Section 3

PREDICTION OF SNOW AND RAIN RUNOFF BY THE CONDITION OF CLIMATE CHANGES

SENSITIVITY OF LIKELIHOOD CHARACTERISTICS OF THE MAXIMAL DRAIN ANTHROPOGENOUS CHANGE OF THE CLIMATE

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INTRODUCTION

Methods of calculation of the basic hydrological characteristics for building and water-economic designing, planning and realization of actions on long-term use of water resources are based on the concept of stability of long-term fluctuations of a drain. However available at the disposal of hydrobroad gullies data, obviously specify that significant changes of characteristics of a river drain take place, deposits and temperature of air. Techniques, in particular [4], historical reconstruction of characteristics of a drain are developed. Data of measurements [2, 3] specify that changes of a climate of anthropogenous character are possible. There are various scripts of its change (both on warming, and on a cold snap). In this connection there is a problem of an estimation of sensitivity of various branches of economy to similar changes.

Now at designing hydraulic engineering constructions the maximal charges of water of the set security are used. For a projected construction build in the ways known in a hydrology a curve of security from which the maximal charges with the certain probabilities of excess are removed. Overestimate of this value reduces economic efficiency of a construction, understating leads to destruction, a material damage and human victims. However such approach is possible, if there are long-term numbers of supervision over charges of water or a layer of a drain of a spring high water. In a context of a considered problem the model is used, allowing to build the most probable curves of security, being guided on the hydrometeorological parameters incorporated in the climatic script.

STOCHASTIC MODEL OF FORMATION OF THE RIVER DRAIN

As is known, for the description of distribution of numbers of a drain (in particular a layer of a drain of a spring high water) use equation of Pirson

$$\frac{dp}{dQ} = \frac{Q - a}{b_0 + b_1 Q + b_2 Q^2} p ,$$

where p - density of probability; Q - a layer of a drain; a, b_0, b_1, b_2 - ctors, which numerical values can be found, solving a return problem for the given equation at known distribution $p(Q)$.

In such kind this equation cannot be used for прогностических the purposes as in it the physical sense of factors a is not opened, b_0, b_1, b_2 which steal up in the formal image that the decision is better corresponded to an empirical curve. This lack can be eliminated [5] if river pool to consider as forming filter and to describe the dynamic equation of the first order

$$dQ / dt = cQ + N ,$$

where $c = 1/k\tau$, k – factor of a drain, τ – time of a relaxation, $N = \dot{X}/\tau$, $\dot{X}$ – intensity of precipitation; t – time. Entering white noise ($c = \bar{c} + \tilde{c}$, $N = \bar{N} + \tilde{N}$) with intensity $G_{\tilde{c}}$, $G_{\tilde{N}}$, $G_{\tilde{c}\tilde{N}}$ and applying known in the theory of casual processes procedure of stochastic generalization (thus the great value has that fact, that the initial dynamic equation - the first order, and the entered noise have zero radius of correlation), we come to the description markovsky casual process of formation of a river drain by means of equation Fokker - Planck - Kolmogorov (FPK):

$$\frac{\partial p(Q,\ t)}{\partial t} = -\frac{\partial}{\partial Q}\left[A(Q,\ t)p(Q,\ t)\right] + 0.5\frac{\partial^2}{\partial Q^2}\left[B(Q,\ t)p(Q,\ t)\right],$$

where factor of carry ($A(Q, t)$) and diffusions ($B(Q, t)$) are defined by expressions

$$A = -(\bar{c} - 0{,}5G_{\tilde{c}})Q - 0{,}5G_{\tilde{c}\tilde{N}} + \bar{N},$$
$$B = G_{\tilde{c}}Q^2 - 2G_{\tilde{c}\tilde{N}}Q + G_{\tilde{N}}.$$

The technology of application of this model for the forecast of curve density of probability consists of two stages. At the first stage under the known decision numerical values of parameters are defined ($G_{\tilde{c}}$, $G_{\tilde{N}}$, $G_{\tilde{c}\tilde{N}}$). At the second stage in factor of carry and diffusions change numerical values of the parameters connected with the climatic script (probable atmospheric precipitation $\dot{X}$, temperature of air through factor of a drain k) and factors of a spreading surface (also, basically, through factor of a drain k). Such procedure carry out on all set region with demanded step-type behaviour, make the numerical decision of the equation and build a card of the settlement hydrological characteristics (moments) defined under the decision $p(Q)$.

At the initial stage of works the estimation of communication in the ranks of a layer of a drain of a spring high water for ETR (European territory of Russia) is executed. Are calculated and cards are constructed of factors of autocorrelation with factor of autocorrelation one year ($r_{(1)}$), the analysis of their importance is given. The significant part of considered numbers has numerical values $r_{(1)}$ below an average quadratic mistake of their definition, i.e. process of formation of a drain of a spring high water in the revealed regions can appear not markovsky. The given conclusions do not contradict the purposes of research - as existing scripts of change of a climate correspond to an equilibrium situation the stochastic mode of formation of a drain will be statistically established. In equation FPK $\partial p/\partial Q \equiv 0$ and it passes in equation of Pirson to which is recommended to describe curve distributions of numbers of all kinds of a drain including maximal.

Further approbation of stochastic model of formation of the maximal drain is executed. For this purpose numbers of a layer of a drain of a spring high water shared by specially developed technique. This technique assumed some variants of splitting (the number of members of some both half changed), but actual division is executed provided that value of factor estimating heterogeneity (see [6]) was maximal. It means, that division of some with the maximal distinction in average values of its half (see figure 1) is executed.

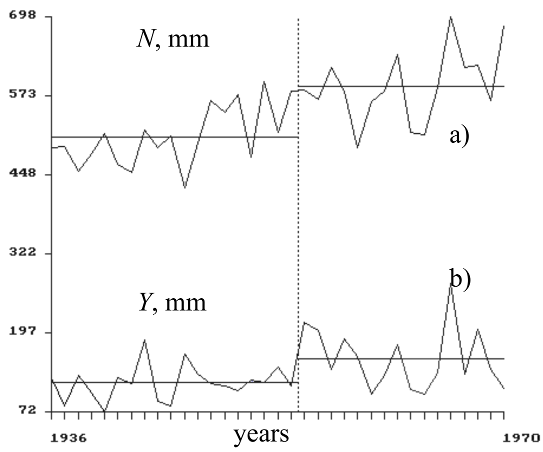

Figure 1. Chronological schedules of the sum of annual deposits (a) and a layer of a drain of a spring high water (b).

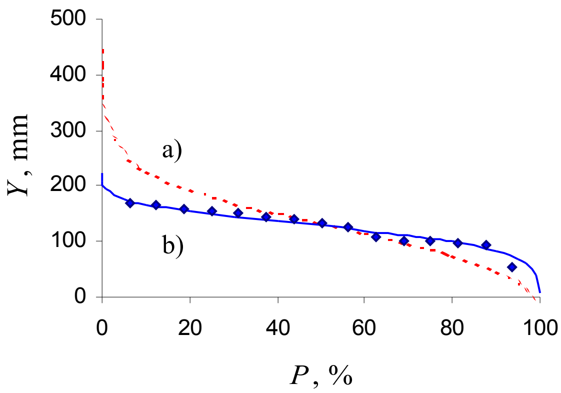

Figure 2. Actual (a) and probable (b) curves of security of a layer of a drain of a spring high water.

For the considered adjacent periods statistical parameters of a layer of a drain of a spring high water ($\overline{Y}$, C_v и C_s) are calculated. A series of cross forecasts for two variants is executed: at constant factor of the maximal drain (k) and at actual ($k_{\text{the fact}}$), supposing, that its value on prospect is known. The estimation of forecasts is executed by Kolmogorov's criterion (see [6]), i.e. for various significance values the consent actual and прогнозной is shown to curve security (see figure 2). Results speak that at the given criterion of the consent the factor of a drain is significant parameter of model for increase in quality of forecasts. However for reception of a full picture of applicability of the given technique of forecasting it is necessary to use additional criteria of the consent, such as χ^2 and $n\omega^2$.

The high degree of quality of the forecast of parameters of distribution of a layer of a drain of a spring high water has allowed to use stochastic model of formation of the maximal drain for an estimation of hydrological consequences of change of a climate for ETP on prospect. Solving this problem, have executed parametrization of model in units of a settlement grid with step in 30 km for ETR.

As external influence in stochastic model of formation of the maximal drain the information from climatic scripts (long-term norms of deposits) was used. The most widespread script of change of the climate, connected with increase CO_2 in an atmosphere has been considered. The method underlying modelling of anthropogenous change of a climate, is based on model of circulation of an atmosphere and ocean. For economic regions of Russia relative changes of deposits to 2020 and to 2100 are received. For example, in area Volgo-Vjatskom relative change of deposits will make 1.12 to 2020 and 1.28 - to 2100.

For considered territory numerical calculations on model FPK considering two variants of change of a climate are executed. On these data are constructed прогнозные cards of statistical parameters of a layer of a drain of a spring high water, and also its anomalies. In figure 3 zones of anomalies of a layer of a drain of a spring high water and factor of a variation for scripts of a climate to 2100 are presented.

At possible increase in norm of deposits to 2010 on the average on 8 – 9 % the norm of a drain also will increase for 7 – 9 %, the factor of a variation and asymmetry will go down on 2 – 7 % and 2 – 6 % accordingly. By 2100 at increase in norm of deposits at 18 – 21 % the drain will raise on 16 – 20 %, factors of a variation and asymmetry will go down on 4 – 15 % and 5 – 12 % accordingly.

As a result of the executed researches the estimation of variability of a hydroclimatic situation based on results of measurements is given. The stochastic model of formation of the maximal drain is approved. Electronic cards of settlement characteristics of a layer of a drain of a spring high water for modern climatic conditions with use of modern GIS-technologies are constructed. On them parameters of stochastic model of formation of the maximal drain for ETR are certain. Numerical integration of equation FPK for all points is executed, using data of the most probable script of change of a climate.

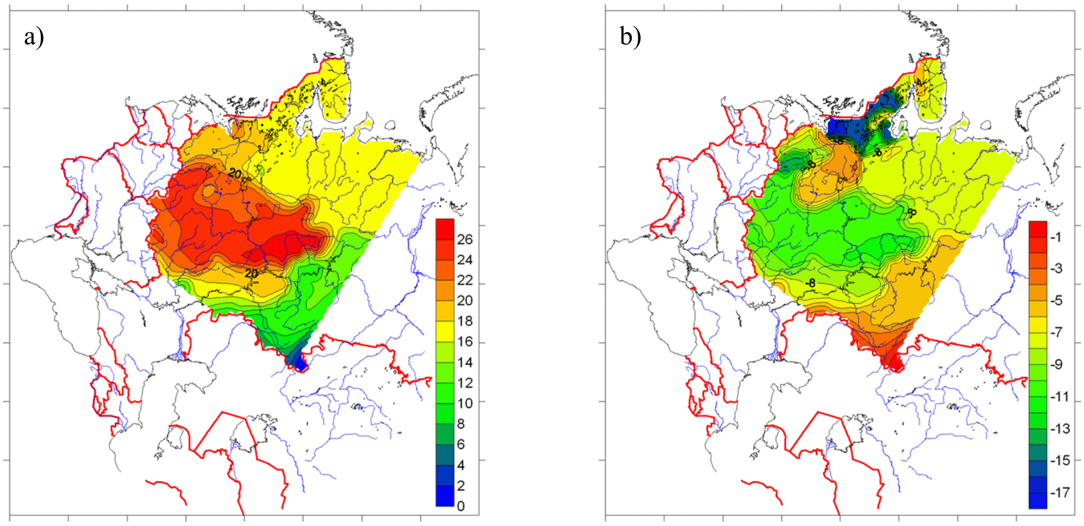

Figure 3. Anomalies (in %) norms of a layer of a drain of a spring high water (a) and factor of a variation (b) to 2100.

Cards of settlement characteristics of the maximal drain for new climatic conditions with use of modern GIS-technologies are constructed. The results received in yielded work allow to estimate except for perfection of the technique of construction of cards of anomalies of the maximal drain of the rivers CIS possible consequences of change of a drain for ecology and the branches of a national facilities using likelihood characteristics of a layer of a drain of a spring high water.

In work the problem of an estimation of sensitivity of various branches of economy to changes of a climate is solved on an example of hydraulic engineering branch. At operation of bridge transitions by the most responsible period when puts on trial stability of all constructions against influence of a river stream, the period of the miss of especially high waters of seldom repeating high waters or high waters is. Norms of settlement probability of excess establish specifications on designing of roads and bridges depending on their value and solidity of constructions.

WATER-DANGER AT OPERATION OF HYDRAULIC ENGINEERING CONSTRUCTIONS

Besides size of settlement charges of a condition of operation of constructions are defined also by factor of a variation of some the maximal charges. The factors defining conditions of operation of constructions, in the sum describing water-danger of separate areas, have a geographic distribution. On the basis of the analysis of normative cards of characteristics of a spring high water and rain high waters, in work [1] areas of various water-danger are allocated. For areas where the maximal charges of a high water are settlement, proceeding from conditions of normal operation, three zones are allocated: the small water-danger located to the north from C_v = 0.35; average water-danger between C_v, equal 0.35 and 0.9; the big water-danger to the south C_v = 0.9. Borders of areas have in general a direction on breadth.

Change of climatic conditions will directly affect conditions of operation of bridge transitions. Changes in a hydrological mode can cause displacement of borders of zones of various water-danger. On the basis of the executed calculations of characteristics of the maximal drain are constructed modern and expected cards of zones of water-danger of considered region. The above-stated assumes, that actual distributions of the maximal drain possess stability, at least, three initial moments without what it would be impossible to build cards of settlement hydrological characteristics.

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COMPUTER REALIZATION OF SIMILARITY METHOD FOR LONG-TERM DAILY FORECASTING OF WATER RESERVOIRS LATERAL INFLOW

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Management of water reservoirs at the floods and high waters passing, and also at use of water resources of water reservoirs in the low waters periods is based on the multiple automated calculations with various variants forecasting hydrographs of inflow to water reservoirs [2]. As a result of each calculation optimum control by the cascade of water reservoirs gets out on modern mathematical methods of optimization [1, 3]. Practical requirements of timeliness and speed of accepted decisions dictate necessity of full automation of calculations on all settlement blocks of the program from which significant calculate labour input the block of construction of a predicted hydrograph of inflow to water reservoirs has.

For reception a forecasting hydrographs of inflow it is possible to take advantage of genetic methods of modelling of formation of a runoff and drain, for example, results of calculations information-modelling complex ECOMAG [4]. However modelling of formation of a runoff authentically for the short-term period, - the long-term forecast is difficult. For forecasting inflow on all examined hydrological phase of a high water or a low water which duration reaches 90 days, physical-statistical hydrometric methods of forecasting are expedient as a result of which integrated on time probable volumes of inflow for the examined periods are defined.

The quarterly and monthly forecasts of Federal Hydrometeorology and Environmental Monitoring Service which used for construction of forecasting hydrographs, are determined as a wide range of values of inflow volumes to each water reservoir of the cascade, from minimal up to greatest possible. For each calculation of an operating control of water reservoir one value of the forecast on each water reservoir is set. The problem will consist in breaking up this set inflow volume for whole period to daily inflow volumes with the coordination of a required daily hydrograph with the actual inflow hydrograph received by monitoring of water reservoir during previous time. Daily elaboration is carried out on a method of similarity with a choice of year-analogue in the assumption of the identical form of inflow hydrographs to each water reservoir during the considered period and during the corresponding period of year-analogue (it is possible, with some time displacement). Competency of such approach is based on a reason about identity of physical processes within the framework of one hydrological phase at correlation of all environment factors making hydrological process.

Thus, at forecasting control of the water reservoirs consisting in carrying out of series of the accountings through certain time intervals and construction of variants of a forecasting hydrograph of inflow to water reservoirs, the following tasks should be solved for each reservoir: 1. A choice of year-analogue for the stayed duration of a considered hydrological phase; 2. Daily elaboration of the set volume of inflow up to the end of the period; 3. Updating constructed forecasting hydrograph in view of actual inflow hydrograph before date of calculation.

Let's enter the following designations:
i – Numbering water reservoirs of water-economic system; $t = \overline{1,T}$ – numbering of day (or dates) a considered hydrological phase of a flood, a high water, a low water; $t_0 = 1$ – a date started, T - date of the end of a hydrological phase, t^0 - date started of calculation, $t^{\sim}$ - date of the end of the period of updating a forecasting hydrograph;
$q^*(t)$ – an actual inflow hydrograph for the previous period of time, $q^{*0} = q^*(t^0 - 1)$ – actual inflow on date, previous to a date started of calculation, q^*_{it} - actually sizes of the daily average charge of lateral inflow to water reservoir in m3/s. with in examined year from date $t_0 = 1$ to date $(t^0 - 1)$;
$q^{\sim}(t)$ – forecasting hydrograph received on the basis of modelling of inflow on year-analogue, $q^{\sim 0} = q^{\sim}(t^0)$ – the forecast of inflow in day of the beginning of calculation, $q(t)$ – finally updated forecasting hydrograph of inflow, $q^0 = q(t^0)$ – forecasting inflow in day of the beginning of calculation in final edition;
$r, \rho = \overline{1,R}$ – Numbering years for which sizes q^r_{it} of lateral inflow are stored in a database to water reservoirs at the past years.
For definiteness we shall consider further a hydrological phase of a flood.

The choice of year-analogue at a computerization is carried out on each series of calculations for each water reservoir. In the designations set above the year-analogue is defined according to the formula:

$$r, K, \Delta t: \quad \Delta W_{r,k,\Delta t} = \min_{r=1,..R}\left\{ \min_{\Delta t}\left(\min_{k}\left[\sum_{t=t_0}^{t^0-1} (K \times q^r_{i,t-\Delta t} - q^*_{i,t})^2 / (t^0 - t)^\alpha \right]\right)\right\} \tag{1}$$

Here K - factor of similarity; Δt – a delay/advancing of an actual inflow hydrograph in considered year in comparison with a hydrograph of the past year-analogue; $0 \le \alpha \le 1$ - the accepted empirical factor which is taking into account value of remoteness of date t from a date started of calculation t_0: the date t is more removed from the beginning of calculation, the difference of actual inflow and inflow of year-analogue in an estimation of the sums written out above has smaller value. Thus $t_0 \le t - \Delta t \le T$. I.e. if $t_0 > t - \Delta t$, it is possible take $q^r_{i,t-\Delta t} = q^r_{i,t_0}$; if $t - \Delta t > T$, then $q^r_{i,t-\Delta t} = q^r_{i,T}$. Recommended values $\alpha = 0{,}25 - 0{,}45$, average $\alpha = 0{,}35$. A range of probable delay (advancing, ±) an actual hydrograph of inflow in the given year in comparison with a hydrograph of year-analogue $\pm \Delta t^*$, as a rule, $\pm \Delta t^* \le 7 \div 10$ days.

For a choice of year of high water - analogue procedure of “golden section” is offered:
1. $\Delta W_{r,K,\Delta t}$ = large number; $\theta = 0{,}62$; $\Delta t = 0$; $K = 0$; $r = 0$.
2. A cycle on years $\rho = \overline{1,R}$. Covers items 3, 4, 5, 6, 7, 8, 9, 10, 11;
   $\Delta t_\rho = 0$; $K_\rho = 0$; $W_\rho = \Delta W_{r,k,\Delta t}$;
3. The cycle on up $\Delta = -\Delta t^*$ to $+\Delta t^*$ through 1 (by days). Covers items 4, 5, 6, 7, 8, 9, 10;
   4. $K_{\max} = 100$; $K_{\min} = 1/K_{\max}$; $W_{\min} = 0$; $W_{\max} =$ large number;
   5. $K_1 = K_{\max} - \theta \times (K_{\max} - K_{\min})$; $K_2 = K_{\min} + \theta \times (K_{\max} - K_{\min})$; $W_1 = 0$; $W_2 = 0$;
   6. In a cycle $t = \overline{t_0, t^0 - 1}$ sizes are calculated:
   $W_1 = W_1 + (K_1 \times q^r_{i,t-\Delta t} - q^*_{i,t})^2 / (t^0 - t)^\alpha$; $W_2 = W_2 + (K_2 \times q^r_{i,t-\Delta t} - q^*_{i,t})^2 / (t^0 - t)^\alpha$;

7. If $|W_1 - W_2| \le 0.01 \times (W_1 + W_2)/2$, then:

$K_\Delta = (K_1 + K_2)/2;\ W_\Delta = (W_1 + W_2)/2;$ and transition to item 10;

8. If $W_1 < W_2$, then: $K_{max} = K_2; W_{max} = W_2;$ and transition to item 5;

9. If $W_1 > W_2$, then : $K_{min} = K_1; W_{min} = W_1;$ and transition to item 5;

10. If $W_\rho < W_\Delta$, then: $W_\rho = W_\Delta; \Delta t_\rho = \Delta;\ K_\rho = K_\Delta;$

11. If $W_\rho < \Delta W_{r,K,\Delta t}$, then: $\Delta W_{r,K,\Delta t} = W_\rho; \Delta t = \Delta t_\rho; K = K_\rho; r = \rho;$

The found sizes: r – year-analogue, $\pm \Delta t$ - time difference the current flood and flood-analogue (delay or advancing), K - factor of similarity.

Daily elaboration of size of the predicted volume of lateral inflow to water reservoirs after a choice of year-analogue will be defined on a method of similarity. Construction a forecasting hydrograph on year-analogue during the considered period of operational control from date up t^0 to $t^\sim$ is carried out under the formula:

$$\tilde{q}_{i,t} = q^r_{i,t-\Delta t} \times W_{i,(t^O \div t^\sim)} / W^r_{i,(t^O - \Delta t \div t^\sim - \Delta t)};\quad W^r_{i,t^O - \Delta t \div t^\sim - \Delta t} = \sum_{t = t^O - \Delta t}^{t^\sim - \Delta t} (86400 \times q^r_{i,t}) \qquad (2)$$

where $W_{i,(t^O \div t^\sim)}$ - the set predicted volume of lateral inflow to water reservoir during the considered period from the beginning of calculation; $W^r_{i,(t^O - \Delta t \div t^\sim - \Delta t)}$ - volume of actual inflow in r year-analogue in view of a delay/advancing. The period of daily elaborations is specified from date up t^0 to $t^\sim$, instead of t^0 to T as in practice some periods up t^0 to T with set forecasting volumes are possible.

Updating a forecasting hydrograph of the lateral inflow constructed above by a method of similarity, it is necessary it is carried out on reasons of authentic joining a forecasting hydrograph with a hydrograph of actual inflow during the previous period of time (see fig. 1).

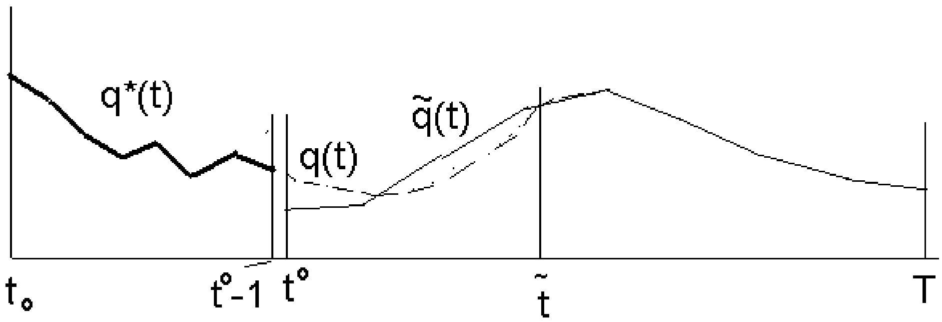

Fig. 1. Updating a forecasting hydrograph constructed on flood-analogue.

Updating a forecasting hydrograph is carried out during the period $t^0 \div t^\sim$ under the formula:

$q(t) = k(t) \times q^\sim(t)$ (3)

Thus $k(t)$ gets out so that to keep balance of inflow of the examined period $t^0 \div t^\sim$ and besides, to reduce changes of a hydrograph for the end the period "to zero", i.e.

$\sum_{t^0}^{t^{\sim}}\left[q(t)-q^{\sim}(t)\right]=0$, and also $k(t^{\sim})=1$ or $q(t^{\sim})=q^{\sim}(t^{\sim})$.

Algorithm of updating a forecasting hydrograph:

1. A choice of initial value of the updated hydrograph:
$q^0=q^{\sim}(t_0)$ at $t^0=t_0$; $q^0=q^*(t^0)$ at $t^0=t_0+1$; $q^0=2\times q^*(t^0-1)-q^*(t^0-2)$ at $t^0\geq t_0+2$;
If in result $q^0=0$, then $q^0=\max[q^{\sim}(t^0);0{,}5]$;
2. Calculation $k^0=q^0/q^{\sim}(t^0)$. At $k^0=1$ updating is not spent, transition to item 9;
3. Calculation of the sums:
$\Sigma_1=\sum_{t=t^0}^{t^{\sim}}\{q^{\sim}(t)\}$; $\Sigma_2=\sum_{t=t^0}^{t^{\sim}}\{[(t-t^0)/\Delta]\times q^{\sim}(t)\}$; $\Sigma_3=\sum_{t=t^0}^{t^{\sim}}\{[(t-t^0)/\Delta]^2\times q^{\sim}(t)\}$;
where $\Delta=(t^{\sim}-t^0)$; if $\Delta=0$, then transition to item 9;
4. Calculation of sizes $\zeta=\{\Sigma_1-\Sigma_2\}/\{\Sigma_2-\Sigma_3\}$; $\alpha=k^0$; if $\zeta=1$, then transition of item 7;
5. It is calculated $(1+\zeta)^2/(1-\zeta)^2$;
6. It is corrected $\alpha=\min\{k_0;\ (1+\zeta)^2/(1-\zeta)^2-0{,}01\}$
7. Factors are calculated: $\beta=(1-\alpha)\times(1+\zeta)/\Delta$; $\gamma=-(1-\alpha)\times\zeta/\Delta^2$;
8. It is calculated updated a forecasting hydrograph on all $t=\overline{t^0,t^{\sim}}$
$q(t)=k(t)\times q^{\sim}(t)$, where $k(t)=\alpha+\beta\times(t-t^0)+\gamma\times(t-t^0)^2$;
9. The end of algorithm for i water reservoir.

The mathematical substantiation of above mentioned algorithm of updating a forecasting hydrograph determined on year-analogue, is based on the square-law change of correction factor $k(\tau)=\alpha+\beta\times\tau+\gamma\times\tau^2$ in a relative time-scale $\tau=t-t^0$, $\tau=\overline{0,\Delta}$; $\Delta=t-t^0$, so that $k^0=q^0/q^{\sim}(0)$ and $k(\Delta)=1$.

The water balance for the examined period is reduced to equality of the sums, whence
$\sum_{\tau=0}^{\Delta}[k(\tau)\times q^{\sim}(\tau)]=\sum_{\tau=0}^{\Delta}[q^{\sim}(\tau)]$, from there
$\alpha\times\sum_{\tau=0}^{\Delta}[q^{\sim}(\tau)]+\beta\times\sum_{\tau=0}^{\Delta}[\tau\times q^{\sim}(\tau)]+\gamma\times\sum_{\tau=0}^{\Delta}[\tau^2\times q^{\sim}(\tau)]=\sum_{\tau=0}^{\Delta}[q^{\sim}(\tau)]$..
From $\tau=0$ take place $\alpha=\mathrm{k}^0$, at $\tau=\Delta$ occur $k(\Delta)=\alpha+\beta\times\Delta+\gamma\times\Delta^2=1$ whence $\beta=(1-\alpha)/\Delta-\Delta\times\gamma$.
From equality of the sums at $\tau=\Delta$ we shall receive $\gamma=-(1-\alpha)/\Delta^2\times\zeta$, where $\zeta=\{..\}_1/\{..\}_2$;
$\{..\}_1=\sum_{\tau=0}^{\Delta}[q^{\sim}(\tau)]-\sum_{\tau=0}^{\Delta}[(\tau/\Delta)\times q^{\sim}(\tau)]\geq 0$ and
$\{..\}_2=\sum_{\tau=0}^{\Delta}[(\tau/\Delta)\times q^{\sim}(\tau)]-\sum_{\tau=0}^{\Delta}[(\tau/\Delta)^2\times q^{\sim}(\tau)]\geq 0$.

Let's show, that $\Delta\geq\zeta\geq 1$; let $\theta=\tau/\Delta$, $0\leq\theta\leq 1$:

1. From $\zeta \ge 1$ take place $\{..\}_1 \ge \{..\}_2$ and $\{\sum_{\tau=0}^{\Delta}[q^{\sim}(\tau)] - 2\times\sum_{\tau=0}^{\Delta}[\theta\times q^{\sim}(\tau)] + \sum_{\tau=0}^{\Delta}[\theta^2\times q^{\sim}(\tau)]\}\ge 0$, as on everyone τ follows $q^{\sim}(\tau) - 2\times\theta\times q^{\sim}(\tau)+\theta^2\times q^{\sim}(\tau) = q^{\sim}(\tau)\times[1-2\theta+\theta^2]\ge 0$;

2. From $\Delta \ge \zeta$ take place $\Delta\times\{\sum_{\tau=0}^{\Delta}[\theta\times q^{\sim}(\tau)] - \sum_{\tau=0}^{\Delta}[\theta^2\times q^{\sim}(\tau)]\}\ge 0$, as on everyone τ follows $\theta\times q^{\sim}(\tau) - \theta^2\times q^{\sim}(\tau) = q^{\sim}(\tau)\times\theta\times[1-\theta]\ge 0$.

Let's study conditions, at which $k(\tau)\ge 0$ and $k(\tau)\le 0$. On borders of the period we have $k(\Delta)=1>0$ and $k(0)=k^0=\alpha>0$. In a point of an extremum of function $k(\tau)=\alpha+\beta\times\tau+\gamma\times\tau^2$ at performance of a condition $dk(\tau)/d\tau=\beta+2\gamma\times\tau=0$ is $\tau^{\min}=-\beta/(2\gamma)$. In a point of an extremum $k(\tau^{\min})=\alpha+\beta\times\tau^{\min}+\gamma\times(\tau^{\min})^2=\alpha-\beta^2/(4\gamma)$. Using the expressions received above: $\beta=(1-\alpha)/\Delta-\gamma\times\Delta$, $\gamma=-(1-\alpha)/\Delta^2\times\zeta$, - we shall receive $k(\tau^{\min})=\alpha+(1-\alpha)\times(1+\zeta)^2/(4\zeta)$.

Let's lead the analysis: 1. At $0<\alpha<1$ it is necessary $k(\tau^{\min})\ge 0$; 2. At $\alpha=1$ always $k(\tau^{\min})=1$; 3. At $\alpha\ge 1$ value $k(\tau^{\min})$ decreases at increase α. Value $\alpha^{\min}$ at which $k(\tau^{\min})=0$ define from a condition $k(\tau^{\min})=\alpha+(1-\alpha)\times(1+\zeta)^2/(4\zeta)=0$, from which $\alpha^{\min}=(1+\zeta)^2/(1-\zeta)^2\ge 1$. At updating a hydrograph it is impossible $k^0=\alpha>\alpha^{\min}$, - such updating is unauthorized: some values $q(\tau)<0$.

All aspects of the given mathematical substantiation of updating a forecasting hydrograph of inflow are reflected in above mentioned algorithm. On fig. 2 the example of calculation a forecasting hydrograph under the computer program realized on the basis of methods stated in clause is shown.

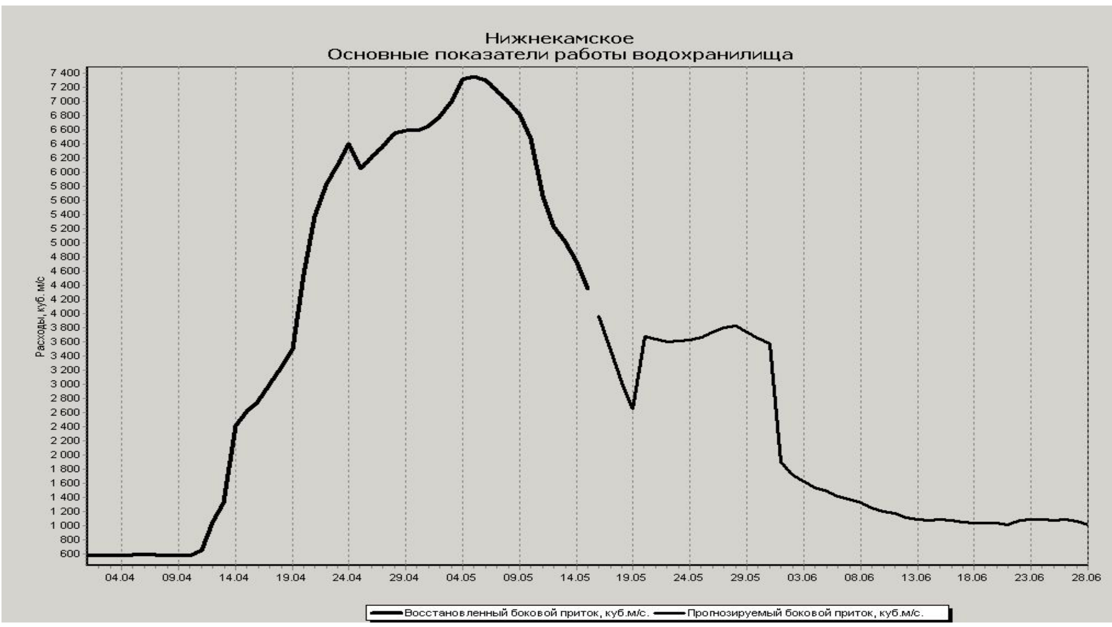

Fig. 2. An example of the designed hydrograph forecasting inflow: the left fat line - actual inflow, the right thin line - constructed forecasting inflow.

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SIMULATION OF RAINFALL–RUNOFF PROCESS AND WATER BALANCE COMPONENTS IN GARMABDASHT CATCHMENT (SOUTHEAST OF CASPIAN SEA, IRAN)

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Abstract Considering the variety of hydrological processes and proportions of water balance components, the impact of basin hydrogeological, morphological conditions and climatic changes on stream flow and water balance components was simulated in Garmabdasht catchment using two deterministic water balance models SAC-SMA and BROOK90. The results of sensitive analysis on model parameters indicates that geological, hydrological and land use factors play important roles in runoff generation and water balance components in the catchment. Simulation of climate changes on hydrologic properties of catchment indicates that evapotranspiration component has the highest sensitivity to temperature changes while runoff component has the highest sensitivity to precipitation changes.

INTRODUCTION

Water balance components and streamflow generation in a catchment are influenced by a multitude of factors which may be broadly classified into climatic, physiographic, geomorphologic and hydrogeologic factors (Nassery & Buchtele, 1997). One of the most common methods for understanding of rainfall-runoff process, and the effects of climate changes on water balance components of the catchment is simulation of rainfall-runoff process using hydrological modeling and analysis of subsequent results. In the past many attempts have been made to assess the role of geology, geomorphology and land-use on runoff process. While some attempts found no conclusive relationships between basin characteristics or the values of model parameters and the runoff process (e.g. Braun & Renner, 1992), some other attempts stated the important role of basin characteristics and presented approaches or regional equations to evaluate the runoff process (e.g. Kobold & Brilly, 1994). The objective of this study is to explore the impact of catchment characteristics, such as vegetation cover and hydrogeology, on evapotranspiration and runoff generation using two different water balance models. In this context the SAC-SMA and BROOK90 models which were applied to the Police and Špulka basins (Nassery,1997) have been tested on different scales in the central Europe (e.g. Buchtele *et al.* , 1997).

STUDY AREA AND AVALIABLE DATA

The Garmabdasht catchment located at southeast of Caspian Sea in Golestan province of Iran was chosen. The catchment covers an area of about 195 square kilometers with a total length of about 28 km and an average width of 11 km. The bedrock geology of the catchment is dominated by sedimentary rocks (mostly limestone).

Time series of precipitation, air temperature and river discharge were available to simulate the rainfall-runoff process. For model calibration a record of one year (1991-1992) was used, and for model verification records of nine years (1984-1993).

METHOD OF STUDY

In order to find out the relationship between rainfall-runoff process, basin characteristics, and the parameters of a water balance model, the Sacramento Soil Moisture Accounting (SAC-SMA) and BROOK90 models have been implemented in Garmabdasht catchment.

Both models have been presented shortly elsewhere (Nassery, 1997) and detail information can be found in the relevant literature (Burnash *et al.,*1973; Federer, 1995).

For calibration of SAC-SMA model, the following three main initial estimations has been simultaneously made and analyzed in an iterative procedure: (a) storages of several soil moisture zones LZFPM, LZFSM, LZTWM, UZTWM and UZFWM which are the main hydrogeological parameters of the model (Table1), (b) precipitation correction factor including snowfall and rainfall, (c) evapotranspiration demand for individual months. The initial estimates were optimized and the SAC-SMA model was verified by using the "differential split sample test" method. For BROOK90 model the default parameters values recommended by Federer (1995) were first chosen to simulate streamflow for catchment. Subsequently the model parameter's values were changed. The calibration was done by curve-fitting and achieving the minimum mean bias error.

Table 1 The major parameters of the SAC-SMA model and statistical indexes for Garmabdasht cathment

Acronym.	Description	Value
	Major snow parameters	
SCF	Snow Correction Factor	0.8
MFMAX	Maximum Melting Factor (mm/°C/6hr)	1.00
MFMIN	Minimum Melting Factor (mm/°C/6hr)	0.45
SI	Areal water equivalent (mm)	120
	Major hydrogeological parameter	
UZTWM	Upper Zone Tension Water Maximum (mm)	250
UZFWM	Upper Zone Free Water Maximum (mm)	30
LZTWM	Lower Zone Tension Water Maximum (mm)	380
LZFPM	Lower Zone Free Primary Maximum (mm)	480
LZFSM	Lower Zone Free Suplement. Maximum(mm)	155
UZK	Upper Zone Coefficient	0.3
LZPK	Lower Zone Primary Coefficient	0.004
LZSK	Lower Zone Supplement. Coefficient	0.075
ZPERC	(Max.) PERcolation rate Coefficient	95
REXP	EXPonent of percolation shape curve	1.8
	Major statistical index	
R	Correlation coefficient	0.8835
$\lvert \Delta \rvert$	Average absolute error of monthly flow (%)	25.64
RMS	Monthly root mean square error (%)	46.97

The models with the parameters optimized against historical streamflow time series, were first applied with different parameter sets to find out the relationship between basin characteristics and model parameters. Subsequently the historical input data were adapted by increasing the temperature and scaling the precipitation (multiplying rainfall data by a constant factor) to define climate change scenarios. The simulations with the adapted data, using the same optimized parameter values, were then compared with the historical runoff data to obtain an estimate of the potential changes. The selected scenarios were: changes in daily precipitation by ±10% and ±20% and increase in daily temperature and evapotranspiration by 1°C, %4, 2°C,%8 and 4°C,%15 for SAC-SMA model in the catchment. The scenarios ±10%, ±20% and 1°C, 2°C and 4°C were selected for BROOK90 model in the catchment.

RESULTS

Analysis of runoff components

The optimal parameter's values of SAC-SMA model are summarized in Table1. Runoff was simulated by the SAC-SMA model which has six components: PRM (primary or long term baseflow), SUP (supplementary or seasonal baseflow), INT (interflow), SUR (surface flow), DIR (direct runoff from temporarily impervious area) and IMP (runoff from permanently impervious area). Runoff was also simulated by BROOK90 model which has four components: GWFL (groundwater flow), DSFL (downslope flow), BYFL (bypass flow) and SRFL (surface flow).

Figures 1 and 2 illustrate changes in the seasonal distribution of the recorded and simulated daily flows and also runoff components simulated by SAC-SMA and BROOK90, respectively in Garmabdasht catchment. Figure 1 shows the usual annual cycle of flows for the catchment, high discharge in the Spring and low flow during the Autumn. The two baseflow components (PRM and SUP), which are controlled by groundwater storages, mainly determine runoff generation. The primary baseflow (PRM) is relatively constant throughout the year, whereas the supplementary baseflow (SUP) occurs mostly during periods with high streamflow. The short-term runoff components (IMP, DIR, SUR and INT) are nearly negligible compared to the baseflow. The SAC-SMA model simulates streamflow better than the BROOK90 model.

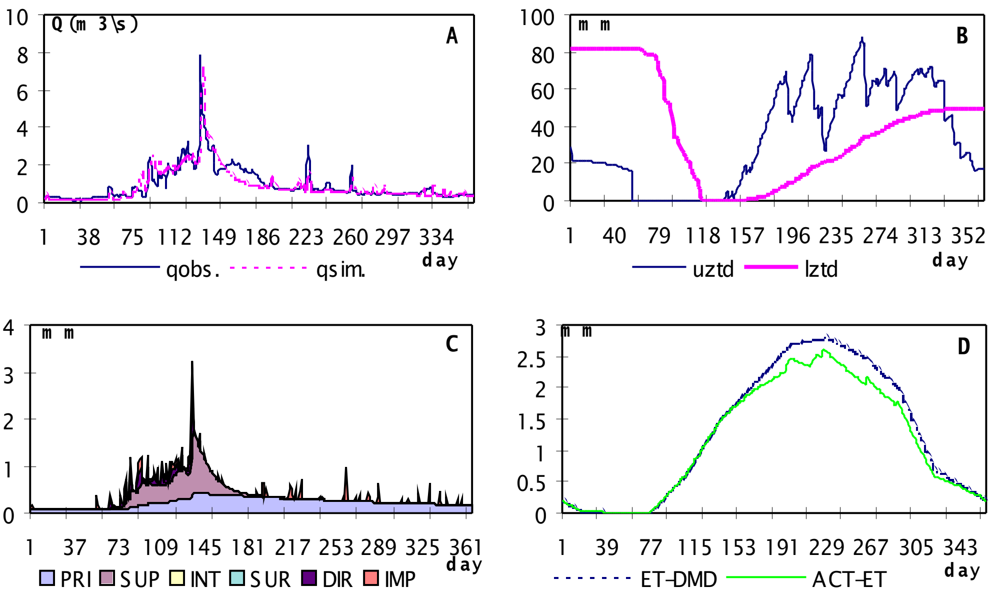

Fig. 1 Observed and simulated streamflow and its runoff components simulated by the SAC-SMA model in Garmabdasht catchment.

Evapotranspiration components

The SAC-SMA model simulates potential and actual evapotranspiration, while the BROOK90 is more sophisticated and can simulate five components of the total evapotranspiration, which are transpiration (TRAN), evaporation from intercepted rain

(IRVP), evaporation from intercepted snow (ISVP), soil evaporation (SLVP) and snow evaporation (SNVP). The simulated evapotranspiration components by the BROOK90 for the catchment are present in Figure 2.

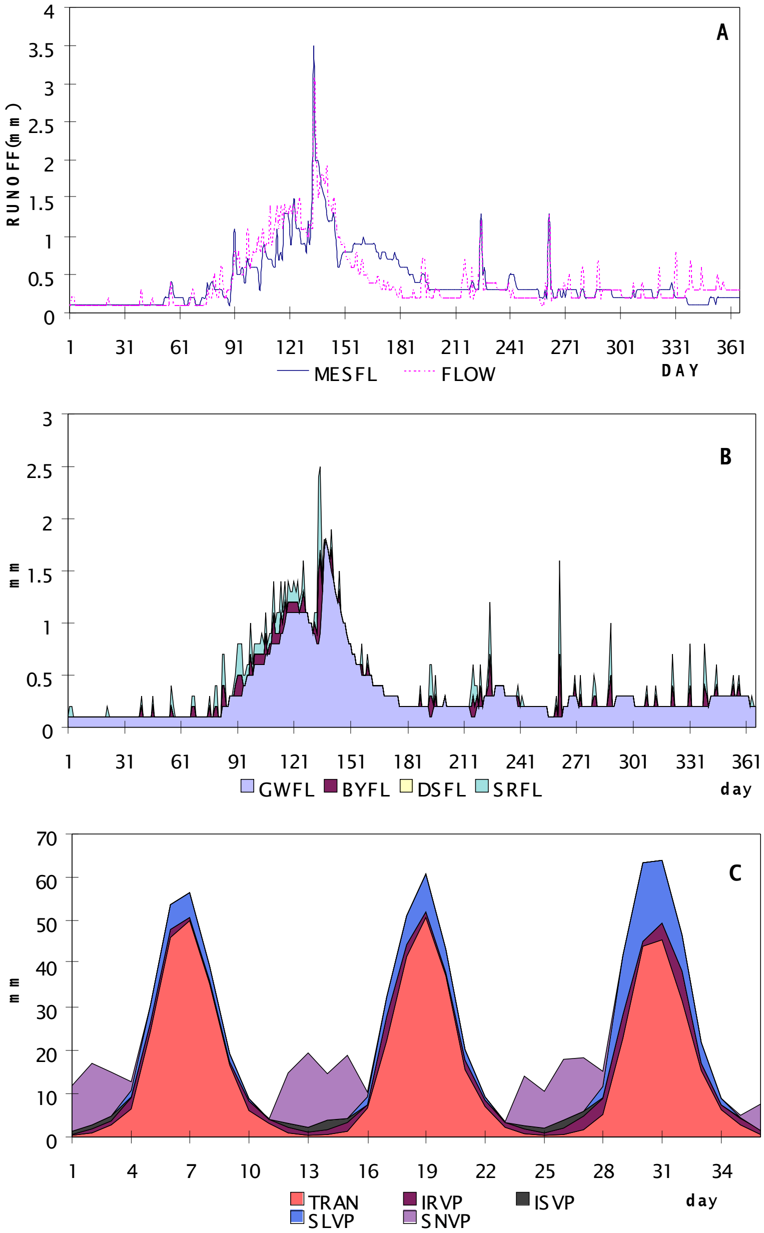

Fig. 2 Observed and simulated streamflow and its runoff components simulated by the BROOK90 model in Garmabdasht catchment.

Influence of vegetation cover on water balance components

In order to study the impacts of land-use changes (deforestation and afforestation) on water balance components, the parameter EFC (effective forest cover) of SAC-SMA and two parameters of BROOK90, which are MAXLAI (maximum leaf area index) and MAXHT (maximum of average canopy height), were changed as different alternative in the catchment. The results of both models under different vegetation change scenarios suggest that there will be a general increase in ground water flow, surface flow and decrease of evapotranspiration components with deforestation and opposite changes with afforestation (Figure 3).

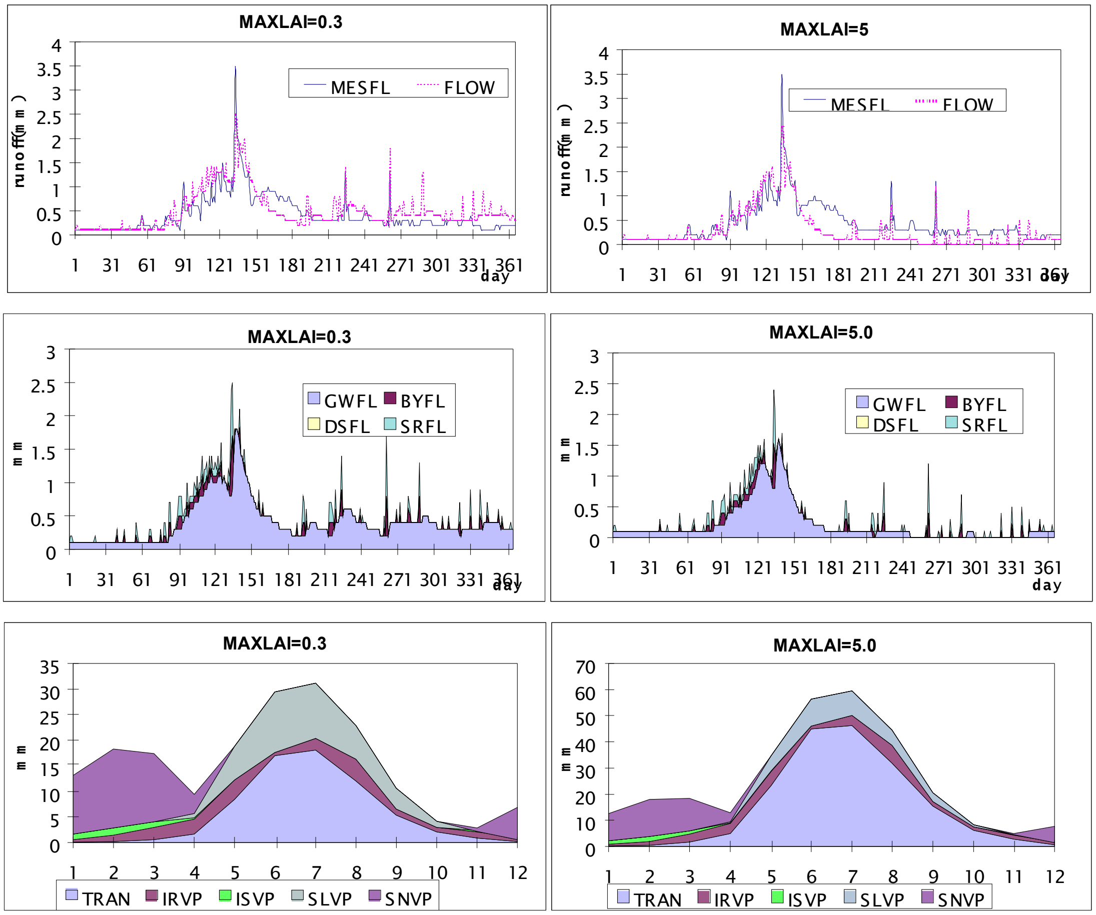

Fig. 3 Sensitivity of runoff and evapotranspiration components to MAXLAI changes simulated by BROOK90 model in Garmabdasht catchment.

Basins hydrological responses to climatic changes

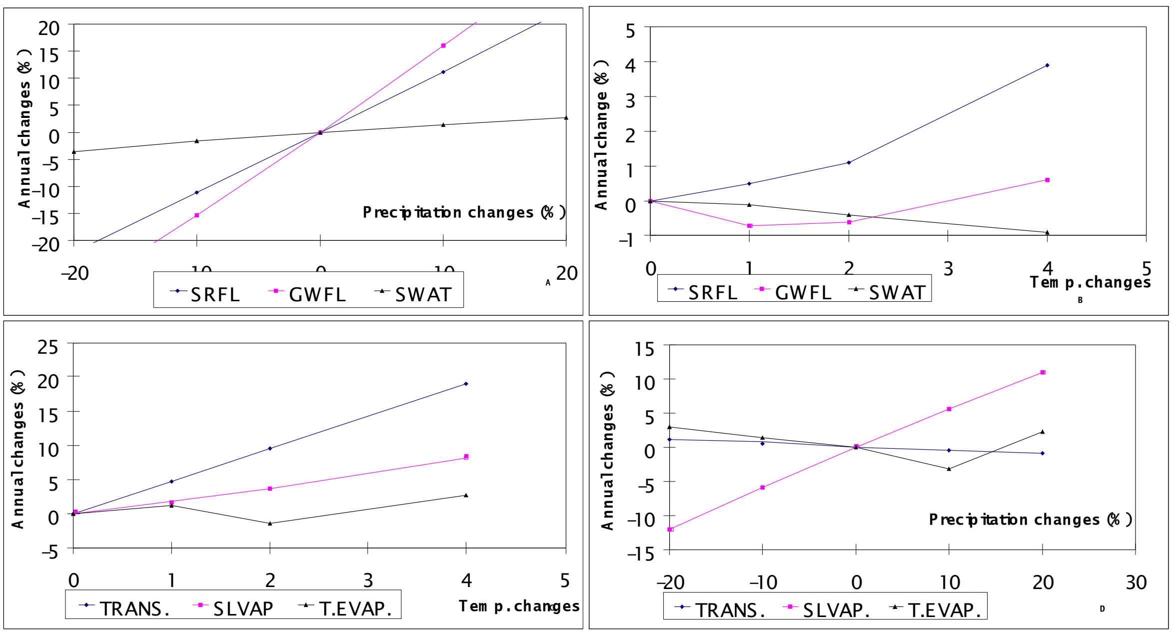

Fig. 4 Sensitivity of soil water, runoff and evapotranspiration components to precipitation and air temperature changes in the Garmabdasht catchment simulated by the BROOK90 model.

The hydrological responses of the catchment were simulated for several hypothetical climate change scenarios. The results were compared with the reference or base case (present climate conditions). Figure 4 illustrates the sensitivity of soil water, evapotranspiration, and runoff components to temperature and precipitation changes in the catchment. The evapotranspiration components appear more sensitive to temperature changes than to precipitation changes, whereas the runoff components are more sensitive to precipitation changes. The transpiration shows a negative correlation to precipitation changes. This behaviour is related to rain interception. Increase of precipitation results into higher rain interception and consequently reduces transpiration.

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MONITORING OF HYDROLOGICAL PARAMETERS OF VAKHSH RIVER IN CLIMATE CHANGE CONDITIONS

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Conceptions arising now in the world practically synonymously value possible future changes of climate. They are connected with degradation of glaciers, drying up of Aral Sea and forming of salt winds, spreading right up to Pamir Mountains, cutting down of woods, erosion of riverbanks, etc. In this case, the valuation hesitates from moderate-pessimistic up to apocalyptic.

Unfortunately, all this is weakly confirmed by actual materials. Systematical observations of glaciers are not carried out in the republic since 1986 yet and the point of view about their sharp restriction is not based enough. There is no any data on salt winds. The connection of other analogous factors with climate is not unambiguous.

In these conditions, it is necessary to use many-factor mathematical models for obtaining objective and reliable valuation of climatic changes. We have four model scenarios of climatic changes developed by western specialists: 1. CCC – EQ; 2. UK – TR; 3. GFDL – model of geophysical hydro dynamic laboratory of the USA; 4. Had CM2 – model of the United Kingdom.

All of them are based on accounting of emission influence of green gases and give valuation of climatic changes by main parameters – temperature of environment and atmosphere precipitation up to the end of 50-year's period. There can be noted a great difference between them.

In general view, matrix of climatic changes according to all of the four scenarios for the whole republic but for different periods of year is given in table 1 and fig. 1.

Table 1. Matrix of climatic changes according to different scenarios.

Scenario	Change of temperatures			Change of precipitation		
	year	winter	summer	year	winter	summer
1	2,6	3,0	2,3	-4,0	1,0	-8,9
2	2,5	2,5	2,5	4,8	2,1	7,6
3	2,0	1,9	2,1	-1,9	2,4	-6,3
4	1,9	1,8	1,9	17,1	16,0	18,2

One can mention that scattering of parameters for various scenarios, especially in relation to temperature is very large and does not allow making synonymous evaluation. In fact, these scenarios do not help much in prediction of climatic change, since preliminary choice of any of them is required without enough criteria for it. This conclusion by the way, was fully affirmed by Convention Framework of UN on climatic change in 1992, which marked numerous indefinites of climatic change forecasts, particularly in relation to their terms, scales and regional features.

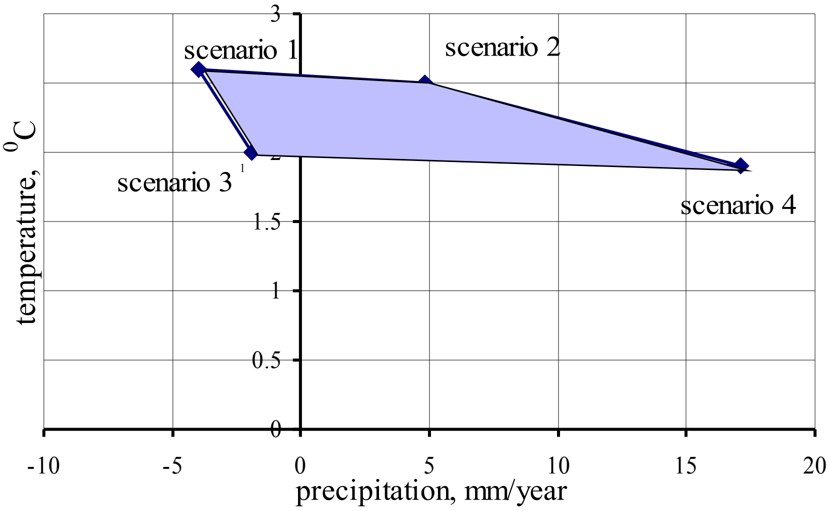

Fig. 1. Diapason of the climatic changes at various scenarios.

As the response to climatic changes, we accepted waterfull of river and spring floods (fig. 2 and fig.3).

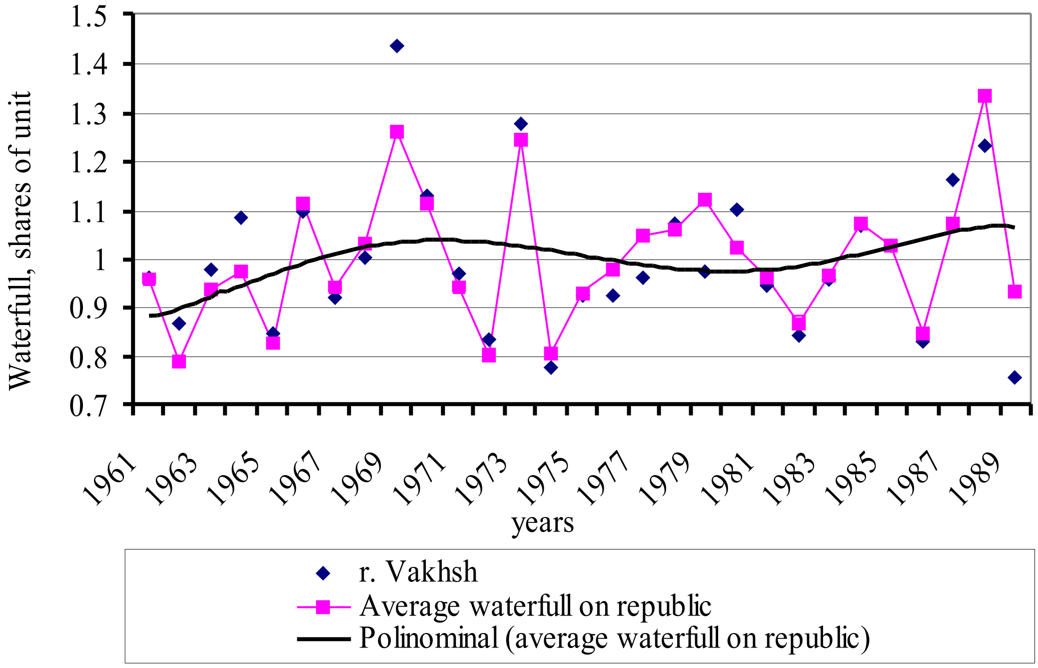

Fig. 2. Waterfull of the Tajikistan rivers.

One can see that diagrams on the fig.2 and 3 are characterized by manifestation of three periods with stable trend of change of the parameters corresponding to 1964-1972, 1973-1982 and 1983-1988 years.

For further analysis, in Table 2 it is given the matrix of actual changes of climate and appropriate responses to them in the form of hydrological characteristics of Vakhsh river. Comparing it with matrix of climatic change scenarios 1 – 4, one can mention that it covers significantly larger range of precipitation and essentially smaller one of temperature. Thus, by all these essential varieties scenario 4 – model Had CM2 and then scenario 3 are closer scenarios for local variation of climate and its fluctuations in Tajikistan.

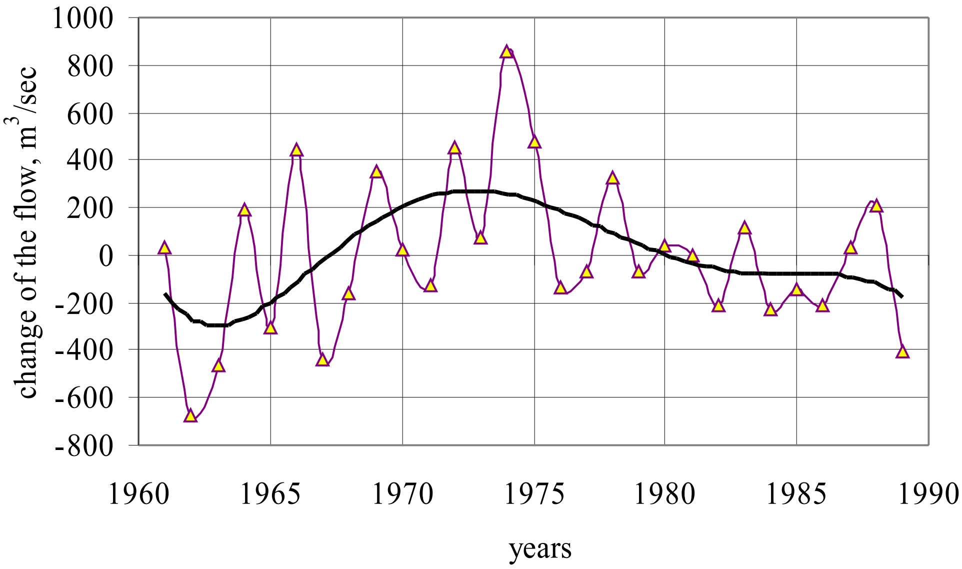

Fig. 3. Change of Vakhsh river spring floods (average for the period).

Table 2. Climatic change periods and change of water regime.

Periods	Climate change		Water regime, m^3/year	
	Temperature change, °C	Precipitation change, mm/year	Waterfull change, km^3/year	Spring floods change, m^3/s
1964-72	-0,2	14,4	0,71	49,7
1973-82	-0,01	-8,37	-0,35	129,2
1983-88	0,16	28,1	0,91	-38,6

These statistics show that there are rather close connection between change of river flow and spring flood on the one side and change of precipitation on the other side. They are given in fig. 4, 5.

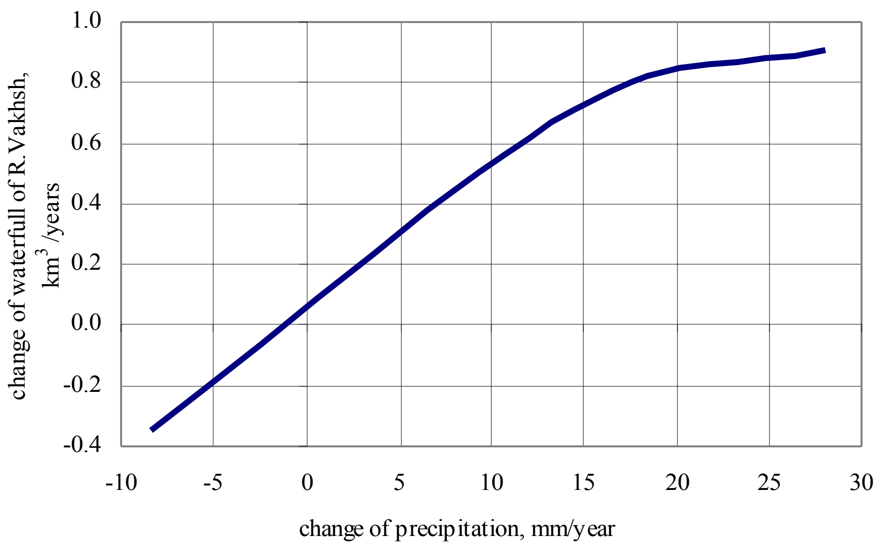

Fig. 4. Change of Vakhsh River waterfull due to the precipitation.

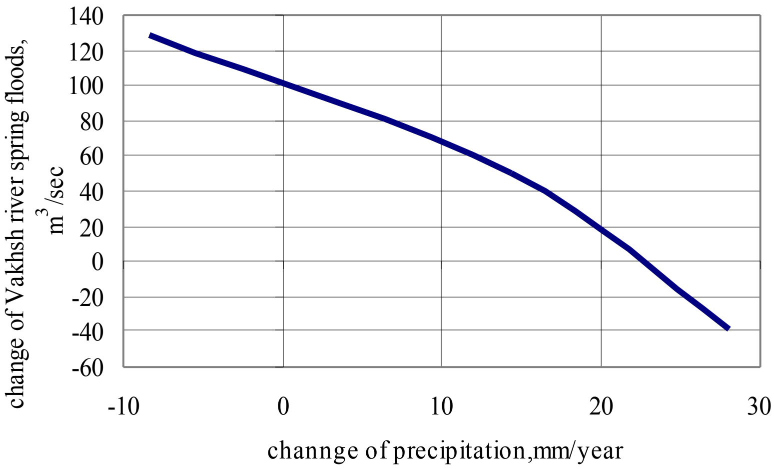

Fig. 5. Influence of the precipitation on waterfull Vakhsh River.

According to the analysis carried out, increase of precipitation increases the common water of rivers, but it decreases spring flood. This is explained by distribution of changes in water – plenty and temperature during the year, leading to their greater smoothing along seasons. Incidentally, such position in mentioned in scenarios of climatic change 1 – 4, examined above.

Unlike precipitation changes, in relation to actual changes of temperature, any distinct connection of them with hydrological parameters of rivers is not possible to be exposed. It is connected with the fact that observed changes of temperature are insignificant; their total range is equal to 0,36^{0}C. However, it does not have great importance for us. Since for us the response to climatic change is hydrological parameters of river runoff, so it is natural to accept changes of atmosphere precipitation to be the most suitable description of climatic change itself. Connections between them are revealed above to be clear enough.