24	0	0	0	0	874000	46,37
2011	6	25	0,23	0	0	0,23	869000	46,41
2011	6	26	0	0	0	0	870000	46,45
2011	6	27	0	0	0	0	873000	46,49
2011	6	28	0	0	0	0	882000	46,51
2011	6	29	0,9	0	0	0,9	896000	46,50
2011	6	30	0	0	0	0	910000	46,51

Table 2. The values of correlation coefficient K_{13} vs shift over days (data of calculations on the basis of database) between groundwater and surface water (river-discharge). Maximal/optimal value of K_{13} is 12-14 days.

Shift over days	**K13 (Pierson coefficient)**
1 day	0.1774149615
2 days	-0.025447488
3 days	-0.232827502
4 days	-0.428477257
5 days	-0.598739916
6 days	-0.735084072
7 days	-0.83667801
8 days	-0.905681037
9 days	-0.949485873
10 days	-0.97561582
11 days	-0.989395821
12 days	-0.994455935
13 days	-0.994245573
14 days	-0.991366622
15 days	-0.987680186
16 days	-0.983998092
17 days	-0.981016474
18 days	-0.97919583
19 days	-0.977515443
20 days	-0.975941175

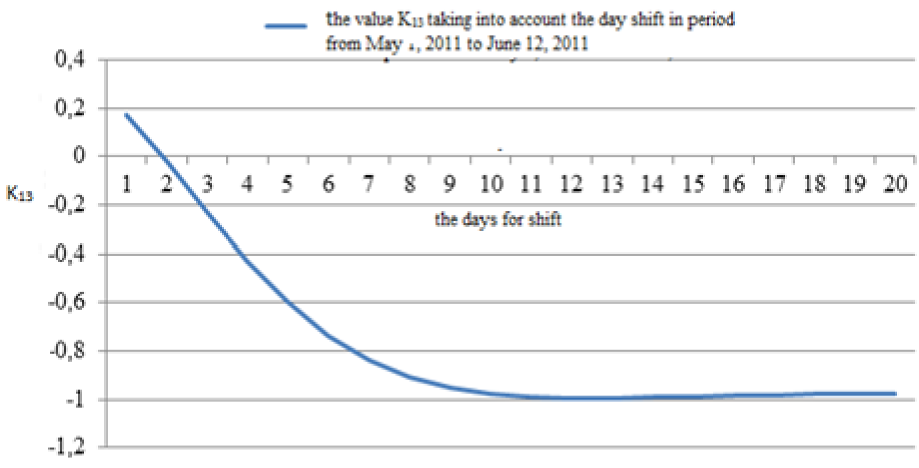

Fig.4. Graph for the values of correlation coefficient K_{13} with a day shift in the flow of water in the Mississippi River and variation of the artesian water level in wells.

The results of the mathematical model for forecasting of floods and analysis of the constructed mathematical model for the predicting occurrence of floods are based on two stages.

First step is modelling taken into account the data of already occurred flood (see Fig.5).

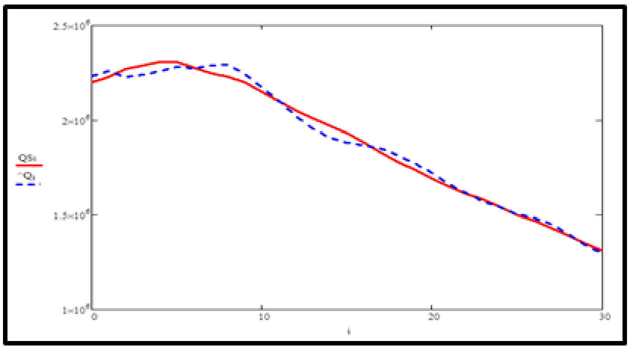

Fig. 5. Observable and predicted water flow during the flood: QSi – water flow/river-discharge according to real statistical data for Mississippi-river area at the time of May, 2011 (flood observation/measurement); $\widehat{Q_{1}}$o – predicted water flow.

Validation of the model can be verified under adequacy by F-criterion of Fisher for different level of significance (α) in frame of regressive model [*Kobzar, 2006*]:

$$F_{calc.} = \frac{S_1}{m} / \frac{S_2}{(n-m-1)}, \qquad (3)$$

where n - the number of observations; m - the number of parameters (n=30; m=2); $S_1 = \sum_{i=1}^{n}(y_{i,calc.} - y_{average\ calc.})^2$, $S_2 = \sum_{i=1}^{n}(y_i - y_{i,calc.})^2$ y_i – observations of number i.

But from the table data we have F_{table} = 2.0423 for α=0.05; F_{table} = 1.6973 for α=0.01.

The condition $F_{calc} > F_{table}$ means that the model is adequate, and, in fact, we obtained that 99.9% of the accuracy of the model has been achieved.

Thus, a conclusion is: water discharge and groundwater level have an impact on water consumption in the future.

Second step is final modelling for the future flood occurrence. The results show a quite reasonable coincidence (see Fig. 6).

The hypothesis is that river-discharge Q in a fixed section of the river channel is a function of groundwater level h in the consequent area taking into account the temporal day shift Q_s: Q = f(h, Qs).

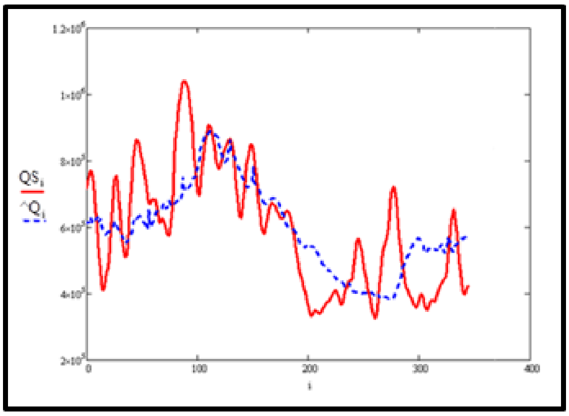

Fig. 6. Result of analysis for predicted floods in parameters QSi and $\widehat{Q_{1}}$o.

Under our consideration the shift is selected by criterion of maximal value for correlation coefficient. The results are presented in Fig. 3, and show the optimal value of the shift in 12-14 days. According to Mathcad-soft for many-factor model of computer simulation we obtained the dependences for forecasting 2015 (in days) which display in Fig. 5 (statistical data) and Fig. 6 (test data) on the basis of the database in 2014 (initial point (i) on the dependence).

Thus, in conclusion, on the basis of recognition of correlation between river-discharge and groundwater level (due to statistical database) we carried out the preliminary forecasting procedure for the floods. The principal item for the future activity in the field is to take into account the real initial contribution of precipitation («day by day») in considered two key parameters, i.e. discharge and groundwater level. For now, this contribution is summarized in final numerical values of the parameters we used.

Impact of tectonic processes on groundwater state: the dominant factors

We believe that in some cases the interconnection of catastrophic floods and preceding earthquakes may occur. The problem has been considered for certain real events (e.g., in addition to the above mentioned events, for the Colorado flood (USA) in September, 2013 and for Western Europe in May-June, 2013).

Some hypothetic considerations under the concept are shown in Figure 7. The database is taken from [*http://www.isc.ac.uk/*, *http://geofon.gfz-potsdam.de/*].

Our statistical analysis showed that more significant impact on the groundwater exit on surface occurs for the earthquake hypocenter depth ∼10 km when the magnitude value is about 5.0 (energy $\sim 10^{12}$ J) which may be associated with 7 points in earthquake epicenter on the land surface. In this aspect seismic properties of the bowels of the earth/soils are presented, e.g. in [*Nikolaev, 1973*].

a) b) c)

Figure 7. The catastrophic floods in 2013 that probably may be associated with the earthquake (it is marked: white flags – the epicenter of the earthquake, semi-circle – a schematic representation of propagating (isotopically) of seismic waves, dark gray area – potentially dangerous in terms of the flooding zones likelihood, the black circles with white border – fixed/observable zones of catastrophic floods): a) the flood in Western Europe (May-June, 2013); earthquakes in the southwest of Turkey on May 16, 2013 (magnitude – M5) and at the Northern coast of Algeria on May 19, 2013 (M5.1); b) the Amur flood (Aug.-Sept. 2013), Russia/China; the earthquakes on Sakhalin island (Russia) on July 4,7,9, 2013 (M5; M4.4 and M2.9, respectively) and Japan – Izu Archipelago, on July 11, 2013 (M5.3), Nord-East Honshu island, on July 13, 2013 (M4.5), respectively; c) the flood in Colorado (September-October, 2013), USA; the earthquake in Northern California (USA) on August 27, 2013 (M4.2); in the North of Mexico on August 28, 2013 (M4.3) and in the East Texas (USA) on September 02, 2013 (M4.5)

In Figure 8 the definition of potentially dangerous areas is explained by the following procedure:

Step 1 – marking of the epicenters for strong earthquakes (e.g. with the magnitude over M5) on the geographical map with designated boundaries of tectonic plates;

Step 2 – schematic depiction of the fronts for seismic waves propagating from the earthquakes epicenters;

Step 3 – defining of potentially dangerous flood areas;

Step 4 – monitoring of the real floods occurrence in potentially dangerous areas.

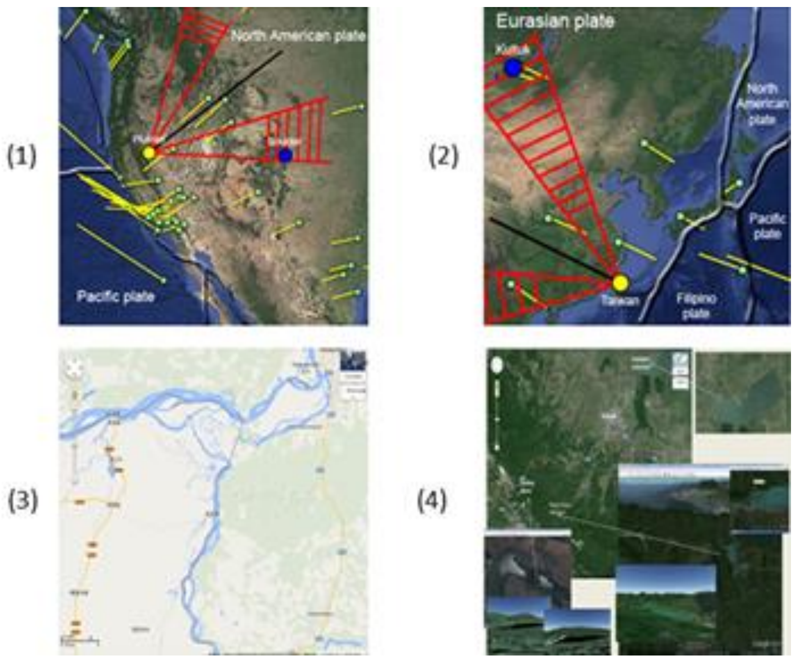

Figure 8. The areas by both seismic waves propagation – (1),(2), and potentially dangerous sectors for catastrophic floods – (3),(4): (1) – for Colorado river region (USA), 2013; (2) – for Amur river basin (Russia/China), 2014; the card movement scheme of the tectonic plates with marked sectors of disasters (preliminary selection): designated of flood, epicenters of earthquakes and/or volcanic eruptions; grey arrow is the vector connecting with the flood and earthquake; risk area (by satellite view – see Space, Stars, Mars, Earth, Planets and More – NASA Jet Propulsion Laboratory; GEOFON Program GFZ Potsdam: GEOFON Main page; BGR – Whymap); (3) – illustration for a good developed 3D-crackness at the Amur river basin (the riverbed dissected area – visible channels on Earth's surface) by using of Google Maps; (4) the Krimsk-city flood (2012, Russia) dangerous area due to both mountain landscape and dislocation of water objects (natural and artificial for up and down of the Krimsk-city) in the Adagum river basin (in respect of the Figure 1-scheme).

As to Mississippi flood (but for the event on May, 2015), being under our analysis as well, the probable earthquake impact on the event is shown in Fig. 9 in respect of our upper concept.

Fig.9. Seismic processes (April, 2017) provoking, probably, the Mississippi catastrophic flood on April-June, 2017: epicenters of earthquake – red circles, areas of flood (Louisiana) – dark blue: the magnitudes (in numbers) and the data (in month/day) are shown in the picture as well.

Conclusion

We have made the analysis of the river basin state for identification of significant factors in formation of the water balance and evaluation of both the sources and water budget for catastrophic floods in mountain areas. The groundwater impact in development of these processes is discussed. The analysis, e.g. for 2011-2016 events in Mississippi-river basin as a

3D-dynamic system is presented. We carried out some computer simulation for the subject. Preceding earthquakes may impact on catastrophic floods due to triggering restructuration of the crack-net river-basin system as a natural transportation system for groundwater exit on land-surface. The approach gives reasonable results for some real water events, and a solitary destructive wave propagation may occur over the land surface during the catastrophic event under trigger mechanism of the crack-net modification due adjustable earthquakes.

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