

USE OF HYDROLOGICAL MODELS IN WATER DESIGN PROJECT IN TURKMENISTAN

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ABSTRACT

In 1998 irrigated area of Turkmenistan was 1750 thousand ha and total water intake was 22.8 km³ which was enough to meet total agricultural water requirements. Pursuant to the programs of the President of Turkmenistan, the irrigated area must be brought to 2250 thousand ha by 2010, but the volume of water taken from the Amudarya river must be kept as 22 km³. Thus in the future irrigation water requirements including the necessity of irrigated area extension can be met only under specific conditions. The given situation demands much from the justification and quality of the projects. In this connection, at present, in the course of designing and renovation of major water projects (reservoirs, main canals and drainage systems) of Turkmenistan, hydrological models and engineering calculation schemes are being used. Sources of initial hydrological data and methods of their processing (depending upon the sphere of their utilization, results of hydrological studies and the problems which solution they will be used for) are under consideration in the Report.

INTRODUCTION

Turkmenistan has very limited natural water resources. Its principal surface waters arise outside the country and are, as a consequence, trans-boundary resources. Annual and longer-term river flow rates are erratic. They are characterized by high turbidities, especially during flood periods. These cause flood control and sediment flow problems in water conduit sections of all of the

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major canals. Water intake from the Amudarya River, the major surface source, is limited to 22 km^3 - in accordance with inter-Governmental agreements. As a consequence of this, irrigated agriculture - which is the basis of agriculture in Turkmenistan - has developed under conditions of water resource deficiency. Water conduit and drainage sections of the canal (from dozens up to 1000 km in length) are usually open and flow through sands under complex hydro-geological conditions. Drainage waters are highly saline, and soils along the canal routes have different degrees of salinity and their seepage capacities also differ. All major hydraulic structures are located in highly seismic zones. These require that specific hydrologic and technical problems be solved in relation to their safety. In this connection, hydrological models (amongst others) have recently been used in the design and renovation of major water projects (reservoirs, main canals and drainage systems) in Turkmenistan. These models have been implemented as independent program modules and as engineering calculation schemes in MS Excel medium for the determination of the following:

1. Hydrologic characteristics of river design (annual, flood, maximum daily average discharge, and pre-set excess probability flow volumes).
2. Flood hydrograph design, according to various scenarios.
3. Catastrophic flood control through reservoirs.
4. Optional parameters (total and effective storage capacities, excess water volumes, and water intake diagrams) for reservoir and flow control modes over a period of several years.
5. Parameters and hydropower plant operating modes. Sediment discharge volumes.
6. Seepage losses (natural seepage, bank backwater seepage in dam bodies and their foundations) and evaporation losses.
7. Breakthrough wave parameters under conditions of storage dam failure, and analysis of their subsequent economic damage.
8. Expedience of economic reservoir construction for alternative reservoir capacities, intake within annual and long-term periods, and agricultural specialization on irrigated lands.
9. Salt balances in reservoirs, irrigation, drainage and water canals.

ACTUAL AND DESIGN HYDROLOGIC CHARACTERISTICS

A series of actual observations over 60 – 90 years are available for daily average discharges and water levels for the three main rivers (Amudarya, Murgab and Tejen) that contribute to the Turkmenistan water balance. Usually the design

hydrologic characteristics of the latter two rivers are rarely altered (not more often than once in 10 years). When they are it has been in connection with the construction of large reservoirs or after great floods. From the point of view of hydrology, the Tejen River is the most interesting. It is characterized by extremely irregular annual and intra-annual flows. The average flow of the river near the Pulihatune gauge station over many years (64 years of continuous observations) is 1066 Mm^3 . The minimum recorded value is 92.1 Mm^3 and maximum 4145 Mm^3 , including respectively 84.1 Mm^3 and 3855.7 Mm^3 for the limiting period (February – June). The average discharge over many years is $35.3 \text{ m}^3/\text{s}$. The minimum recorded value is $2.9 \text{ m}^3/\text{s}$ and maximum is $131.5 \text{ m}^3/\text{s}$, including respectively $6.5 \text{ m}^3/\text{s}$ and $297.5 \text{ m}^3/\text{s}$ for the limiting period (February – June). The Tejen River's intra-annual flow distribution is unfavorable for irrigation: 80 - 85 % of the flow passes during the period March - May. The river actually dries up in the July - August period when demand for irrigation water is greatest. The maximum observed daily average discharge during the flood period is $1090 \text{ m}^3/\text{s}$. In one year, the maximum value was only $26 \text{ m}^3/\text{s}$. Full-scale hydrologic calculations were made in 1996 – 1998 when the Pulihatune reservoir was designed on the Tejen (Herirude) River between Turkmenistan and Iran. Hydrologic and water economy calculation data was used in all the above models. Although it was not actualized in a single program, it did in actual fact form a single calculation system. A brief description of the basic calculation blocks (models) of the calculation system is given below.

INITIAL HYDROLOGIC DATA

Data from the Pulihatune, Turkmen gauge station has been used for daily and monthly average flows for the period 1915 – 1978 (the station was subsequently ruined by flooding and has so far not been restored). Data from a similar Iranian gauge station has been used for the period of 1968 – 1994. After checking the series for coinciding periods, values were reduced to a homogeneous row on the basis of correlation dependence. Samples from the 69-year series of observations were used for all subsequent calculations.

Empirical distribution curves are smoothed and extrapolated by means of SNIП (Construction norms and specifications) 2.01.14-83 «Determination of Design for Hydrologic Characteristics». These provide for the use of three-parameter gamma distributions that are generally being used in Turkmenistan up to the present day. Our experience of hydrologic data processing shows that for practical calculations Pearson's Type III Analytical Curve is more convenient to use. We used a computer actualization of the design algorithm developed by one of the authors of the Report. This actualization involved the statistical processing of a series of daily observations of direct and total solar radiation taken over many years (using a modified equation of Pearson's curve expressed through complete and incomplete gamma functions). Analytical distribution curve parameters (average, coefficient of variation, asymmetry coefficient, etc.) forming the equation were determined by the moment method. Output data were presented in the form of

diagrams and tables (through 1% of probability, and 99.99%, 99.9%, 0.1%, 0.01% on the edges of the distribution respectively) – average value, upper and lower limit of the confidence level ($p=0.95\%$) for the corresponding probability value.

In view of the great spread of maximum daily average discharge values during the flood period, a 58-year truncated sample was used to calculate analytical curves instead of using all 69-year observation data. This means that the dry year data were excluded from the sample. When judged from the formation of the flow, a real flood - as such - did not take place. A complete sample calculation would require using a rather long series of observations and other analytical distribution curves (which would result in lowering the calculation accuracy in the most critical part of the curve - 0.1, 0.01% of probability). From the calculation results:

Flow volume $P = 0.01\%$ probability for one year is 8351 Mm^3 ; for the flood period (February – June) it is 7559 Mm^3 ;

Maximum daily average discharge $P = 0.01\%$ probability for the flood period is $2192 \text{ m}^3/\text{s}$.

Flood Hydrograph Models

Design parameters are accepted on the basis of upper limit of confidence probability. First class safety structures whose damage could result in disaster and great losses are designed allowing for emergency operation, i.e. for $P = 0.1\%$ exceedence probability (basic calculation) catastrophic flood control and for $P = 0.01\%$ exceedence probability (check calculation). Flood volume and maximum discharge of pre-set exceedence probability have been determined for the February – June period, which includes the beginning and end of the flood period in a number of the observed years. Based on the observation data for the flood period, design probability flows and discharges were determined by mathematical statistics methods. They are 7559 Mm^3 and $2192 \text{ m}^3/\text{s}$ when $P = 0.01\%$ and 5843 Mm^3 and $1759 \text{ m}^3/\text{s}$ when $P = 0.1\%$ respectively. Design hydrographs were made up on the basis of real hydrographs of the greatest floods occurring during the available observation period. Those years with the highest annual flow value, maximum discharge peaks and typical time flow distributions (1939, 1991, 1992 and 1993) were chosen as model years on which scenarios of design flood hydrograph were made. A typical year was chosen from a real year for which the basic statistical parameters were close to the average over many years. Ordinates of design hydrograph sections (150-day period from 1 February to 30 June) were determined by equidistant transformation of ordinates of the observed flood daily average discharges. The design hydrographs are then used to design a spillway structure and the alternatives for floodwater transportation through it.

SEEPAGE LOSSES FROM THE RESERVOIR

Total seepage losses from the reservoir consist of temporary seepage losses

during saturation of the aeration zone, backwater bank seepage, annual full saturation of the reservoir basin and edges, evaporation losses and seepage from the dam body and its foundation. To analyze seepage losses, so-called geo-seepage model of the reservoir basin was developed. It consists of nine geological and hydro-geological cross sections; the distance between them is from 1 – 2 km up to 4 – 5 km. They reflect geological and lithological structure, initial hydro-geological conditions and rock seepage properties. Based on the results of the filtration profile solutions annual seepage losses from the reservoir were estimated, taking into account the reservoir design operation mode and the special features of the Herirude River's hydrology. As the length of the Report is limited, a detailed description of the models used for the calculation of the losses is not given. It should be mentioned however that they were developed in different research institutes of the former USSR and actualized as computer programs in FORTRAN in the 80's and 90's.

Sediment Discharge

The annual average turbidity of the Tejen River is 13.0 kg/m^3 according to the Pulihatune gauge station data (fluctuations are $2.5 \text{ kg/m}^3 - 190 \text{ kg/m}^3$). The average discharge of suspended sediments below the confluence of the Herirude and Keshifrude rivers (Pulihatune gauge station data) is 360 kg/s for the design number of years, i.e. 1929 - 74. When the liquid discharge is $30.8 \text{ m}^3/\text{s}$, the turbidity value is 11.7 kg/m^3 for the same period. The annual volume of silt accumulation is 8.1 Mm^3 when the (many-year) average volume of liquid flow is 970 Mm^3 (for 1929 - 74 years) and the volumetric weight of sediments is 1.39 kg/m^3 . In view of the fact that sediment flow values in the Keshifrud River, the Tejen's tributary, have a great influence on the suspended sediment value in the Pulihatune gauge line, the annual volume of silt accumulation is slightly less than 7.5 Mm^3 . The annual reservoir dead storage capacity is accepted as being 300 Mm^3 . This value must be enough for the 45-50 year period of the reservoir's operation.

MODE OF RESERVOIR OPERATION IN ACTUAL YEARS

Discharge control calculations have been made in real years to determine the reservoir's rational capacity - within the range of $600 \text{ Mm}^3 - 1500 \text{ Mm}^3$. Under the preset intake diagram for $420 \text{ Mm}^3 - 920 \text{ Mm}^3$ per year, the flow alternatives in the Pulihatune reservoir line are as follows:

1. Under many-year average flow $S = 1070.8 \text{ Mm}^3$;
2. Under many-year average flow considering lower limit of confidence level $S = 867 \text{ Mm}^3$;
3. If 600 Mm^3 Salma reservoir (Afghanistan) with $300-400 \text{ Mm}^3$ intake is available.

Calculations for river flow control under varied reservoir preset capacities and irrigation volumes contain the following:

1. Many-year average values for evaporation and seepage losses from the reservoir.
2. Discharges, actual intakes, many-year average reservoir volumes, water levels and filling respectively.
3. Many-year average filling coefficients (the ratio of many-year average reservoir capacity to planned reservoir capacity).
4. Probability of intake assuming water supply continuity (a number of years with 100 % efficiency to a number of years of a designed series ratio – year continuity water supply coefficient).
5. Volume intake probability coefficient – ratio of many-year average actual intake to planned intake volumes.
6. Coefficients of river flow control (ratio of actual intake to many-year average river flow).

A 59-year continuous sample (from 1936 to 1994) of actual monthly average discharges from the Tejen River was used as the initial data. It was assumed that the sample was stationary and homogeneous, and that its statistical characteristics within accidental error would be maintained for the future period of the reservoir's life. In this case one of the calculation alternatives assumed the evaluation of the reservoir operational mode under the forecast of many-year average flow in accordance with the lower confidence level. Water balance calculation schemes were actualized using the MS Excel medium. The value for reservoir capacity and intake at a guaranteed efficiency is chosen on the basis of calculated data and from general considerations. Basic characteristics for long-term flow control are the guarantee of many-year fail-safe flow transportation and the guarantee of the adequate volume of water supply.

P = 0.01 % PROBABILITY FLOOD CONTROL AND DETERMINATION OF SURFACE DISCHARGE VALUES

A design hydrograph made upon the scenario of 1992, as the most unfavorable year from the point of view of flood transportation dynamics, was used for the flood calculation and control. Calculation conditions are as follows:

A constant discharge, $30 \text{ m}^3/\text{s}$, is carried out through the dam's bottom outlet in accordance with the schedule of irrigation demand and water supply.

Calculation of regulation is made in several versions with specific

reservoir capacity from 850 to 1250 Mm³ - total reservoir capacity at surcharged level, from 700 to 1000 Mm³ actual capacity at full reservoir level and intake from 420 to 920 Mm³.

By the flood beginning (1 February) the reservoir is filled up to the full reservoir level.

Flood water is started to be discharged when the water level in the reservoir is higher than the full reservoir level.

Flood water transportation starts when the water level is higher than the structure's crest. Volume of the discharged water increases as the reservoir volume increases when the flood reservoir is filled and reaches its maximum value under the surcharged reservoir level. Scheme of water balance calculation (together with the hydraulic calculation of surface discharge) was actualized on the basis of the catastrophic flood design hydrographs.

STABILITY OF DAM SLOPES

Calculations determining cross-section of the rockfill dam with a loamy core were made with the help of the "STAB" program under various combinations of loads and exposure to various actions for the dam 1st safety class. The following load and effect combinations have been considered:

Static version with level of water in reservoir at mark of surcharged reservoir level = 475.00 m, without earthquake effect and with earthquake effect ($K_{\text{horiz}} = 0.15 g$);

Dynamic version with fast drawdown of reservoir from mark of Full Supply Level = 470.00 m to mark of Dead-Storage Level = 445.50 m in 63 days (discharge $Q = 120 \text{ m}^3/\text{sec}$; $\Delta h = 0.4 \text{ m/day}$, at $K_{\text{horiz}} = 0.15 g$);

Dynamic version with fast drawdown of reservoir from mark of Full Supply Level = 470.00 m to mark of Dead-Storage Level = 445.50 m in 6 days (discharge $Q = 1200 \text{ m}^3/\text{sec}$; $\Delta h = 4 \text{ m/day}$, at $K_{\text{horiz}} = 0.15 g$).

AGROECONOMIC CALCULATIONS

Basis for the agro-economic calculations was the determination of the reservoir construction economic feasibility and its optimum capacity, which were calculated for various alternatives varying the reservoir capacity from 600 to 1500 Mm³, intake from 600 to 1500 Mm³ flow, structure of irrigated lands, cost indexes, engineering solutions and water division between Turkmenistan and Iran. The economic figures on irrigated area of Turkmenistan were calculated under the following structure:

Version of a cotton specialization: wheat - 25 %, barley - 5.5 %, cotton - 25 %, alfalfa - 32.5 %, orchards - 4 %, vegetables - 8 %, other - 4 %.

Version of a vinicultural specialization: wheat - 4 %, corn - 6 %, vineyard - 67 %, lucerne - 6 %, gardens - 5 %, vegetables - 8 %, other - 4 %.

All economic calculations for various alternatives were done on the basis of the calculation of net present value (NPV) and internal rate of return (IRR). In order to determine an economically beneficial alternative of the reservoir capacity and the intake volume, elements of optimization calculation were used. While carrying out optimization calculations for the actual hydrological series the irrigated area was assumed in accordance with the value of planned water intake (420 ... 920 Mm³/year). Income from agricultural activity was taken into account only for the lands, which had a guaranteed supply with water. Wasteful expenditure on the lands not irrigated in some specific years were referred to the costs.

BREAKTHROUGH WAVE

In case of the dam failure under force majeure conditions, a breakthrough wave is formed. Calculations were carried out with the help of the "WAVE" program (developed by Scientific and Industrial Enterprise SANIIRI, Uzbekistan) that has been widely used in the CAR countries for more than 10 years. As the result of the calculation the following have been determined: time of wavefront travel to section line involved in calculation starting from the moment of dam breakthrough, wavefront width, maximum height, velocity of wave travel, and discharges at discharge sites. Forty design section lines were determined in the section from the dam site to the Garagum canal section line which is 166 km in length. Two zones can be selected in this section of the Tejen (Herirude) river, they are as follows: wave front zone and flooding zone. Calculation of damage resulting from the breakthrough wave has been done considering the cost of economic enterprises located in the zones and rehabilitation work costs.

MODERN LARGE WATER PROJECTS OF TURKMENISTAN AS PROJECTS UNDER HYDROLOGICAL STUDIES

First it is Turkmen Lake which projects' construction has started recently in Turkmenistan. As far as this project is concerned the following should be mentioned. Social and economic reforms reflected in "Strategy of social and economic reforms in Turkmenistan for the period of up to 2010", new program of President Saparmurat Turkmenbashy, provide a stable development of all branches of national economy, including gaining of food independence of the country. In this connection water resources will be mainly used for crop production on the irrigated areas in the nearest future. Nowadays total volume of drainage waters formed in the irrigated areas of Turkmenistan is estimated as 6.0 km³ and including drainage waters coming from the territory of neighboring

country (Republic of Uzbekistan), this figure can become more than 11.0 km³ (1998 data). In Lebap velayat (velayat means region) most part of the drainage waters is drained to the Amudarya and the smaller part of them is transported to the natural depressions of the locality. Waters from the territory of Turkmenistan drained to the Amudarya and drainage waters from Uzbekistan cause low quality of the river water resulting in high salinity in the middle and lower parts of the river and negatively influencing social, economical and environmental situation in Dashoguz velayat (Turkmenistan), Karakalpakistan (Uzbekistan) and Aral Sea region of Kazakhstan. Drainage waters formed within Mary, Ahal and Balkan velayats are transported to the natural depressions of the Karakum desert and on their ways to the depressions they flood pastures, causing decrease of pasture areas or decline in their efficiency. Under these conditions quick salinization of soils makes desert species of flora and fauna poor. For the purpose of efficient use of drainage waters, creation of water reserve fund and environment improvement in the country, President of Turkmenistan decided to construct a unique 132 km³ capacity Turkmen lake in the center of the Karakum desert (in Karashor natural depression) in April 2000. Proceed from all above mentioned, it is quiet obvious that the implementation of this project will require carrying-out of the whole complex of research works on different technical disciplines of water management sphere. It is planned to select the following characteristics under study: stationary and dynamic water-salt balance of drainage system and water reservoirs; dynamics of hydraulic regime through transit drainage canal lengths taking into consideration irregularity of supply, canal annual flow; expert estimation of canal bed processes. It is planned to use modern computer technologies widely while preparing this work (computer models, GIS, time-tested program complexes, search for information through Internet, etc.).

It is expected that the fulfillment of the given work will allow to give the first appraisal of the possible solution of the problems regarding the Turkmen lake project necessary for the further reasoning for design, site investigation and construction works. It is also expected that the work will help to initiate a number of joint studies in the sphere of priority trends of the Turkmen lake project with the participation of foreign companies (experts) within the frameworks of international programs.

It should be taking into consideration that there are two more groups of water structures in Turkmenistan. From the point of view of financing the priority should be given to these two groups as compare to Turkmen lake project, as they also influence the stability of economic and social development of the country. These two groups of water structures are as follow - the Karakum canal and existing water reservoirs. Despite the fact that the problems of these groups is not a subject of this work, one can say for sure that they require close attention and taking of urgent measures not in the future, but now. Delay in the solving of this problem can lead to great negative results not only for water and agricultural spheres, but also for the country's economy on the whole.

ECONOMIC AND MATHEMATICAL MODEL FOR OPTIMIZATIONAL USE OF WATER AND LAND RESOURCES

We would like to draw the specialists' attention to one more of the aspects that relates to hydrology indirectly – the sphere of the hydrological study result utilization and the problems which solution they will be used for. Water activity of the Central Asian Region (CAR) countries in the Aral Sea basin is carried out on the background of developing ecological crisis under conditions of water deficit, state different interests in the water strategy, and operational water management. After split of the USSR and establishment of independence states there is a new political and economic situation, including water management, which has formed in the region. The situation needs a review of all problems at the national level and then their interconnecting and coordination on the regional level, where Aral Sea should be counted as the separate main consumer. Solution of these multilevel problems, related by common water resources and by their lack, requires an accounting of all level priorities and their dynamics in the temporal scale. The main purpose of optimization and simulation mathematical models development is the creation of the instrument for water planning and water management under conditions of water deficiency, limited financial resources of the CAR countries and the approved commitment of guarantee a water supply to the Aral Sea. In this context, complex models which were prepared not only considering hydrological features of the region main water sources but also considering the requirements of real economic and political situations in the countries of the region will be of great interest for the CAR countries according to our opinion. One of the authors' works aimed at identifying the expediency and potential for utilizing economic and mathematical models to solve basic problems in CAR countries by integrating and specifying agricultural production in the Aral Sea basin countries. In regions where one of the main purposes of the project is the solution of environmental problems, special attention must be paid to "a virtual redistribution of water resources" and not to a direct redistribution of water resources - although this issue has already been touched on by some politicians and scientists. The distribution of "virtual water resources" means the import of foodstuff from one part of the region to another, since the imported foodstuff contains water that was used in its production. Based on such an approach, it is possible to consider and compute optimal alternatives for the location of agricultural production that will provide maximum profit and minimum environmental impact in the region. It is obvious that no country will approve a policy that will lead to heavy dependence on food imports. However, a policy of full self-sufficiency in basic types of agricultural production - which has been implemented in CAR countries (based on the available water resources) - pays more attention to political and social criteria than to economic and environmental ones. Implementation of this policy for a long period of time, set against the background of the actual demographic and environmental situation, will lead to the aggravation of negative events.