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Flow Control By Water Reservoir In Conditions Of Torrential Floods

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FLOW CONTROL BY WATER RESERVOIR IN CONDITIONS OF TORRENTIAL FLOODS

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ABSTRACT

Majority of water reservoirs are located in conditions of torrential floods. Difficulty of flow control by such water reservoirs consists in next: different requirements can take place in same within-year intervals during different years. Irrigation requests the big water storage in reservoir, but during the same time a low water level of the reservoir is more preferred for safe drafts during possible catastrophic flood. Accordingly, main aim of the research is search of profitable and safe rules of flow control by water reservoir. The aim has required of solving of next problems: to choose a duration of within-year interval for simulative models of reservoir operation; to develop stochastic model of the runoff to water reservoir; to develop the logical conditions for flow control by water reservoir with help of short-term forecasting of the runoff; to check the developed flow control rules with help of simulation of reservoir operation. Krasnodar water reservoir has been chosen for research. That is located in the southern part of the Russia on the Cuban River. A big part of the river basin is occupied by mountain territory and therefore a time of concentration of maximum water discharges is small. The river can have dangerous rain-ice floods during summer period of biggest water demand for rice irrigation systems.

Key words: stochastic flood modeling, water reservoir, Cuban River, Russia

Base of approach

Two stochastic models of the river runoff have been developed for decision of the problem. The first runoff model was made with help of the simple Marcov chain respect to within-year intervals [1]. The model gives a possibility to develop the logical conditions for flow control by water reservoir. Other model of the river runoff was developed according to Monte Carlo methods for simulation of the artificial long time series of runoff [2,3,4]. The model gives a possibility to check the flood control rules by water reservoir respecting of probability of dangerous situations.

Equation of water reservoir balance for every within-year interval (t) was next:

$$Vend = Vst + W - U - S \qquad \text{Eq. (1)}$$

Where: Vst and Vend – water reservoir storages at the start and end of internal within-year interval accordingly; W – river flow volume (runoff) come in water reservoir; U –water consumption volume including water losses from water reservoir; S – water drafts without use for consumers.

Precipitation on the surface of water reservoir did not take in attention because the precipitation value is small in comparison with other components of water balance equation for flood period.

It is necessary to notice: in equation (1) – the means W and Vst are probabilistic values; the mean U is real value, which depends on water consumption plan respecting of every within-year interval (t); the means S and Vend are probabilistic values since they are depending on values W and Vst.

Duration of the within-year intervals (5 days - pentad) for models of runoff and of water reservoir operation was confirmed by analysis of several criterions: possible duration of catastrophic precipitation, concentration time of maximum runoff, possibility to obtain accurate flow forecasting and accurate stochastic parameters for the within-year interval.

Model description

So, a discreteness of model has been chosen on the base of complex analysis. At first, joint analysis of storm rainfalls together with consequent flood hydrographs [5,6,7.] was made respect to near mouth of the Cuban river (city Primorsk-Ahtarsk) and in the upper part of the river basin (city Teberda). It was established that catastrophic floods have place in the cases when precipitations exceed 60 mm during storm rain and duration of such rain is not less two days. Total concentration time of maximum flood discharge to the water reservoir is not less 4 days. So we have possibility to obtain the forecast earliness respecting of dangerous runoff values – five days (pentad).

The fluctuations of the river runoff during 5 days or 10 days can be significant, accordingly relations of maximum daily discharges to the average discharge defines the balance of model accuracy too. Calculations (on the base of observed discharges values during 32 years) have showed - the such average relations respecting of 5 day and 10 day were equal 1,19 and 1,32 accordingly [8]. Possible accuracy of measurement and definition of the water discharges during floods is approximately 20%. So, average discharge during 5 days saves the balance of accuracy.

The development of stochastic runoff model respect to pentad intervals requires of check of homogeneity for hydrological ranks. Accordingly the criterions of Student and Fisher were used for the check [8] on the base data observations for the 32 years. Practically for all pentad intervals were obtained results, under which zero-hypothesis of homogeneity of the water discharge averages and their dispersions can't be rejected. Exception was only for pentads 6.07-15.06, where there was not significant excess of critical means for significance level - 0,05.. However hypothesis of homogeneity was accepted.

Stochastic model of the runoff to the water reservoir have been developed on the base of Markov chains model respecting of within-year interval. The interval is equal of forecast earliness - five days (pentad). Preliminarily the main statistical parameters of the pentad runoff ranks (averages, variation and autocorrelation coefficients) and their standard errors were calculated. Percent share of standard errors of the average respecting of the own average (percentage error) was not more 10% in the all cases. Similarly, the percentage errors of the variation coefficients did not exceed 14% and of the autocorrelation coefficients – 10% [8]. So balance of accuracy respect to observation data was saved.

Stochastic model of runoff to the water reservoir (under type of Markov chain) is represented by totality of conditional probabilistic functions $P_{t,j}(W_{t,,j}(W_{t-1,j}))$ for every pentad –t (t – number of pentad of year: 1 ÷ 73). The runoff ($W_{t,,j}$) during every pentad (t) depends on conditional runoff ($W_{t-1,j}$) of the previous pentad (t-1); j – number of the conditional runoff value. Such model is based on hypothesis of same laws of probabilistic distributions for runoff values of temporary interval (t) and conditional values of previous interval (t-1). However statistic parameters have to calculate according to conditional moments.

Conditional averages of runoff volumes ($W^*_{t,j}$) are calculated:

$W^*_{t,j} = \hat{w}_t + R_{t/t-1} \times \sigma_t / \sigma_{t-1} \times (W^*_{t-1,j} - \hat{w}_{t-1})$, Eq. (2)

where:

$\hat{w}_t$ and $\hat{w}_{t-1}$ – averages of runoff volumes for intervals t and (t-1) accordingly;

σ_t and σ_{t-1} – deviations of runoff volumes for intervals t and (t-1) accordingly;

$R_{t/t-1}$ –correlative coefficient between runoff volumes of intervals t and (t-1) accordingly;

$W^*_{t-1,j}$ - conditional values of the runoff respecting of every pentad.

A total quantity of the conditions -j and consequent value of $W^*_{t-1,j}$ are fixed according to logic of the future model of the water operation by water reservoir, usually j=5÷10 - it is enough [1].

A second statistical parameter of conditional probabilistic functions – conditional variation coefficient ($Cv^*_{t/t-1}$) is calculated:

$Cv^*_{t/t-1} = (Cv_t \times \hat{w}_t / W^*_{t,j}) \times (1 - R^2_{t/t-1})^{1/2}$, Eq. (3)

where, aside from former indications: Cv_t – variation coefficient for the interval t.

Third statistical parameter - skew coefficient is connected with variation coefficient $Cs_{t/t-1} = K\, Cv_{t/t-1}$ for the all conditions j. Coefficient K was chosen on the preliminary definition of Cs by not standard method [9], which allows evaluate Cs enough accurately according to data observation during 32 years.

A complex of the conditional probabilistic functions of runoff for every pentad presents the probabilistic model of the runoff to Krasnodar water reservoir.

Totality of conditional probabilistic functions of water volumes of runoff to the water reservoir for the first July pentad is represented on fig.1 According to fig.1, for example: if runoff will be equal 950 million m^3 during last June pentad (previous within-year interval: *t-1*), then the forecasted probabilistic function of runoff for next pentad (*t*) will be represented by upper curve (1) of probability.

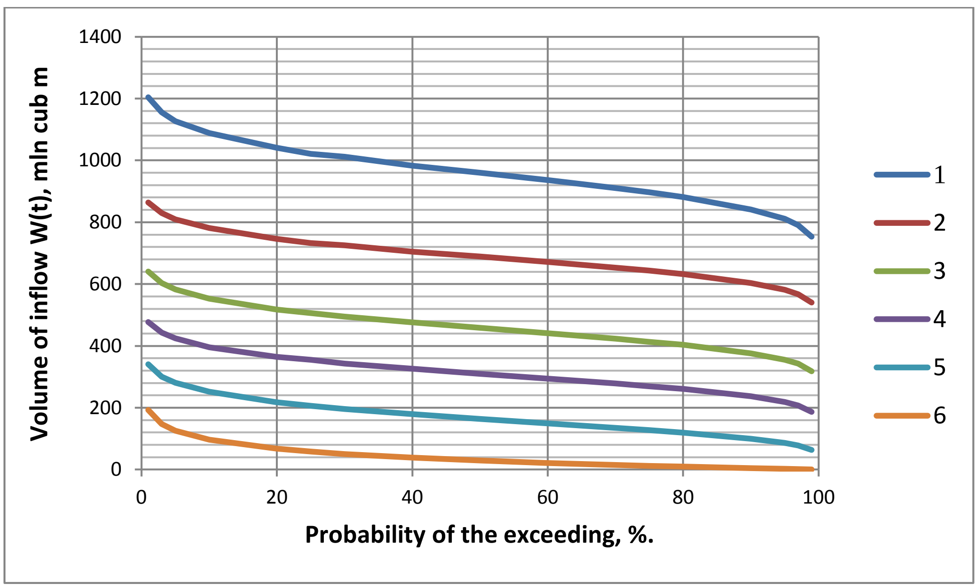

Fig 1. Conditional probabilistic functions of runoff for the first July pentad

Conditions:1)W_{t-1} *=950 million* m^3*; 2)*W_{t-1} *=690 million* m^3*; 3)*W_{t-1} *=475 million* m^3*; 4)*W_{t-1} *=300 million* m^3*; 5)*W_{t-1} *=200 million* m^3*; 6)*W_{t-1} *=80 million* m^3*.*

A time interval of the model is equal to earliness of the short-term forecast of runoff. So, the reliable short-term forecast of the runoff for the forthcoming pentad gives a possibility to value the runoff in the following pentad with the defined probability that gives the more possibilities for safe and profitable use of the water reservoir.

Analogically, there is possibility to obtain complex of conditional probabilistic functions for the water reservoir storages respecting of every pentad end in dependence on the initial storage to the pentad and on the conditional probabilistic runoff functions $P_{t,j}(W_{t,,j}(W_{t-1,j}))$. At first the probabilistic functions of water reservoir storages were obtained on the base of traditional rules of water reservoir operation [4].

Fig.2 contains 6 conditional probabilistic functions of water reservoir storages to end of the first July pentad (number *t*) in dependence on conditions (*k*-number of conditions respecting of initial storage) of the different initial storages to the start of pentad. The graph is represented within space of little probability (dangerous for flood control) respect to single condition of runoff ($W_{t-1,j=3}$) during previous pentad: *t-1*.

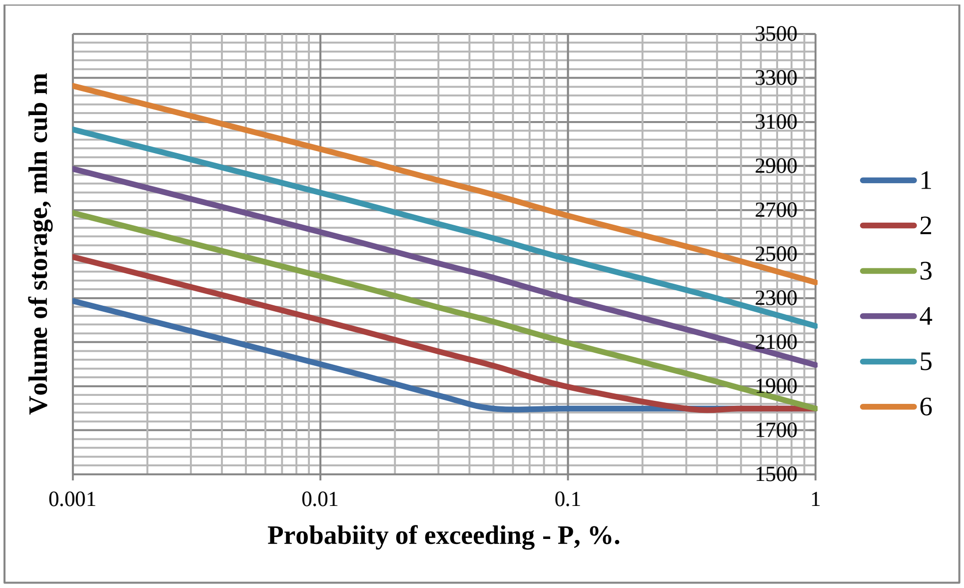

Fig. 2. Conditional probabilistic curves of water reservoir storages to the end of the first July pentad

Conditions (k):1)V_{t-1},=1000 million m^3(lower curve); 2) V_{t-1}=1200 million m^3; 3) Vt-1=1400million m^3 4) V_{t-1}=1600 million m^3; 5) V_{t-1}=1798 million m^3(full capacity); 6) V_{t-1}=1996 million m^3.

According to fig.2 there is possibility to define probability of the exceeding of flood capacity (total maximum capacity = 1996 million m3) during forthcoming pentad. We can see that before forthcoming pentad there is possibility to keep storage safely more of full capacity if runoff volume will not exceed of the value of 1% probability. So the added storage of water can decrease a risk of the water deficits in the case of the following of the dry period.

According to fig.1 and fig2, for example: if runoff would be 950 million m^3 during last June pentad, then probabilistic model of runoff for next pentad will be represented by upper probabilistic curve (fig.1) and we can evaluate a probability of dangerous flood situation and accordingly we have to do drafts beforehand nearly always (in dependence of start storage to the pentad - fig2) until safe storage for future pentad; if the runoff forecast (for last June pentad) will be equal 475 million m3, then there is possibility to make the drafts from water reservoir beforehand and to free some part of useful capacity of water reservoir for case of dangerous flood increase. However, we save possibility to accumulate the necessary part of useful capacity (until Normal level) during next pentad with the defined warranty in the case of the flood decrease. If the runoff will begin to exceed the normative discharges through spillway then a part of the freed useful capacity may be used for flood accumulation with aim - not allow inundation on the tail-water territory.

Verification

Such approach for controlling flood by water reservoir was tested according to conditions of catastrophic flood of 2002 year in comparison with traditional water reservoir operation when flood discharges are drafted after of storage exceeding upper full capacity (Normal level). Results are represented on fig.3. We can see that full storage of water reservoir took place before flood under traditional rules of water reservoir operation. According to the offered approach - the storage was beforehand decreased on the value in dependence on the forecasted pentad runoff and on conditional probabilistic curves of runoff for the next pentad and on conditional probabilistic curves of storages. Accordingly beforehand, the pentad drafts were increased until the allowed maximum value (518 mln cub m). In result – flood capacity was used less and drafts did not exceed of the allowed value during flood. Variants respect to controlling of normative flood (probability P=0,1%) are represented on fig.4. It is obviously that water reservoir storage is equal the allowed maximum capacity much longer according to traditional rules of the water reservoir operations.

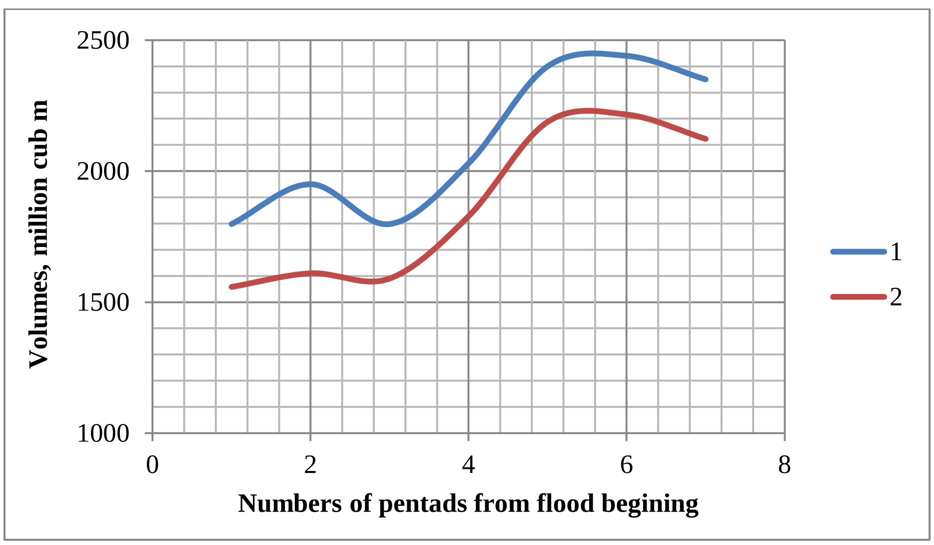

Fig. 3. Storages of the water reservoir operation during catastrophic flood (2002 year)
1 – real graph of storage of 2002 year; 2 – graph of storage under new approach to water reservoir operation.

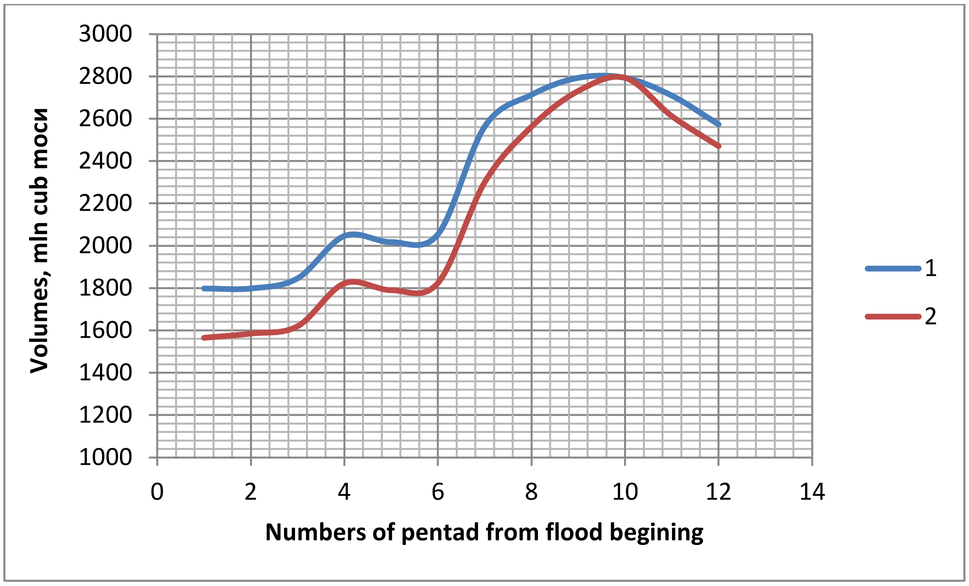

Fig. 4. Storages of the water reservoir operation during catastrophic flood (P=0,1%)
1 – according to traditional rules of the water reservoir operation; 2 – according to new rules

The new obtained flow control rules were checked with help of the simulative model of the water reservoir operation on the base of the modeled artificial long time series according to observed 30 year's rank. The artificial 100000 year's rank has been modeled adequately to all statistic parameters of the observed rank. Results of simulation of the water reservoir operation are represented in the table 1.

Table 1. Probabilities of risk situations

Probability (%) of accident situation respect to flood controlling by water reservoir		
Normative	according to traditional rules	according to new rules
0,1	0,092	0,077

Results of table shows: new rules of the water reservoir operation are more safe.

Conclusions.

- The chosen duration of within-year interval for simulation of the water reservoir operation model and for stochastic runoff model is enough identical respecting of accuracy of data observations.
- The represented probabilistic runoff model together with new logical conditions for the control by water reservoir with help of the short-term runoff forecasting gives possibility to decrease use of flood capacity during torrential floods and to decrease risk of alarm situation both respecting of floods and respecting of the possible deficit of water consumption.

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REFERENCES

[1] Ilinich.V.V. "*Probabilistic approach for modeling hydrological catchments"*. Indo-Russian International Long Term Project. India, Chennai, (2004).

[2] Svanidse G.G.,Khomeriki I.V. "General scheme for calculation the water balance of closed inland seas and lakes by the method of statistical modeling". *Proceedings of the International symposium on World water balance.* Gol. 2, Reading (Britain), (1970), pp. 289-294.

[3] Ilinitch V., Gmorshuk N. "Simulation of hydrological time series of river flows to Kama cascade of water reservoirs." *Proceedings of the Second International Iran and Russia Conference " Agriculture and Natural Resources"*. Moscow, Russia, (2001), pp.286 – 290.

[4] V.V. Ilinich., "Search of Anti-Accident Function for Flood Flow Management by Water Reservoir", *Proceedings of the 7-th International Conference on Hydroinformatics 2006*, Nica, (2006) pp.1025-1031.

[5] Larina T.D. "Analysis of dependence between the runoff precipitations on meteorological stations on the Cuban river catchment". *Book of proceedings: "Technologies and developments in environmental engineering"* . Moscow.; (2009), pp. 97-101. (Rus).

[6] Lim I.L. "Stochastic simulation of the storm precipitations for calculation of maximum runoff". *Proceedings of International public academy of ecological safety and use of nature*. Issue №12 (19), Moscow, (2012), pp. 72-77. (Rus).

[7] Larina T.D., Ilinich V.V. ".Experience of flood modeling for the mountain Caucasus conditions on the base of the GIS-technologies". *Proceedings of Conference : "21 century: fundamental science and technology III",* Vol. 3, North Charleston, SC, USA 29406, (2014) pp 114-1117

[8] Il'inich V.V., "Simulation of fast-moving flood runoff for cost-effective water reservoir control". *International technical-economic journal*. No. 5, Moscow, (2012), pp 83-87. (Rus).

[9] Ilinich V.V. "Evaluation of asymmetry for ranks of extreme hydrological values". *Proceedings of Conference : "21 century: fundamental science and technology III"*, Vol. 3, North Charleston, SC, USA 29406, (2014) pp. 10-13.