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Establishing Legal *Force Majeure* Case for the Interruption of Hydro Energy Supply Related to an Extreme Hydrological Drought Event

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Abstract: The management of water resources and specifically the energy supply from hydropower systems are strongly affected by drought events. This paper is devoted to the unfolding of legal consequences caused by an extreme hydrological drought event. The legal litigation occurred when – due to a severe deficit of water – the hydropower company that manages the hydro energy resources over the entire territory of Romania was unable to deliver the amount of electricity stipulated in the power purchase agreements. The studypresents an extensive statistical analysis of extreme hydrological drought events occurrence, using the threshold level method. The statistical analysis was applied on large historical records of the flow rates (50-90 years) and revealed the occurrence of extreme drought events, i.e. extremely low occurrence frequency phenomena. The characteristics of the historical data were studied to highlight the area where the forecast normally used in the hydro generation planning is not possible. In order to evaluate the occurrence of extreme drought phenomena, the natural monthly and annually flows of the Danube and other seven major interior rivers in Romania (Argeș, Bistrița, Olt, Lotru, Sebeș, Someș, Siret and Raul Mare) were analyzed, reflecting fairly a general picture of the flow distribution on the entire territory. The analyzed cases refer to periods when – due to a severe deficit of water – the Romanian hydropower company was unable to generate electricity according to the power purchase agreements (PPA). The results of the statistical analysis were further used as the base for the legal cases that confirmed the *force majeure* situations claimed by the hydropower company.

Keywords: Water Resources, Extreme Drought, Unpredictability, Statistical Analysis

1. Introduction

The drought phenomena are widely spread all around the world. In 1991, E. Bryant stated that of all natural hazards, drought has the greatest impact beyond the period of its occurrence [1]. The importance of this phenomenon is lately confirmed by many studies [2-7]. The present analysis is all the more important as unpredictability in nature and in hydrology in particular indicates the impossibility to forecast the future state of a natural phenomenon.

The chaotic nature of the atmospheric system sets the limits of the river flow predictability. As it is well known a statement of probability is not a forecast. Extensive studies indicate that variations of hydrologic phenomena are not cyclic [1, 7-10]. To forecast future hydrologic events there must be repetitive cycling phenomena i.e. in the future the experience of the past could be duplicated. In fact, repetitive cycles are absent in hydrologic data. Therefore, the past record can be used as a probability that certain events will occur in the future, not as a forecast.

Simulation programs created on the specific of the hydropower system could be used for hydro generation forecasts based on the historical record of the river average flow, but with a certain, limited precision. Still, the perfectly accurate operation sequence of the hydropower systems - both theoretically and practically - is unattainable. The probability analysis is essentially the analysis of the sample variability of the recorded data – called historical record. Based on those samples, one can identify some regularity of the phenomena, usually the phenomena with high occurrence frequency, for which the prediction is fairly good. Still, for phenomena with very low occurrence frequency, the prediction is impossible.

Typical events that generate *force majeure* situations include natural disasters, especially under the current consequences of climate changes, war, armed conflict, terrorism and others. In the literature, floods are encountered almost exclusively within the concept of a natural disaster [11]. This is quite peculiar since obviously droughts represent a natural disaster as severe if not worse in some cases than floods.

Very low river flow events are quantitatively defined using the threshold method. This method is relevant for storage/yield analysis and is commonly applied to hydropower and water management [9].

The hydrological drought is identified when the water flow falls below a certain threshold [5, 12]. This approach allows the simultaneous features of the hydrological drought from the point of view of the duration, the severity of the resources deficit and the occurrence period [9, 13, 14].

According to the methodology used by the ARIDE Project the threshold can be identified within the spread of 70% – 90% exceeding probability [9]. In the present study the 90% probability value was adopted meaning the flow with the 10% occurrence frequency on the flow curve.

This paper refers to the periods when – due to a severe deficit of available water – the hydropower company in Romania was unable to generate to the customers the amount of energy stipulated in the power purchase agreements (PPA). The two periods are October 2011 –April 2012 and August – November 2012. The litigation subject concerned the opposition of the customers to the decision of the hydropower company to stop the hydro generation under the protection of the *force majeure* clause stipulated in the PPAs. Both parties engaged in hydrological expertise supporting the legal matter. It must be mentioned that in the specific PPA between the Romanian hydropower company and their customers the *force majeure* situations were not detailed in any manner, and no drought events, inflow or precipitation limits were stipulated as escape clauses. Therefore, the authors' contribution was needed to establish - using the statistical analysis applied to a large amount of historical data - that this particular drought events were both exceptionally severe and unpredictable ones, therefore, a *force majeure* case.

In order to evaluate the occurrence of extreme drought phenomena, the natural flows of the Danube and other seven major interior rivers in Romania (Argeș, Bistrița, Olt, Lotru, Sebeș, Someș, Siret and Raul Mare) were analyzed, reflecting fairly a general picture of the flow distribution on the entire territory. The available historical records of flow rates cover 94 years in case of the Danube and 50-70 years in case of the interior rivers.

The severe drought situations were evaluated by the threshold set at 10% occurrence probability within the occurrence probability curve computed using the historical records of monthly and annual flows.

The novelty of the present situation derives from the use of the *force majeure* case as a consequence of the unpredictability of hydrological events with very low occurrence frequency, such as extreme drought. Eventually, in all of the lawsuits engaged against the hydropower company, the court decided in favor of the *force majeure* case.

2. Unpredictability and Climate Change

One can consider it useful to adapt the analogy of the dualistic philosophy in modern physics in order to fathom out the unpredictability concept. The knowledge of nature is divided into facts and probabilities. Observation of the natural objects that are directly observable gives us facts about what happened in the past, but offers us only probabilities about what may happen in the future. Future is uncertain because in the intimacy of nature the processes are essentially not predictable. Climate change added a vast array of consequences directly affecting the management of water resources. The world has been confronted in the last years with both acute excesses and deficits of water. And this trend is continuing implacably.

The stability of nature – as predicted by classical models – is possible as long as the influence of small oscillations of the natural parameters is indeed negligible. For instance recent studies concerning the airplane crash due to icing of the wings or engine in the high atmosphere show that the so-called *crystal icing* – as a natural phenomenon – is unpredictable [15].

As Edward Lorenz put it in 1972, within a complex system, as it is the earth's atmosphere, even the tiniest approximation (of the initial conditions) can drastically affect the result [16]. This is what makes the weather so hard to predict. Its eventual state is highly dependent on the initial measurement - and one can never have a perfect initial measurement. Turbulent phenomena in the atmosphere are mathematically simulated using, for instance, the Reynolds-Averaged Navier Stokes equations but they do not have an exact analytical solution. The state of the fluid at every moment is characterized by a very large number of variables. Even if all of them will be defined and measured, the resulting model would be a mathematical system impossible to resolve.

The management of water resources and namely the hydro generation is strongly affected by extreme drought [17, 18]. The analysis of very low river flows used in the calculation of available hydro energy can be overturned by events with very low occurrence frequency. Estimates of the probability of occurrence of low-flow events are normally derived from historical records using the frequency analysis [19].

Therefore, such an analysis could be used as an objective tool to conclude on the unpredictability of a drought event and its impact on the hydro generation.

It means that the power supplier will be excused from its obligations during such a hydrological force majeure event on the grounds that unforeseeable (unpredictable) climatic conditions including any periods of drought disrupt the operation of any hydropower facility. Unpredictable means climatic conditions reasonably expected to occur less frequently than once every 15 years [20].

The objectively determined probabilities cannot dictate a particular course of action of the hydropower company's decision but they can provide at least a framework within which decisions on hydro generation deficit can be made.

3. Statistical Flow Analysis

The water management for the energy production is primarily targeted at maximum yield from the available river flow. It follows that in all operational planning the basic parameters are designed at the multiannual average level (statistically established with a reasonable accuracy) and certainly not at the low level of the river flow. In Romania's situation the water storage in artificial reservoirs covers maximum 2/3 of the water resources of the entire hydro energy system. Even this optimal solution is not applicable during extreme drought events when the inflow river water cannot replenish the reservoir in order to keep the level above the minimum (warning) line. In such a case the amount of water transformed in energy should not be larger – not even for a single day – than the amount being stored in the reservoir. The available amount of water is the key variable in the hydraulic system management. This means that the analysis of the water constraints constitutes the main task. As it happens, the maximum demand of electricity coincides with the minimum available resources of water. Conversely, the producer of hydro energy is usually calculating the amount of energy to be delivered on the market based on the multiannual average natural flow. From this, one can see that when a severe drought occurs the producer could be unable to deliver - partially or totally - the PPA.

In Romania, the power generating companies are organized in relation to the energy resources. From the total electricity production in the last four years, 25-30% is supplied from water resources (approx. 2500 MW). The hydro energy producer has a total installed power of 6300 MW, which makes it the biggest energy producer in Romania.

In an average hydrologic year, its energy production is approximately 17.4 TWh. During the years 2011 and 2012 which include the periods subjected to in the present analysis (October 2011 – April 2012 and August - November 2012), the annual energy production was considerably reduced, up to 14.4 TWh and 11.9 TWh respectively, due to severe droughts.

On the average, half of the hydropower energy production is generated from the Danube River, in Iron Gates I and II hydro power plants (HPP) – the only power production units built on this river. The rest is generated from the interior rivers, which are spread on the entire territory of the country. The interior rivers are all discharging their flow in the Danube River downstream the two above-mentioned hydropower plants, thus their hydro potential is not used by the Danube HPPs.

It is necessary to highlight the legal context in which the Iron Gates I and II power plants are allowed to use the Danube flow.

The natural Danube water flow is equally split between Romania and Serbia. In the meantime, no water storage is permitted whatsoever. This regulation is set by the Danube International Commission, which has an imperative role in assessing the river's navigability. Additional storage or discharge of the inflows, naturally leads to an increase / lowering of Danube river level upstream or downstream the power plants. Due to this reason, Iron Gates I and II power plants are imperatively using (strictly) the Danube inflow.

In the present study the natural flows of the Danube and other seven major interior rivers in Romania (Argeş, Bistrița, Olt, Lotru, Sebeş, Someş, Siret and Raul Mare) are analyzed. The aforementioned selection reflects fairly a general picture of the flow distribution on the entire territory of the country (Figure 1 and Table 1) in order to evaluate the impact of extreme drought phenomena.

The aim is to establish the unpredictability of extreme drought occurrence, largely spread on Romanian territory during extended periods. The analysis is focused on two time periods between 2011 and 2012: October 2011 –April 2012 (7 months) and August – November 2012 (4 months). In the case of the Danube, the available historical records of flow rates cover 94 years, registered upstream of the Iron Gates I power plant between 1921 and 1960 as average monthly data and between 1961 and 2014 as daily data [21]. In the case of the interior rivers historical flow records of 50-70 years, starting with 1960, are available.

The analysis tracks the hydrological event previously defined: minimum flow rates due to the extreme hydrological drought. This drastic restriction of the available flow for the electrical energy production is the situation that the hydropower company faced during the above mentioned periods in 2011 and 2012, and that need to be grounded as *force majeure* case.

3.1. The Analysis of the Flow Rates During the October 2011 –April 2012 Period (X-IV Calendar Months) – First Analyzed Period

In order to determine the threshold value that indicates the severe drought situations, the occurrence probability curve was computed using the historical records of flows. The recorded values were arranged in ascending order and then the occurrence probability was calculated using the Beard equation for each flow rate value [22]:

$$p\,[\%] = (i - 0.31)/(n + 0.38)\cdot 100, \qquad (1)$$

where i is the position in the arranged data set and n is the number of data in the set.

In the following the data are standardized non-dimensionally, denominated by the maximum recorded average flow of the analyzed period (Q/Q_{max}).

Table 1. *Installed power and average energy production on the Romanian rivers hereby analyzed.*

Symbol	River	Installed power [MW]	Average energy [TWh/year]
	Danube	1415	5.2
	Olt	880	2.5
	Argeș	364	1.5
	Raul Mare	350	0.63
	Sebeș	300	0.6
	Lotru	643	1.25
	Someș	300	0.5
	Siret	200	0.23
	Bistrita	454	1.37
	Total	4906	13.78

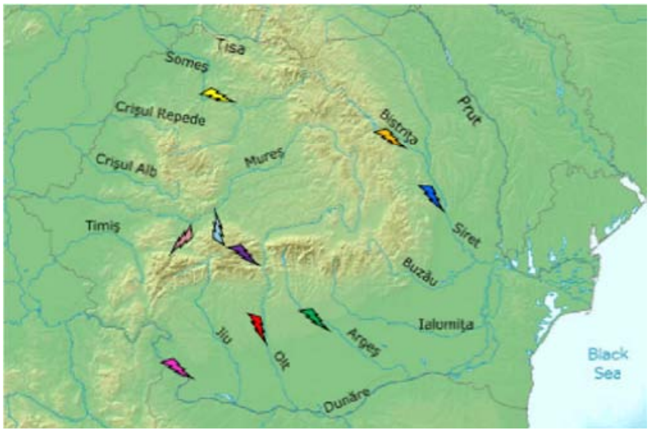


Figure 1. *Map of the main Romanian rivers hereby analyzed.*

The minimum flow of the Danube river usually occurs in three periods within the year: at the beginning of the spring, in autumn and in winter. The minimum flow variability upstream the Iron Gates I and II power plants is low compared to the maximum flow due to the small contribution of the affluent rivers during the low season. The extreme situations as shown by the multi-monthly minimum flow values, included in all the three above mentioned periods, are events with a very low occurrence frequency.

The Danube River standardized average annual flow occurrence probabilities during 1921 – 2014 periods are presented in Figure 2. The threshold set at 10% occurrence probability resulted in a standardized flow rate value of 0.53 on the probability curve.

With the same procedure, the threshold set at 10% occurrence probability for the first analyzed period (October 2011 –April 2012, X-IV months), resulted in a standardized flow value of 0.5 on the probability curve (Figure 3). It follows that flows lower than this threshold are recorded as indicated: 1924-1925, 1942-1943, 1948-1949, 1953-1954, 1971-1972 and 2011-2012 (Table 2 and Figure 4).

The drought in 2011-2012 is the fifth most severe one recorded in 94 years, with an occurrence probability of 6% (Figure 3). The worst droughts occurred in 1953-1954 and 1971-1972 (Figure 4).

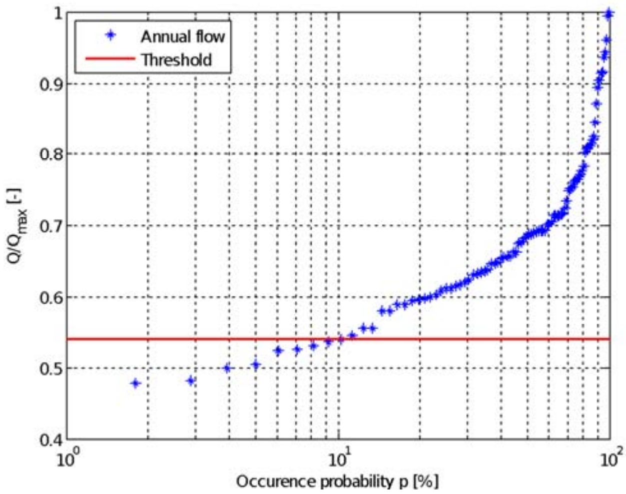


Figure 2. *Danube River standardized average annual flow occurrence probability curve for the historical records during 1921 – 2014 period.*

Table 2. *Danube River standardized average monthly flow values in the X-IV period.*

Period /Month	$Q_{average}/Q_{max}$ [-]							
	X	XI	XII	I	II	III	IV	X-IV
1924-1925	0.44	0.36	0.36	0.26	0.33	0.61	0.54	0.41
1942-1943	0.30	0.41	0.36	0.28	0.54	0.40	0.52	0.40
1948-1949	0.30	0.46	0.29	0.34	0.26	0.39	0.72	0.40
1953-1954	0.30	0.31	0.22	0.18	0.26	0.75	0.68	0.38
1971-1972	0.28	0.25	0.40	0.30	0.37	0.47	0.57	0.38
2011-2012	0.36	0.29	0.34	0.46	0.39	0.67	0.74	0.46

The unpredictability of the drought event is well understood from the data of the occurrence frequency computed on the entire 1921-2014 sample interval (Figure 2).

In situations like this the forecast concerning the electrical energy production at Iron Gates I and II power plants is severely affected. For example, the 0.46 standardized value (Figure 3 and Table 2) is normally outside the usual statistical forecast of the hydro generation.

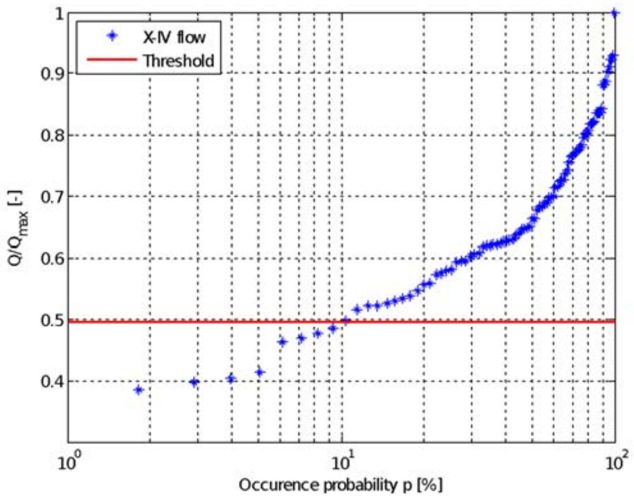


Figure 3. *Danube River standardized average flow occurrence probability curve for the X – IV period based on 1921 – 2014 historical record.*

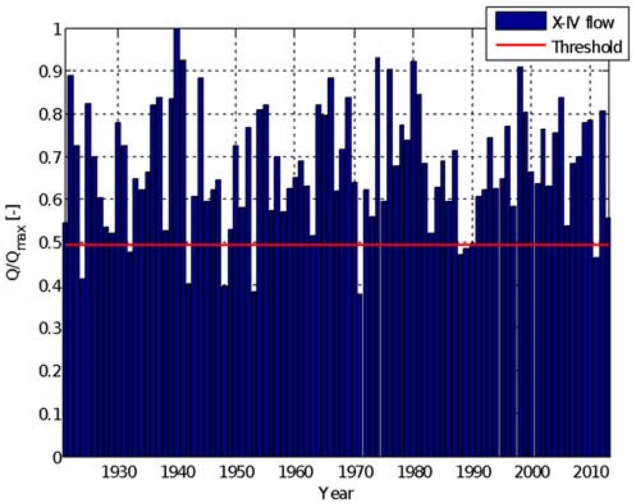


Figure 4. *Danube River standardized average flow during the X – IV period.*

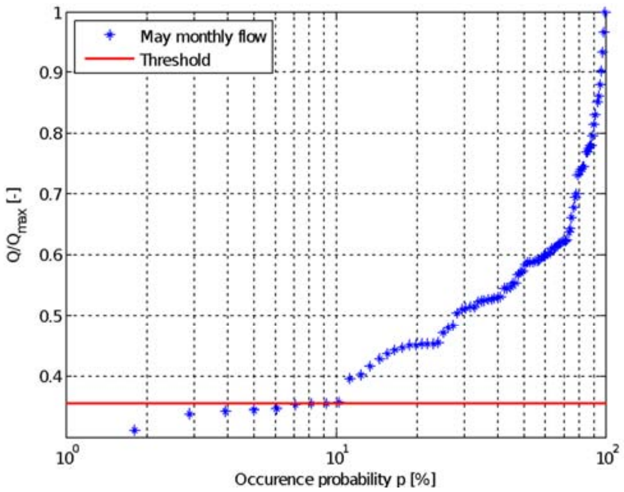


Figure 5. *Danube River standardized average monthly flow occurrence probability curve in May, based on 1921 – 2014 historical record.*

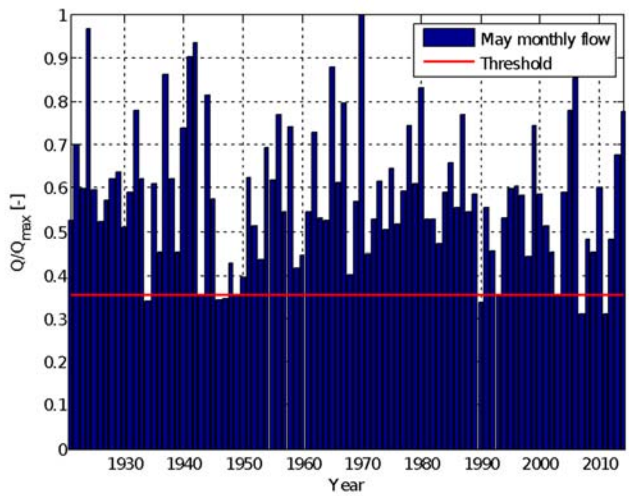


Figure 6. *Danube River standardized average monthly flow during May, from 1921 to 2014.*

This 0.46 value occurred only five times in 94 years, so the recurrence period is in this case approximately once every 20 years. This situation is more severe than the one of 15 years indicated by [20]. Moreover, since after the last drought event in 1971-1972 no other one of such amplitude was recorded until 2011. One can conclude that this is specifically an unpredictability situation. The unpredictability is well emphasized by the recorded May flows during the 94 recorded years. Normally, the spring floods occur in May. Or, what one can see in Figures 5 and 6 is the fact that by far the flow rate in May 2011 is at extremely low level. It is especially significant for this drought event that the recorded value in May 2011 is never encountered elsewhere in the entire period of 94 years.

It is worth mentioning that a significant number of flow measurements on the Danube started in 1840 with the purpose of flood recording, especially in May. One can safely extend the previous conclusion to 175 years (1840-2014). This fact speaks by itself about the impossibility to insure the contracted amount of power production, and to claim the *force majeure* case clause.

In the meantime, during the October 2011 – March 2012 period, a severe drought was recorded all around the territory of Romania. The flow rates were 40-60% lower than the average multiannual flows, which are taken into account when forecasting the energy production during an average hydrologic year.

The interior rivers chosen for this analysis have an important contribution to the electrical energy production. The Argeş, Bistriţa, Lotru, Sebeş, Someş and Raul Mare rivers have upper storage reservoirs ensuring annual and multi annual water volume redistribution followed downstream by a series of run of river hydropower plants. The Olt and Siret rivers have only a run of river hydropower plants, so they do not have storage and therefore produce only the instant available energy.

In the case of the Bistrita river which is situated in the eastern part of Romania the 10% threshold was determined at 0.4 and occurred four times (Figure 7) in 47 years (1967-2013). The recorded standardized average flow during the first litigation period (X-IV calendar months) on Bistriţa

River was 0.38, situated below the threshold.

The occurrence period of this event in 2011-2012 is about once in every 25 years, showing a very low occurrence frequency. Only three more such events occurred, in 1983-1984, 1986-1987 and 1989-1990, the occurrence probability being about once in every 50 years (Table 3, Figures 7 and 8).

Table 3. *Bistrița River monthly standardized average flow values for October- April period, during 1967 – 2013 interval.*

Period/Month	$Q_{average}/Q_{max}$ [-]							
	X	XI	XII	I	II	III	IV	X-IV
1983-1984	0.29	0.22	0.18	0.18	0.16	0.25	1.02	0.33
1986-1987	0.25	0.23	0.11	0.12	0.17	0.22	1.08	0.31
1990-1991	0.31	0.75	0.37	0.29	0.21	0.35	0.46	0.39
2011-2012	0.29	0.22	0.23	0.19	0.15	0.44	1.21	0.39

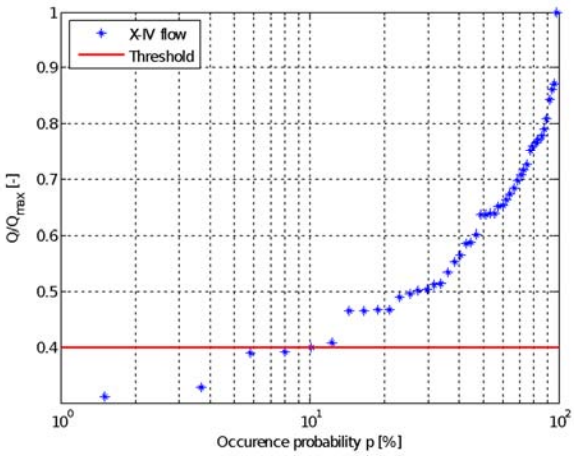


Figure 7. *Bistrita River standardized average flow occurrence probability curve for X-IV period, during 1967 – 2013 interval.*

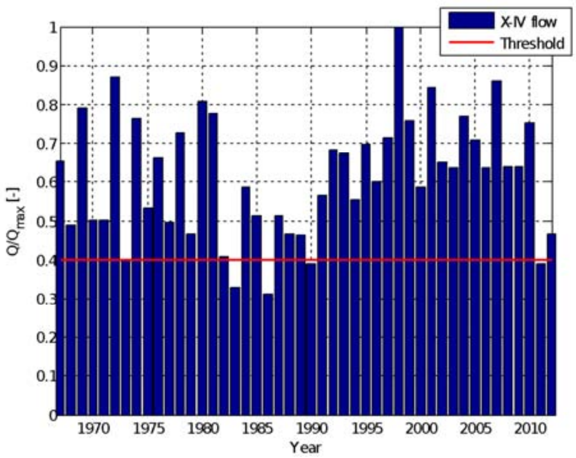


Figure 8. *Bistrita River standardized average flow for X-IV period, during 1967 – 2013 intervals.*

In the western part of Romania on the Someș River, the standardized value corresponding to the 10% threshold is determined at 0.52 (Figures 9 and 10). Even if the three severe drought periods occurred similarly to the Bistrita River, no other extreme drought took place up to the end of the analyzed period. It is obvious therefore there is no predictability in the drought event occurrence.

In the central and southern part of the country, the situation of the Sebeș, Argeș, Lotru and Olt rivers is similar to those presented above. The average monthly flows in X-VI calendar months of the 2011-2012 interval are considerably lower than the multiannual average of the entire historical record (1974-2014, Figures 11, a-d).

A relevant feature appears when considering the 2000-2012 period. The standardized average flow of the X-IV calendar months (October-April) is compared to the average annual flow every year of the 2000-2012 period (Figures 12, a-f). It shows that the X-IV period is constantly lower than the annual average. The case of the 2011-2012 periods is accentuated by the fact that the average annual flow is relatively low in itself.

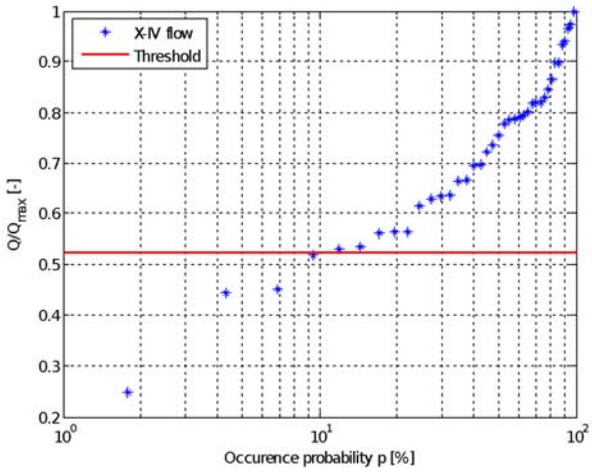


Figure 9. *Someș River standardized average flow occurrence probability curve for X – IV period, during 1974-2013 interval.*

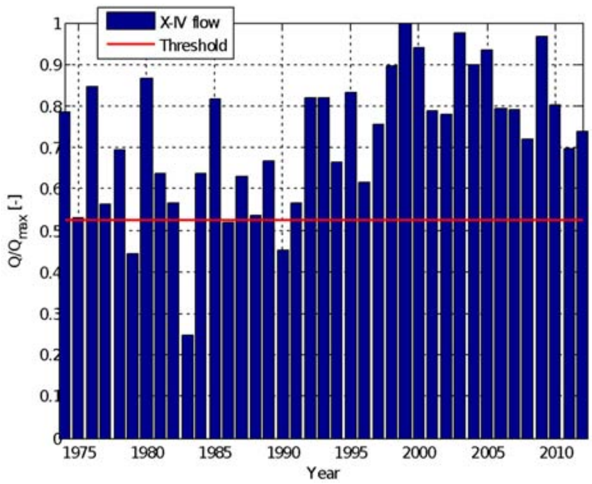


Figure 10. *Someș River standardized average annual flow for X – IV period, during 1974 to 2013 interval.*

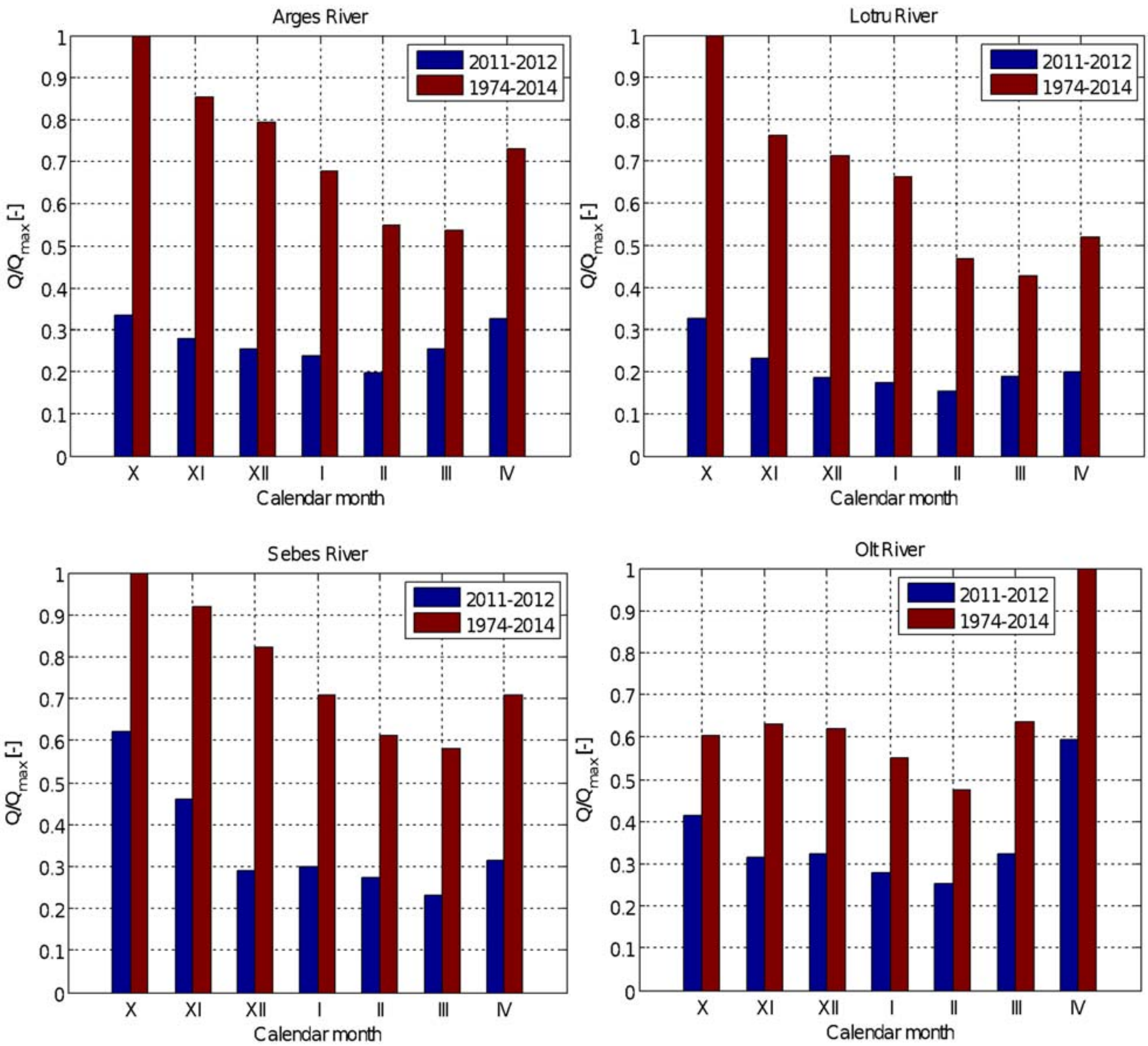
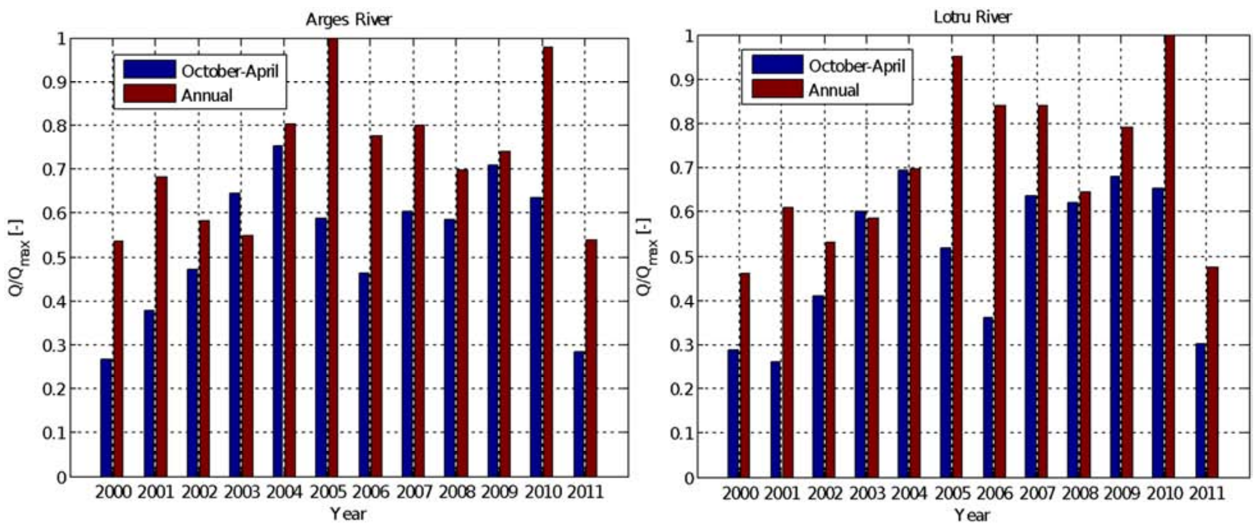


Figure 11. *The standardized average monthly flows 2011-2012 and 1974-2014 periods: a) Argeș; b) Lotru; c) Sebeș; d) Olt.*



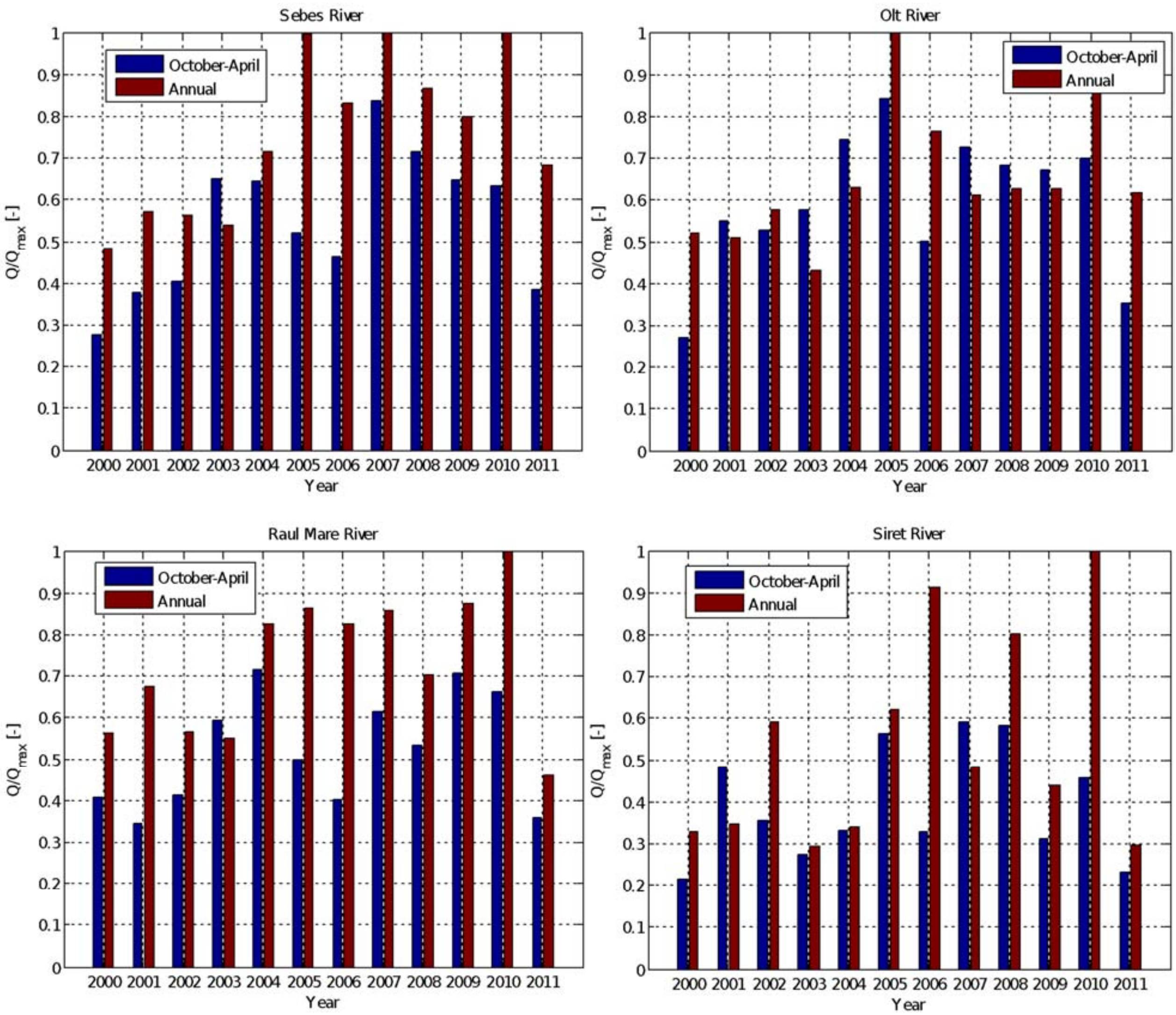


Figure 12. *The standardized average flow of the interior rivers in the X-IV interval and the average annual flow during 2000-2012 period: a) Argeş; b) Lotru; c) Sebeş; d) Olt; e) Raul Mare; f) Siret.*

The strong hydrological variability in such a short period of 13 years is indicated by the fact that in 2003 the X-IV average flow is higher than the annual flow.

This variability can safely be related to the unpredictability of droughts (or floods) events.

During the first analyzed period (October –April) the hydropower company – in order to fulfil the PPA – generated an amount of energy considerably larger than the available hydro energy of the instant inflows. Previously, the production of energy during September 2011 using flow rates higher than the inflows imposed the renewal of the water storage in April 2012, when the inflows increased significantly. As a result in April 2012 the company had not been in a position to use the inflows entirely. In spite of these constraints in April 2012 the company was able to deliver 90% of the obligations under the PPA.

The hydrological picture of the October 2011 - April 2012 period shows that the company was confronted with an event of extreme drought. Such a low occurrence frequency of the flow could not have been taken into consideration under any foreseeable condition when the PPAs were concluded.

3.2. The Analysis of the Flow Rates During the August – November 2012 Period (VIII-XI Calendar Months) – Second Analyzed Period

The overall picture of August 2012 shows the constraints under which the company had to deliver the energy according to the PPA during the second analyzed period. Obviously, the critical situation is accentuated by the previous period, which ended in April the same year.

The August historical flow records of the Danube (1921-2014) establish the threshold at the 10% occurrence frequency (once every 10 years) at 0.25 based on the maximum recorded flow (Figures 13 and 14). As a result, 8 times in 94 years, the flow rates have an exceptional character of accentuated drought.

The daily flows during August 2012 on the Danube River show a continuously sharp decreasing phenomenon. It starts with 0.4 standardized flow and downs at 0.2 after only 26 days. Simultaneously, the flow rates on the interior rivers attain extremely low values, similar to the first litigation period. This phenomenon forces the company to re-evaluate the hydro generation capacity for the next months, in which usually the flow continues to decrease and to trigger again the *force majeure* clause.

The analysis of the monthly flows recorded in 2012 show in every case values 10-30% lower than the multiannual monthly flows over the historical record (Figure 15). This highlighted the unicity of the hydrological events for the entire 2012 year and therefore the unpredictability feature.

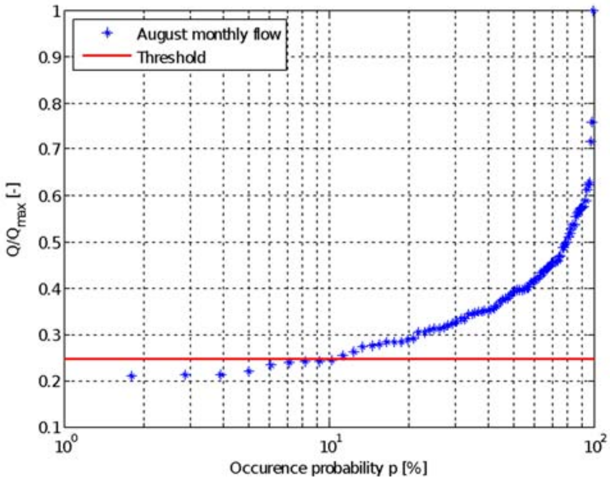


Figure 13. *Danube River standardized average monthly flow occurrence probability curve in August, from 1921 to 2014.*

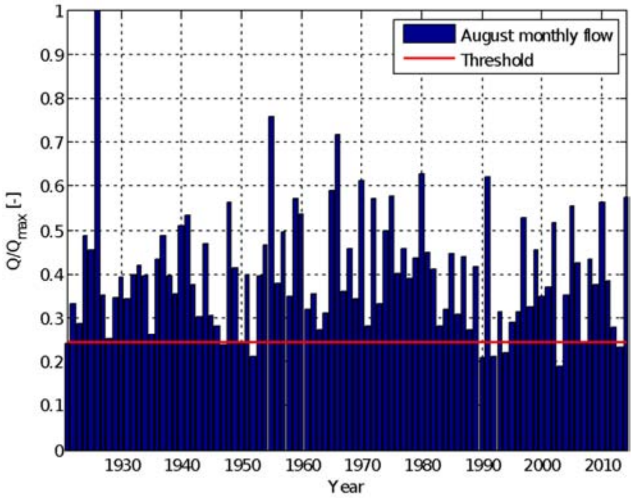


Figure 14. *Danube River standardized average monthly flow in August, from 1921 to 2014.*

The Bistrița River has the highest flow rate among the interior rivers of Romania with one of the largest active storage reservoirs in Europe (1·109 m^3). The 2012 extreme drought event occurred in the August-November period which is clearly indicated by the standardized average flow below 0.25 threshold value (Figures 16 and 17). During the historical record such a situation occurred only in 1987 and 1994.

This critical hydrological moment is accentuated by the fact that previously, in 2011, during August-December there was a 25-30% deficit with respect to the average flow. As a consequence the hydropower company didn't have any chance to restore the storage level in the reservoir in order to compensate for the 2012 situation described above.

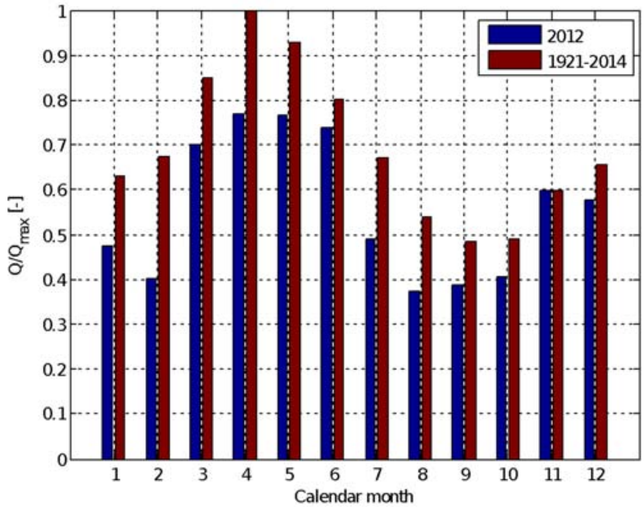


Figure 15. *Danube River standardized monthly flow.*

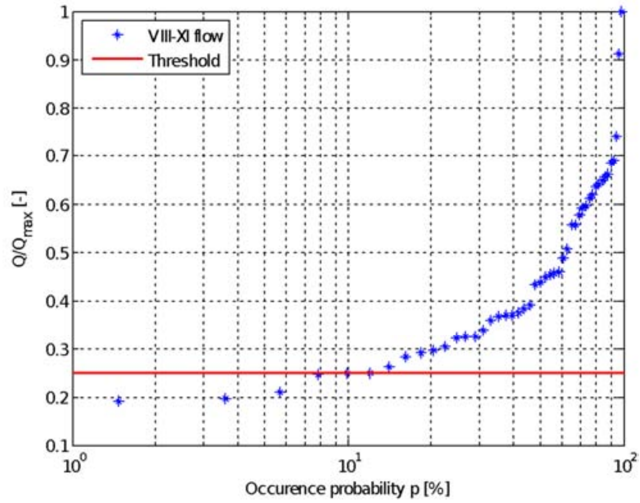


Figure 16. *Bistrita River standardized average flow occurrence probability curve in August-November period, from 1967 to 2013.*

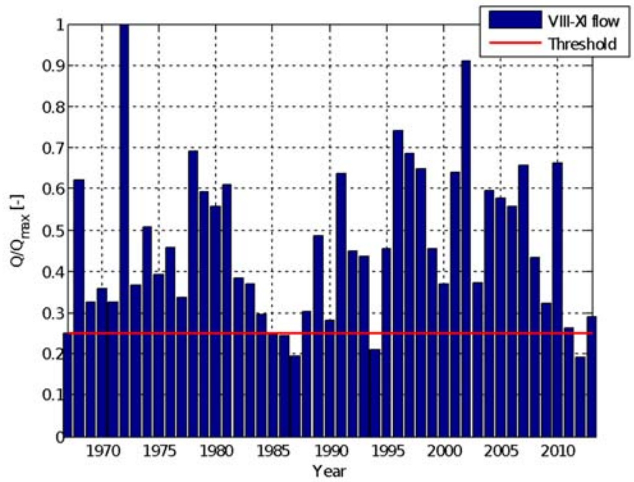


Figure 17. *Bistrita River standardized average flow in August-November period, from 1967 to 2013.*

The analysis of the second period on the interior rivers shows that in the last 13 years (2000-2012), the year 2012 is the one with the lowest flow rates (Figure 18, a-f). As a rule, the recorded flows in the August – November period are close and in some cases higher than the annual flows. On the contrary, in 2012 the August – November flow is half the annual value, which shows both the severity of the drought and the same unpredictability feature of the hydrological event.

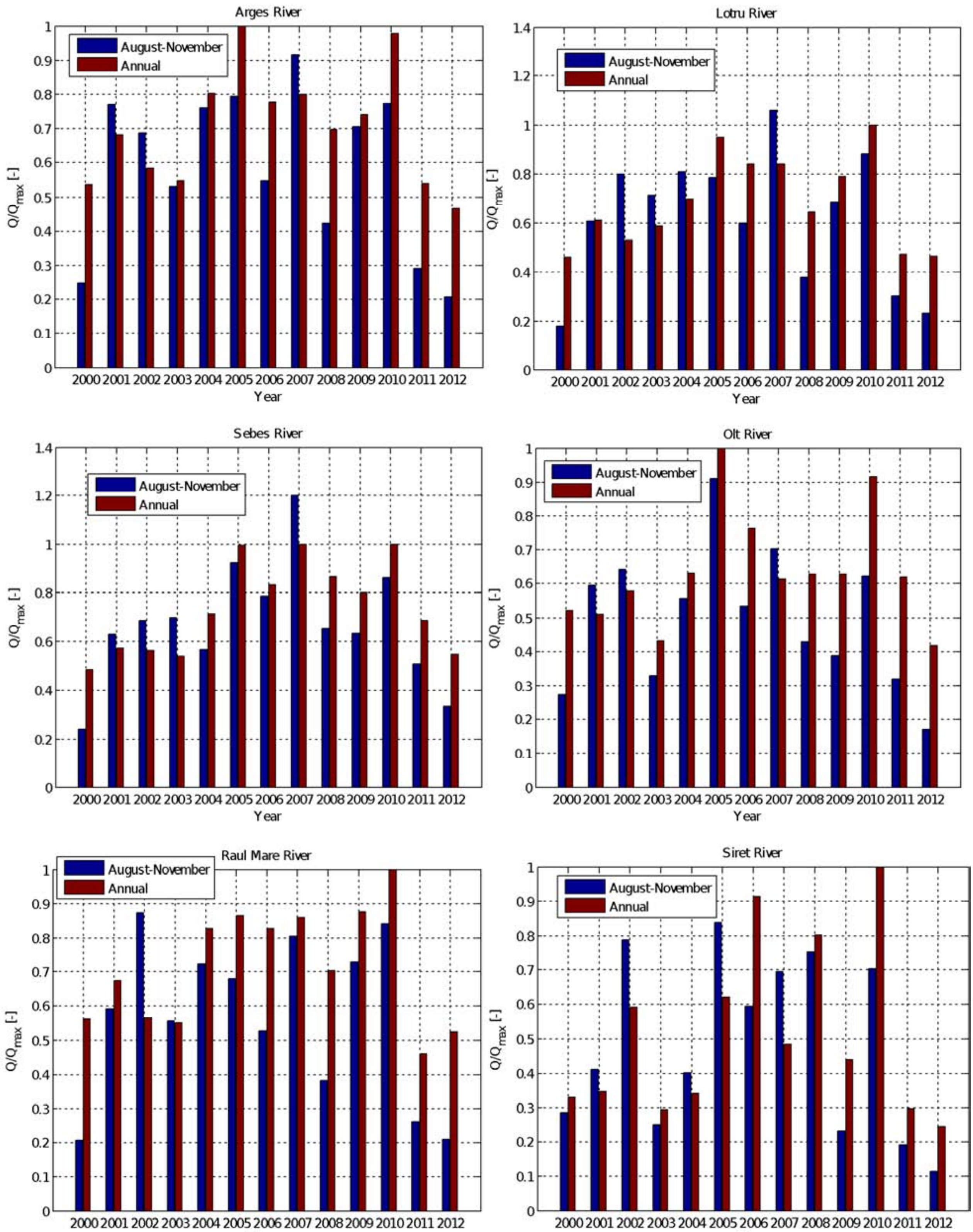


Figure 18. *The standardized average flow of the interior rivers in the VIII-XI interval and the average annual flow during 2000-2012 period: a) Argeș; b) Lotru; c) Sebeș; d) Olt; e) Raul Mare; f) Siret.*

Obviously, the result was a strong deficit of the available water resource for energy production.

This analysis reveals an accentuated hydrological drought event, characterized by low and very low occurrence frequency spread within the entire Carpathian Basin of Romania and not only [7, 23]. This situation imposes a drastic reduction in the production of hydroelectric power. The drought recorded in August – November 2012 has to be included in the category of the events for which the forecast is not useful when planning the hydro energy production. The unpredictability character of the event is determined by the statistical analysis of hydrological data, and definitively leads to the confirmation of the *force majeure* case claimed by the producer.

One more argument is presented in Figures 19-22 in favor of considering the two analyzed periods as extreme hydrological drought events. Using more recent flow data recorded during 2012 and 2017, the standardized average flow in October-April period together with the threshold value determined for that period are presented for Danube River in Figure 19 and for Someș River in Figure 20.

In Figure 21 are presented the Danube River standardized average flow in May, from 2012 to 2017, together with the corresponding threshold, and in Figure 22 the Danube River standardized average flow in August, from 2012 to 2017, together with the corresponding threshold. In all figures it can be seen that the recorded flow data are above the corresponding threshold values, confirming that values below the threshold are rare hydrological drought events.

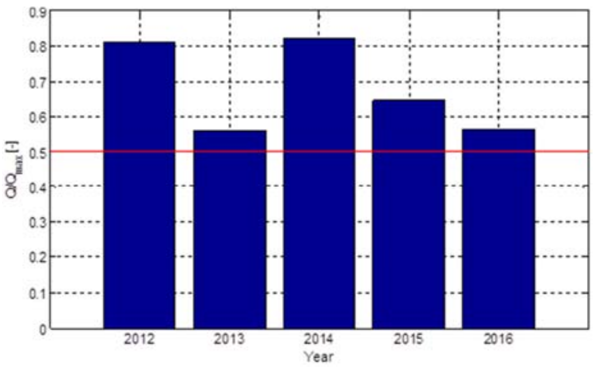


Figure 19. *Danube River standardized average flow in October-April period, from 2012 to 2017.*

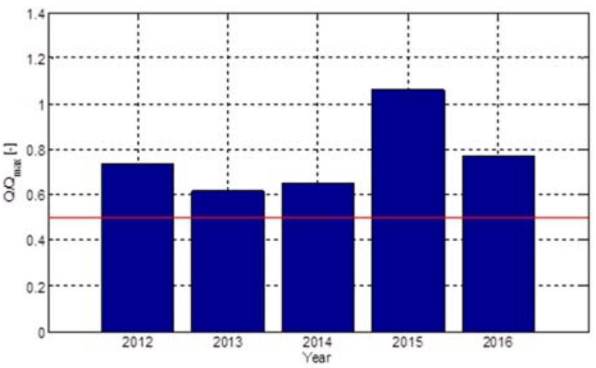


Figure 20. *Someș River standardized average flow in October-April period, from 2012 to 2017.*

4. Conclusions

In the presented hydrological study it was grounded that the two considered periods of time- October 2011- April 2012 and August –November 2012- occurred under extreme strain conditions due to a hydrological drought event with very low occurrence frequency. Such events are not predictable and could not be, by any means, taken into consideration for the PPA between the producer of hydro energy and the buyer of electricity. As such, the described hydrological events fall under the incidence of the *force majeure* case, written as a clause of the PPA.

The very rare situation of a monthly or multi monthly period of successive minimal flow with very low occurrence frequency is implied both by the producer and the buyer when the clause of the *force majeure* case is mentioned in the PPA.

The severity of the drought was determined based on statistical analysis, by means of the threshold method. In order to determine the threshold value, the occurrence probability curve was computed using the historical records of the Danube, Argeș, Bistrița, Olt, Lotru, Sebeș, Someș, Siret and Raul Mare river flows.

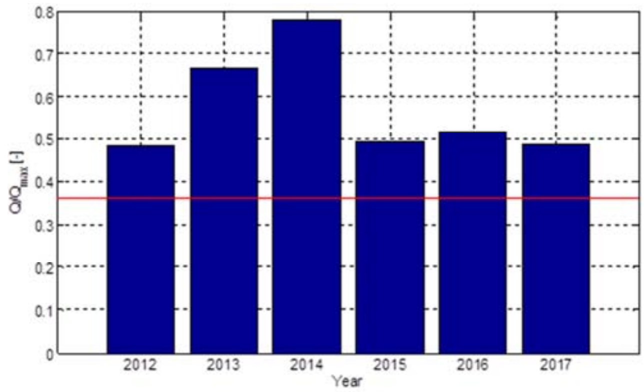


Figure 21. *Danube River standardized average flow in May, from 2012 to 2017.*

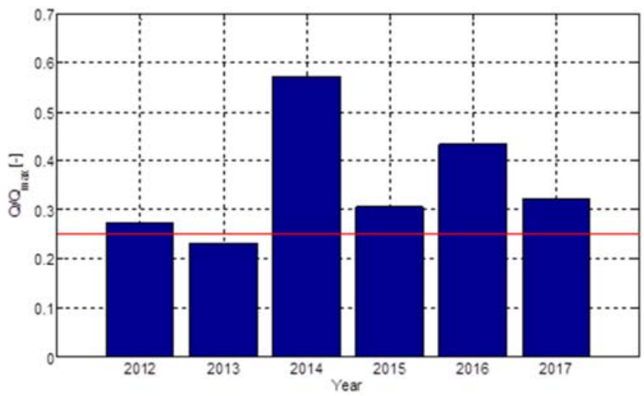


Figure 22. *Danube River standardized average flow in August, from 2012 to 2017.*

The threshold was set at 10% occurrence probability, and revealed the very rare situation of monthly or multi monthly period of successive minimal flow with very low occurrence frequency, for the two aforementioned periods.

The concurrence of the average flow with minimum values on the Danube and on all the interior rivers represents an event with low occurrence frequency and unpredictable character. The only solution in this case was to strictly limit the power generation to the available inflow, in order to avoid further decrease of the level in storage reservoirs down to dangerous and illegal values.

The *force majeure* case from the hydrological point of view should not and cannot be considered as a reference in the calculation of the flow rates normally used for the planning of the hydro generation. Indeed, such very low flow rates references would entail great losses of energy both for the producer and the buyer who would not benefit from the non-used hydro potential.

Nevertheless, the implications of the current climate changes are compelling and probably strengthen the importance of the *force majeure* case within water resources management.

5. Recommendations

1. Although we have not established a robust correlation between the weather parameters and the Danube River flow, on one hand, and the occurrence of the extreme droughts events, on the other hand (it was not the purpose of our work) we know that both acute single-year and prolonged multi-year droughts occur naturally due to variations in precipitations and other factors. Moreover, *"as a result of a warming climate, the global water cycle becomes more intensified and as a result wet regions are getting wetter and dry regions are getting drier"* [24].

A significant situation in our analysis regarding the hydrological uncertainty is revealed by the extremely low value of the average flow of the Danube recorded in May 2011. As a general feature, the historical data of the Danube flow indicate that May is the month of high and highest flows and frequent flooding. By any means we cannot expect in May a flow which corresponds to a dry season. When one thinks about the reliance of probability tools in computational hydrology, we accept that there are undecidable complex principles. As Robert Jackson put it: *"At any rate, undecidability is very much the norm and no amount of added computational power will allow computation to fully predict the unpredictable"* [25]. Droughts are a combination of factors that are much more difficult to manage. Recent weather extremes show that long standing records are not anymore valid. *"Events that break previous local records by large margins are hereafter defined as record-shattering extremes and their intensity quantified as the standardized anomaly by which the previous record is exceeded"* [25]. *"These record-shattering extremes, nearly impossible in the absence of warming, are likely to occur in the coming decades"* [25].

As indicated in our study unpredictability can trigger very rare extremes events, like heatwaves and droughts. Their probability of occurrence could be higher than historical local records suggest. As a consequence scientific research should not focus only on moderate extremes which occur several times a year or every few years but also on the possibility of the record-shattering extremes.

We recommend that along with the search for a hydrological pattern derived from the study of recorded drought data to search for critical points which exists as a reflection of unpredictability.

2. When we focus solely on calculating probabilities and developing our mathematical tools in order to extract a maximum of information from raw data of natural events we are ignoring societal contexts and histories that may benefit some groups of businesses over others. It is time to adopt an energy equity principle as a goal of emerging scientific evidence and/or theories.

We recommend including in the legal contracts (like PPAs) between the producers of hydro energy and the final providers of electricity well-grounded provisions related to the possible impact of climate change.

3. Extreme drought is primarily the result of a long period (over at least a year) of very dry season due to sunny hot days or heat waves.

We recommend, as a possible means of mitigating the drastic reduction of hydro energy production during such season, to install solar panel farms over the water surface of the dam lakes. It could be also beneficial to the reduction of water evaporation of those surfaces.

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