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DEVELOPMENT OF THE GIS MODEL FOR IDENTIFICATION OF MINIMUM FLOW AT ANY CROSS-SECTION OF RIVER AND ITS APPLICATION ON EXAMPLE OF ARPA RIVER BASIN

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The method for minimum flow identification at any cross-section of the river is presented in this paper. A GIS model has been developed for this purpose using ArcGIS 10.2.1 Model Builder amd Spatial Analyst extension toolbox. The input data for the model are the monthly minimum flow values of hydrological posts and Digital Elevation Model (DEM) of the basin of interest. The model have been tested for Arpa River Basin.

Key words: *GIS, ArcGIS, water resources, hydrology, watershed, DEM, minimum flow*.

In the last two decades Geographical Information Systems (GIS) have been widely used for addressing scientific and practical, as well as hydrological and water resources management issues. GIS technologies are providing new analytical opportunities and increasing the results accuracy of calculations and modelling, but only in the case if the right method is chosen and a precision, particularity and actuality of input data comply with the requirements of the addressing problem.

Flow modelling of Armenian rivers is very complicated task taking into account mountainous topography and inadequate hydro-meteorological data on river basins. It is necessary to have an accurate data on all characteristics of river flow within the entire watershed of the river.

In this paper the procedure of model development for construction of the GIS raster layer of minimum flow of the river basin is presented on example of Arpa River Basin. Constructed raster layer allows to get the annual minimum flow value for any cross-section of the river.

The minimum flow model constructed by ArcGIS ModelBuilder using Hydrology and Map Algebra toolsets of ArcGIS Spatial Analyst extension.

The monthly minimum natural flow values of operating and closed hydrological monitoring posts of Arpa River Basin (fig. 1, table 1) and the Digital Elevation Model of Arpa River Basin have been used as a model input data.

Developed model is applicable for all mountainous river basins. The raster layers of other flow characteristics such as maximum or average flow can be developed by this model too.

Annual minimum flow module values have been calculated using the monthly minimum flow values and watershed areas of hydrological monitoring posts. The results are presented in Table 1.

Main river basins of Armenia have been delineated using ArcHydro Tools [2] from ASTER GDEM which has 30m resolution [4]. DEM of Arpa River Basin has been extracted from ASTER GDEM using Extract by Mask tool of ArcGIS Spatial Analyst extension [3].

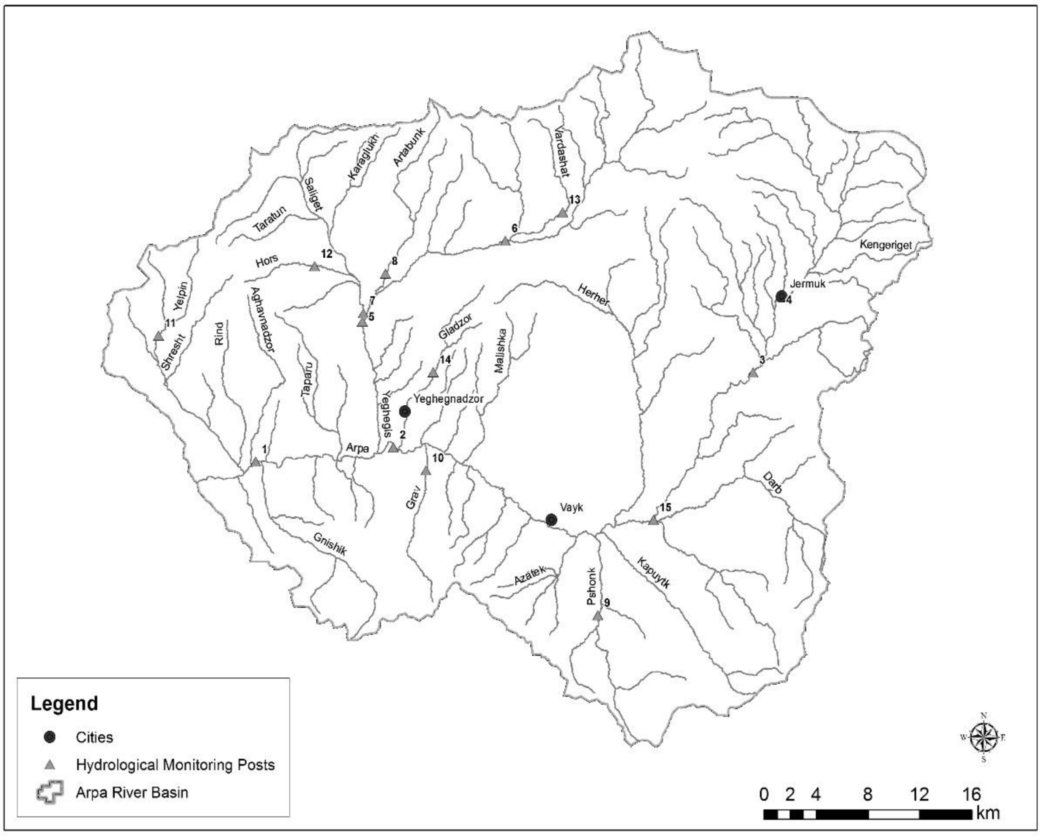


Figure 1. Hydrological Monitoring Posts of Arpa River Basin

Table 1

Flow Characteristics of Operating and Closed Hydrological Monitoring Posts of Arpa River Basin

№	River-Post	Year	H, m	Watershed area of the post, km^2	Weighted mean elevation of watershed area of the post, m	Annual minimum flow, m^3/s	Annual minimum module of flow, l/s x km^2
1	Arpa - Areni	1976	980.1	2040	2110.0	6.73	3.30
2	Arpa - Yeghegnadzor	1946	1075.4	1220	2140.0	3.56	2.92
3	Arpa - Kechut	1949	1923.6	322	2750.0	2.36	7.33
4	Arpa - Jermuk	1963	2033.7	190	2790.0	1.4	7.37
5	Yeghegis - Shatin	2015	1214.3	458	2353.9	2.12	4.63
6	Yeghegis - Hermone	1960	1675.4	205	2637.0	1.09	5.32
7	Saliget - Shatin	2001	1242.7	144	2070	0.36	2.50
8	Artabun - Artabuynk	2005	1406.1	45.6	2460	0.16	3.51
9	Vayk - Zaritap	2009	1540.1	58	2280	0.11	1.90
10	Grav - Agarakadzor	1981	1194.2	40.7	1862.9	0.04	0.98

№	River-Post	Year	H, m	Watershed area of the post, km^2	Weighted mean elevation of watershed area of the post, m	Annual minimum flow, m^3/s	Annual minimum module of flow, l/s x km^2
11	Yelpin – Yelpin	1976	1545.0	31.5	2194.4	0.051	1.62
12	Hors - Hors		1519.0	24	2024.5	0.054	2.25
13	Vardashat - Vardahovit	1984	2013.4	22	2570.9	0.09	4.09
14	Gladzor - Vernashen	2001	1488.6	20.5	2270	0.014	0.68
15	Darb – Chaykend	1962	1332.0	161.7	1338	0.027	0.17

For the construction of minimum flow raster based on DEM first of all it is necessary to establish connection between elevation and flow. Below is presented the dependence of annual minimum flow module from the weighted mean elevation of watershed of hydrological monitoring post in Arpa River Basin (fig. 2).

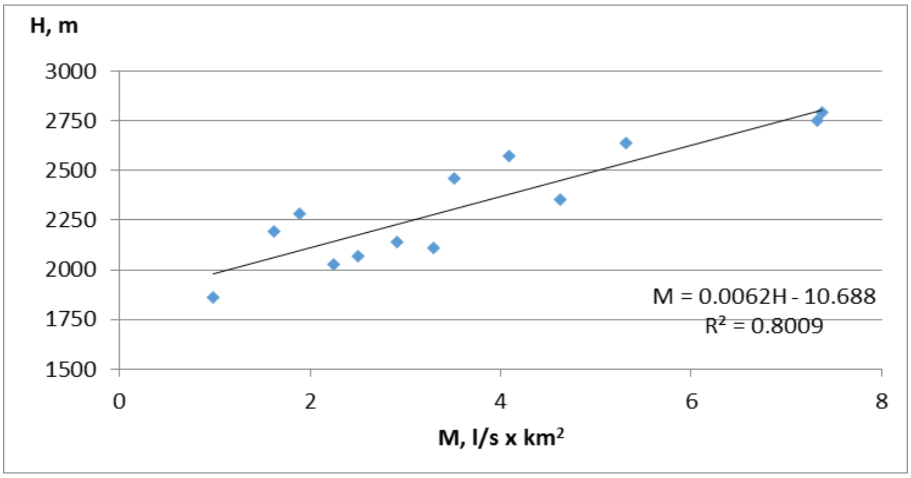


Figure 2. Relation between Annual Minimum Flow Module and the Weighted Mean Elevation of Hydrological Monitoring Post Watershed in Arpa River Basin

Model for identification of minimum flow at any cross-section of the river has been developed by ArcGIS ModelBuilder using Spatial Analyst extension toolboxes, using the basin DEM and equation of correlation between weighted mean elevation and minimum flow of module (Fig. 3).

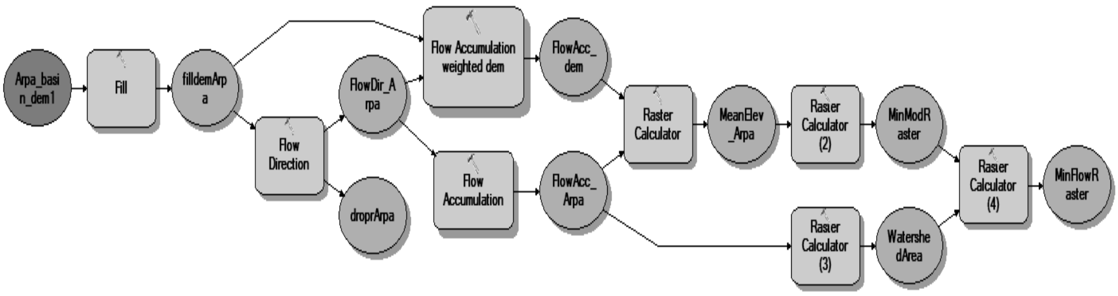


Figure 3. Scheme of the Model for Minimum Flow Raster Construction

Below are presented description of the tools included in the model and their application.

1. **Fill.** DEMs often contain inaccuracies such as local sinks and peaks. Sinks (and peaks) are often errors due to the resolution of the data or rounding of elevations to the nearest integer value. Sinks should be filled to ensure proper delineation of basins and streams. If the sinks are not filled, a derived drainage network may be discontinuous. Sinks and peaks for Arpa River Basin have been corrected by Fill tool of Spatial Analyst Hydrology toolset [2, 3].
2. **Flow Direction.** raster of flow direction from each cell to its steepest downslope neighbor have been created using Flow Direction tool. The input surface raster is the filled DEM created in previous step.
3. **Flow Accumulation.** Using flow direction raster as an input, a raster of accumulated flow into each cell have been created by Flow Accumulation tool.
4. **Flow Accumulation with Weight Raster.** The flow accumulation area for each cell of of Arpa River Basin raster have been calculated. The calculation has been done using Flow Accumulation Tool and Flow Direction raster also, but here the filled DEM of the basin has been used as an input weight raster.
5. **Raster Calculator.** Using the resulting rasters of previous two steps, the watershed weighted mean elevation for each cell of basin's raster has been calculated by Raster Calculator tool (Fig. 4.).

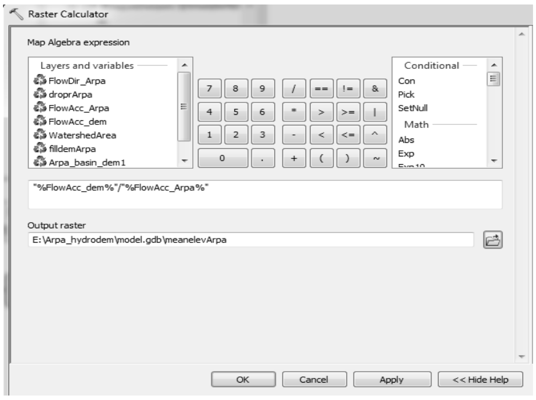


Figure 4. Calculation of Watershed Weighted Mean Elevation for each Cell of the Basin

6. **Raster Calculator (2).** Annual minimum module of flow raster have been constructed using Raster Calculator. The input data for calculation is the weighted mean elevation raster developed in previous step and the equation of relationship between mean elevation and minimum flow module in Arpa River Basin: M=0,0062H-10,688, where M is minimum flow module, H is weighted mean elevation (Fig. 5).

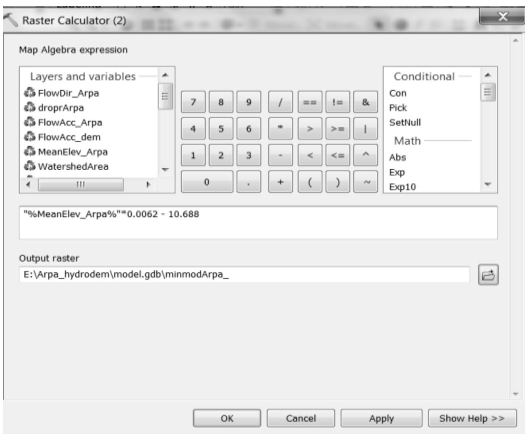


Figure 5. Construction of Annual Minimum Flow Raster for Arpa River Basin

7. **Raster Calculator (3).** Watershed area for each cell of Arpa River Basin raster have been calculated (fig. 6).

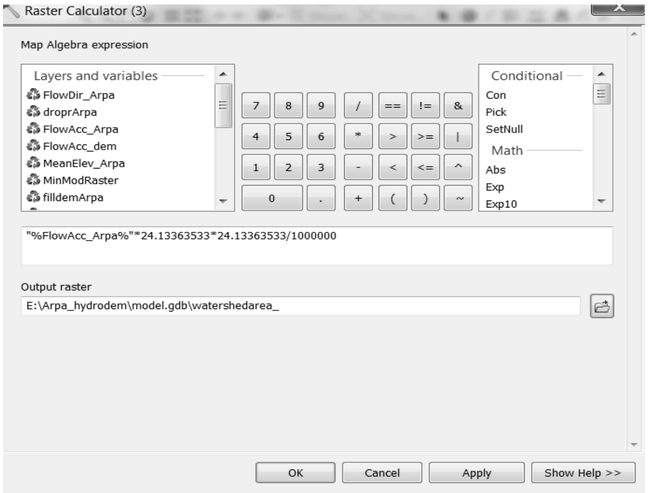


Figure 6. Construction of Watershed Area Raster for Arpa River Basin

8. **Raster Calculator (4).** The annual minimum flow raster for Arpa River Basin have been calculated by following formula:

(Watershed Weighted Mean Elevation x Watershed Area) / 1000 (Fig. 7).

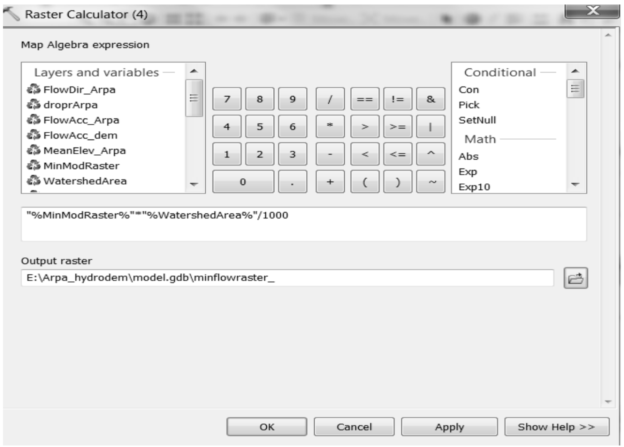
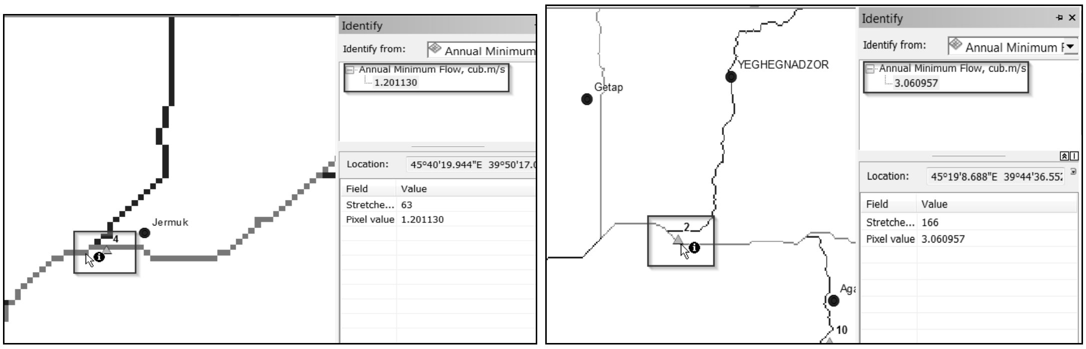
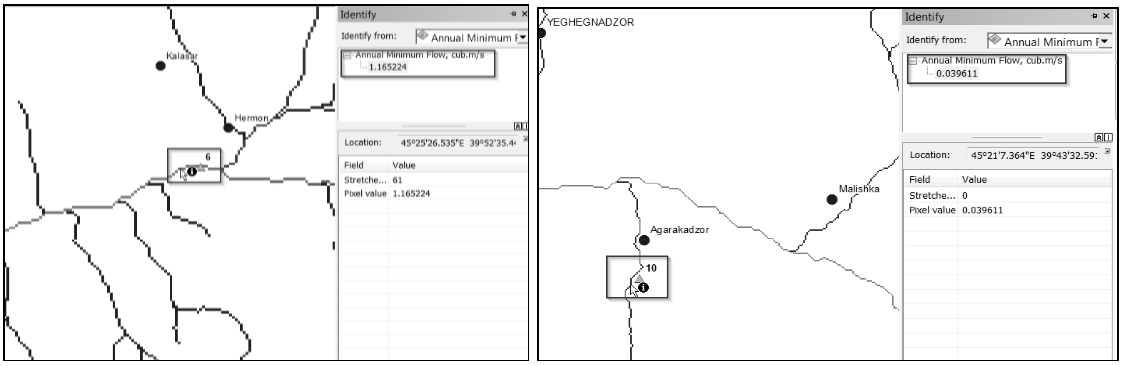


Figure 7. Calculation of Annual Minimum Flow Raster for Arpa River Basin

Each cell of the river network raster contains one annual minimum flow value. In GIS software, such as ESRI ArcMap or QGIS, it is possible to get the annual minimum flow value for each cross-section of the river by clicking on the point of interest by Identify tool. Below are presented several examples of the annual minimum flow value extraction from the developed raster layer.



a) **b)**



c) **d)**

Figure 8. Identification of Annual Minimum Flow from Raster Layer for Hydrological Posts a) Arpa-Jermuk, b) Arpa-Yeghegnadzor, c)Yeghegis-Hermone, d) Grav-Agarakadzor

The values extracted from raster layer have been compared with the observed annual minimum flow values, and the relative error of the model have been identified (table 2).

Table 2

Comparison of Annual Minimum Flow Values Observed in Hydrological Monitoring Posts and Identified from Developed Raster Layer

Hydrological Monitoring Posts	Annual Minimum Flow, m^3/s		Relative Error, %
	Observed	Identified from Raster Layer	
Arpa-Jermuk	1,40	1,20	-14
Arpa-Yeghegnadzor	3,56	3,06	-14
Yeghegis-Hermone	1,09	1,16	6
Grav-Agarakadzor	0,04	0,04	0

The relative error of the model in tested points is in the range of 0 to 14%, which is acceptable for hydrological calculations.

The methodology presented in this article can be used for development of similar raster layers of monthly minimum flows or other characteristics.

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ԳԵՏԻ ԿԱՄԱՅԱԿԱՆ ԿՏՐՎԱԾՔՈՒՄ ՆՎԱԶԱԳՈՒՅՆ ՀՈՍՔԻ ՈՐՈՇՄԱՆ ԱՏՀ ՄՈԴԵԼԻ ՄՇԱԿՈՒՄԸ ԵՎ ԴՐԱ ԿԻՐԱՌՈՒԹՅՈՒՆԸ ԱՐՓԱՅԻ ԳԵՏԱՎԱԶԱՆԻ ՕՐԻՆԱԿՈՎ

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Սույն հոդվածում ներկայացված է գետի կամայական կտրվածքում նվազագույն հոսքի որոշման համար ռաստրային ԱՏՀ շերտի մշակման մեթոդը և արդյունքներն Արփայի գետավազանի օրինակով: Շերտի ստացման համար ArcGIS 10.2.1 ծրագրային փաթեթով կառուցվել է հաշվարկային մոդել՝ օգտագործելով Spatial Analyst ծրագրային հավելվածի գործիքները: Որպես մուտքային տվյալներ օգտագործվել են Արփայի գետավազանի գործող և փակված հիդրոլոգիական դիտակետերի բազմամյա տարեկան նվազագույն հոսքի արժեքները և գետավազանի բարձրությունների թվային մոդելը (DEM):s

Բանալի բառեր. ԱՏՀ, ArcGIS. ջրային ռեսուրսներ, ջրաբանություն, ջրհավաք ավազան, ԲԹՄ, նվազագույն հոսք:

РАЗРАБОТКА ГИС МОДЕЛИ ОПРЕДЕЛЕНИЯ МИНИМАЛЬНОГО СТОКА В ПРОИЗВОЛЬНОМ СТВОРЕ РЕКИ И ЕЕ ПРИМЕНЕНИЕ НА ПРИМЕРЕ БАССЕЙНА Р. АРПА

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В статье представлен метод построения растрового ГИС слоя для определения минимального стока в произвольном створе реки и результаты применения метода на примере бассейна реки Арпа. Для получения слоя посредством программного пакета ArcGIS 10.2.1 была построена расчетная модель, используя инструменты программного модуля Spatial Analyst. В качестве входных данных использованы многолетние значения минимального стока действующих и закрытых пунктов гидрологических наблюдений и цифровая модель высот речного бассейна Арпа.

Ключевые слова: ГИС, ArcGIS, водные ресурсы, гидрология, водосборный бассейн, ЦМВ, минимальный сток.