Catchment Delineation for Vjosa River WEAP Model, using QGIS Software

Liljana Lata*

Institute of GeoSciences, Energy, Water, and Environment (IGEWE), 'Don Bosko', No. 60, Tirana, Albania

Abstract: The Vjosa River (Aoös in Greece) is the second largest river basin of Albania and one of the main transboundary wild rivers in the Europe. Actually, the Vjosa river basin, widely known for its beautiful landscapes and ecological values, offers an important national economic growth potential, coming mostly from the tourism sector. Vjosa River basin has no water management or hydrological model, nor a proper integrated management plan. Therefore, in 2016, a project under the framework of the EU Flood Protection Infrastructure Project (FPIP) was implemented at IGEWE. The main purpose was the development of an integrated hydrological and water management model for the Vjosa Basin to identify key vulnerabilities to climate change between the years 2015-2050, applying Water Evaluation and Planning (WEAP) system, by Stockholm Environment Institute (SEI). This paper describes details on the methodology used for the delineation of the Vjosa catchment, as a crucial part for the development of the hydrological model of Vjosa river. The GIS model builder is introduced, as a first step of the Vjosa river WEAP model development.

Keywords: *Catchment delineation, hydrological model, model development, flow accumulations*

Introduction

Specific methodologies were considered with the intention of preparing the appropriate dataset for the WEAP Vjosa model, as required for the WEAP format (SEI, 2016). Entirely suitable data can be inserted for any element built into the WEAP schematic: water supply (*e.g.* rivers, reservoirs, etc.) and demand (e.g. irrigation, drinking water demand, industrial water demand etc.). The needed information has been gathered via a thorough scanning of all available reports and maps related to water resources and water use in Albania and Greece (Wickel *et al*., 2017). This document represents in details the methodologies used for the Vjosa river catchment delineation. Upon implementation, other phases of the project were also related to data preparation in regard to different elements and subcatchments for an integrated water use of the planned Vjosa subbasins (Wickel et al., 2017). Then the data were inserted into the WEAP model and the model calibration was performed for specific climate scenarios that were prepared during implementation of the project with the intention of being as close as possible to the natural conditions of the Vjosa river basin (Mucaj, 2016). The data monitoring and processing methodology have been in full accordance with the guidelines related to Integrated Monitoring Guide for SDG 6 (UN-Water, 2019).

Materials and Methods

Study area:

The Vjosa River, being roughly 6,808 km^2, is the second largest transboundary river in Albania. Around one-third of the basin is located in northwest Greece (Figure 1). The annual average discharge of the Vjosa river in the Greek part is about 70 m^3/s, and that of the Vjosa River in its outlet into the Adriatic Sea is about of 195 m^3/s. The minimum flow of Vjosa River during summer time is of 33 m^3/s (Wickel et al., 2017). The Vjosa river catchment (in Greece) is shared between three prefectures: Ioannina, Grevena and Kastoria, having an estimated population of about 35,000 inhabitants in 2001, with density of about 14.4 inhabitants/km² (Seferlis et al. 2008). The river's source is located at 2600 meters above sea level (m.a.s.l.), in the Pindus mountains in Greece, flowing over a distance of 85 km. Once crossing the Albanian border, it continues as Vjosa River for about 190 km before reaching the Adriatic Sea on northern side of Vlora city. The Vjosa catchment has an average elevation of about 855

---

*Corresponding: E-Mail: lataliljana@gmail.com; Tel: +355696531070;

m, and is shared among five prefectures: Gjirokaster, Vlore, Fier, Korçe, and Berat. In 2015, the Albanian population in the Vjosa basin was approximately 200,000 inhabitants (CNR Cereg, 2015). On the western side, downstream of the river basin, the population density was about 100-250 inhabitants/km², while in the upper area of the basin the density is about 10-15 inhabitants/km². The mean annual precipitation in the catchment is 1965 mm. The Vjosa river has three important branches, known as the Sarantaporos in Greece (18 m³/s annual average discharge), and Drinos (39 m³/s) and Shushica (19 m³/s) in Albania. Vjosa river, being largely free of man-made big hydraulic developments such as dams, is considered one of the last remaining wild rivers in Europe, covering more than ten protected areas (Wickel et al., 2017). Numerous scattered wells are used to meet household, industrial and agricultural needs, but no systematic data related to water availability was in place for the calibrated period of the Vjosa WEAP model (2001-2008) (Lata *et al.*, 2018).

Figure 1. The Vjosa/ Aoös basin location (in blue).

Methods:

This manuscript provides a description of the methods used for developing the delineation of the Vjosa catchment for the hydrological model of Vjosa river basin. WEAP then simulates water supply, demands, management priorities, existing infrastructure and infrastructural constraints within the Vjosa WEAP model. The spatially-based models can incorporate climatic and land use conditions that determine water supply, and this allows the model to investigate many changes within system to consider the several outcomes of uncertain futures, whether climatic, managerial, infrastructural or demographic (Wickel et al., 2017). A full description of the WEAP model can be found in the User Guide, developed by SEI and available on the WEAP website (SEI, 2016). Figure 2 show the main components incorporated in Vjosa WEAP model.

Catchment is physically delineated by the area upstream from a specified outlet point. Watershed delineation for the Vjosa river is performed in the open-source QGIS software. The main data required are derived from a global hydrologically corrected Digital Elevation Model (DEM) and stream network file for Vjosa. The data source: DEM Digital Elevation Model (DEM) developed by Lehner et al. (2010). 5-Degree tiles at a spatial resolution of 90 m that cover the Vjosa basin for elevation (DEM) were combined for this project. QGIS software has been used to calculate the basin outline and flow accumulation/drainage network that are used to delineate the catchments of the Vjosa.
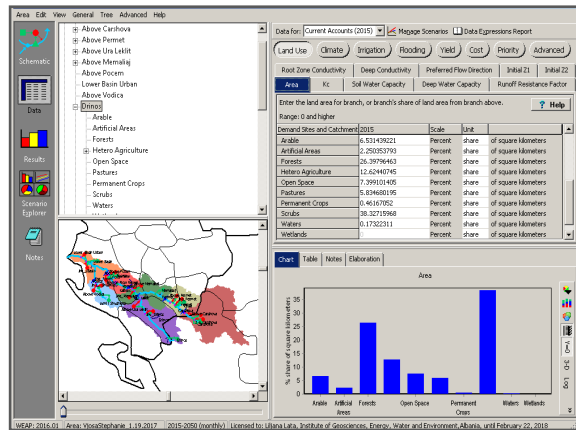
Figure 2. The main components incorporated in Vjosa WEAP model.
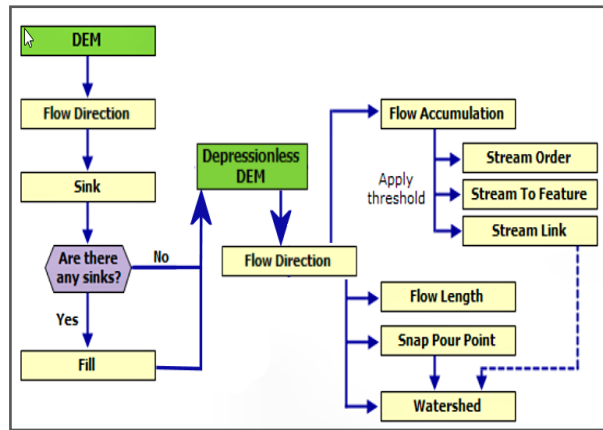

Figure 3. View of the hydrological modeling flowchart (Balázs, 2017)

Figure 3 represents the hydrological modeling flowchart, with the step-by-step methodology of the Vjosa catchment delineation. The process description is explained below:

I.   Setting up the work environment

Watershed delineation process enables the users to set up the map document in QGIS and create the needed working directory through the following steps:

- First, a new blank document was created in QGIS. Then the DEM of Vjosa (raster file) was added in the map using Add Data button (Figure 4). Raster should be projected in Albanian 1987 GK Zone 4, under GIS (Spatial Reference System Layer): WGS84_UTM _zone_34n. Raster Metadata can be seen at Layer Properties of the Raster.
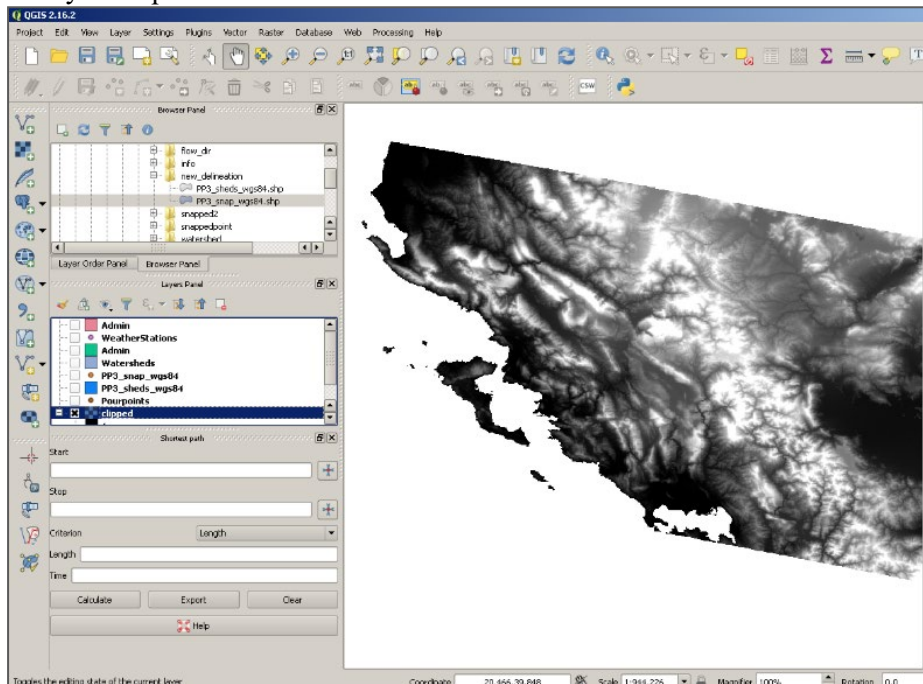
Figure 4. View of the Raster file of Vjosa catchment in QGIS software.

At the Geoprocessing/Environments (under Workspace), the variables for Current workspace and Scratch workspace are determined in the directory where the results will be saved, as shown in Figure 5 (a) and (b).

Under Environment Settings/Raster Analyses, the Cell size property was set to be the same as DEM layer (90), as shown in Figure 6.

Then the Spatial Analyst extension browsing was enabled under Costumize/Extentions/Spatial Analyst, as shown in Figure 7.
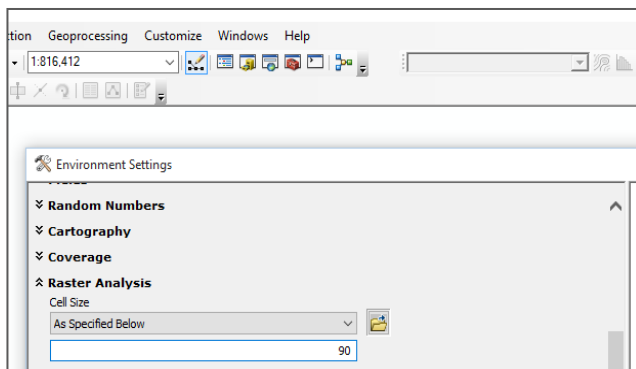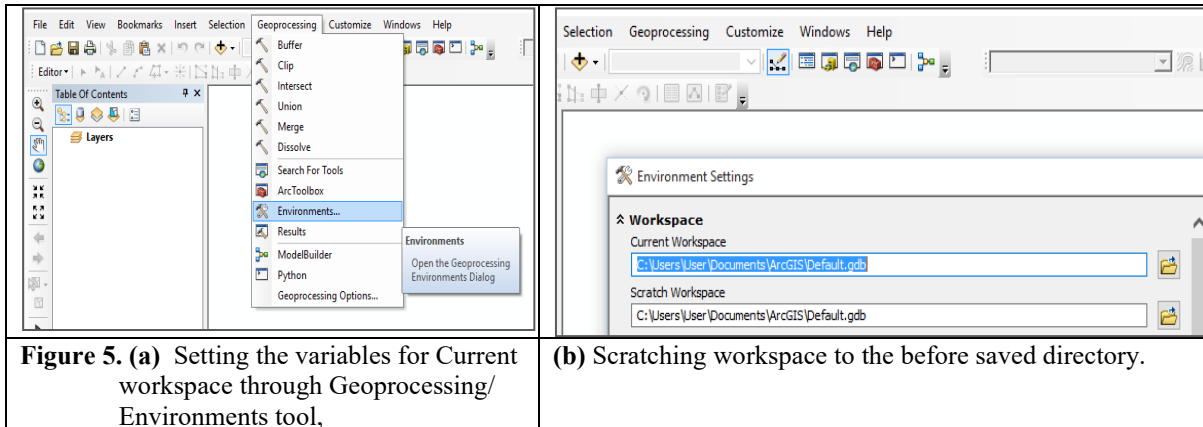
Figure 5. (a) Setting the variables for Current workspace through Geoprocessing/ Environments tool,	**(b)** Scratching workspace to the before saved directory.

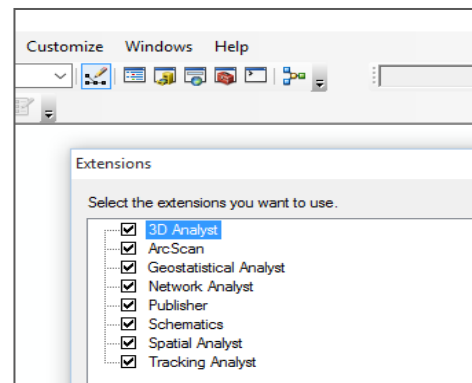**Figure 6.** Setting the cell size of the Current workspace.

Figure 7. Enabling the Spatial Analyst.

Subsequently, we execute one by one processes that are within ArcToolbox/Spatal Analysis Tools/Hydrology as shown in Figure 8. The map document was saved in QGIS.
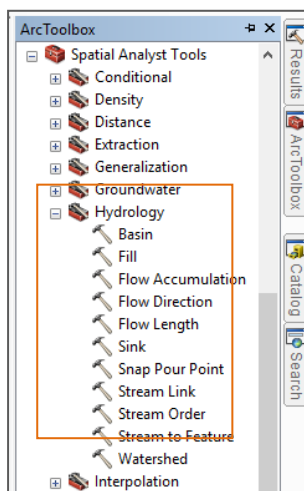

Figure 2. View of the Hydrology toolset in QGIS;

II. Building the Depressionless DEM

It is entirely possible that our DEM might have sinks or imperfections. To remove them we have applied Fill tool at Hydrology Toolbox. Sink is a sell without an associated drainage value. Drainage values determinate the direction of the water when flowing out of the sell. They are determined during the Flow direction grid process for the basin. Filling sinks is a very important step, because finding the flow path of every cell of the grid will then determine the drainage network. Therefore, browsing the Fill tool at Hydrology was performed as shown in Figure 8 by setting DEM grid as Input surface raster, and

by setting the output surface raster, naming it and saving it in the created directory. Then after confirming (pressing 'OK') the tool was executed.

After the run was complete, a new grid has been added to the data frame in the map document (Figure 9). There were differences in the lowest elevation value between the first DEM and the new filled one. The new map document was saved.
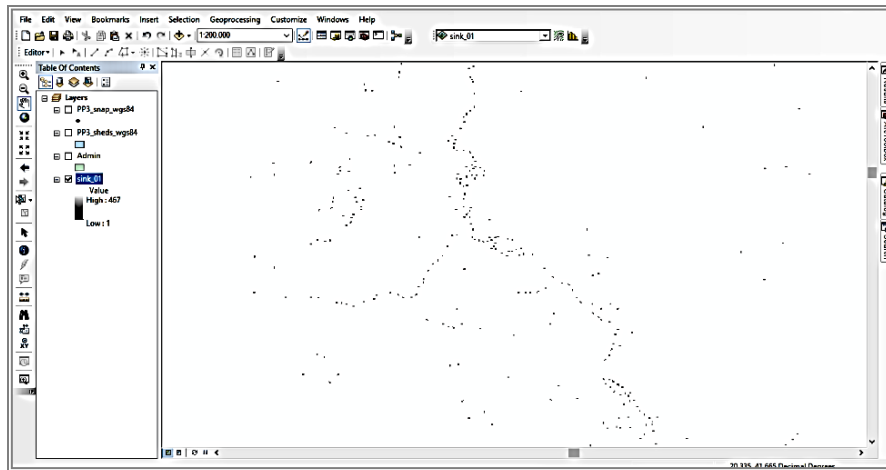

Figure 9. Sinks (the black dots) that are filled in the DEM raster.

III. Flow Direction grid

The direction grid has a value for each cell that indicates the flow direction. The flow direction shows the direction that the water will flow from that cell, according to the topography of the land. This is a very important step for the hydrological model, as the flow direction will tell us where the water will flow on the land surface.

In the Figure 10 numbers are special codes used for the specified direction of the water from the center cell to the others. The numbers should be (1;2;4;8;16;32;64; or 128). For example, when the flow direction is north, cell is coded 64, etc. So, through browsing the Flow direction tool, the parameters were changed (Figure 11):
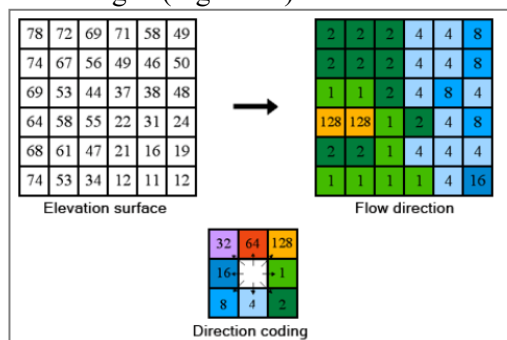

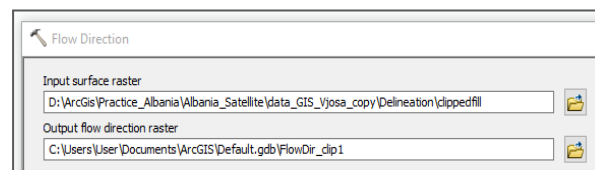**Figure 3.** The coding of the direction of flow (Balázs, 2017)

Figure 4. Setting the parameters in Flow Direction tool

The input surface raster will be the Filled DEM created in the step II.
The output flow direction raster was named with a significant name. At the Environment Settings/Raster Analyses, cell size should be the same as the filled DEM (Figure 6). The tool was executed. After the run was complete, a new flow direction grid will be added to the map document (Figure 12).

I. Flow Accumulation step

This tool calculates the flow in each cell, by identifying the upstream cells that flow in each downslope cell. So, each flow accumulation value is dependent on the number of the upstream cells that are flowing inside it, according to the topography of the landscape.
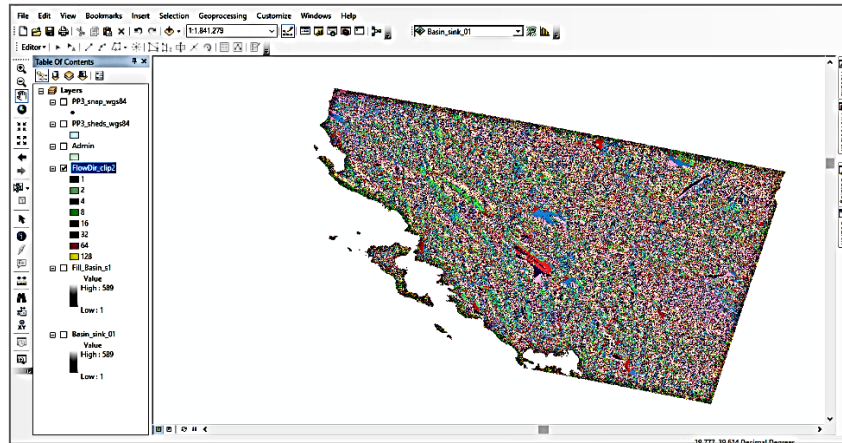
Figure 5. View of the new Flow Direction raster.

By browsing the Flow Accumulation tool, under Hydrology, the following parameters are set:
- The input surface raster will be the flow direction raster created at the step III;
- Set a significant name as output accumulation raster (Figure 14);
- Set the Cell size parameter equal to that of filled DEM (as previously done). Click ok.
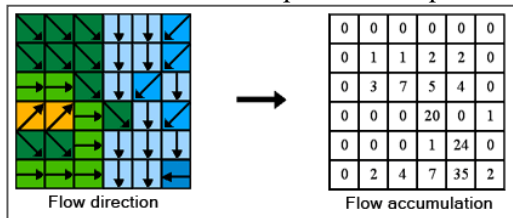

Figure 6. Flow Accumulation – number of cells draining to a given cell along the flow network *(*Balázs, 2017*)*
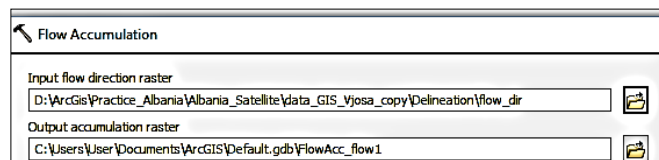

Figure 7. Setting the parameters during the flow accumulation process

After the run was complete a new accumulation raster had been created in our map document. Every cell of the grid has a number that shows the number of cells upstream from this cell. Therefore, the bigger the accumulation flow values of the cells are, the lower elevation they have in valleys, channels, or river beds flowing freely according to the landscape. If the new raster has a very dark color (black color) it is possible to change the number of classes (ex. equal to 5 in Vjosa case), browsing the Property of the layer name, then Classified. The Color Ramp is chosen as presented in Figure 15.
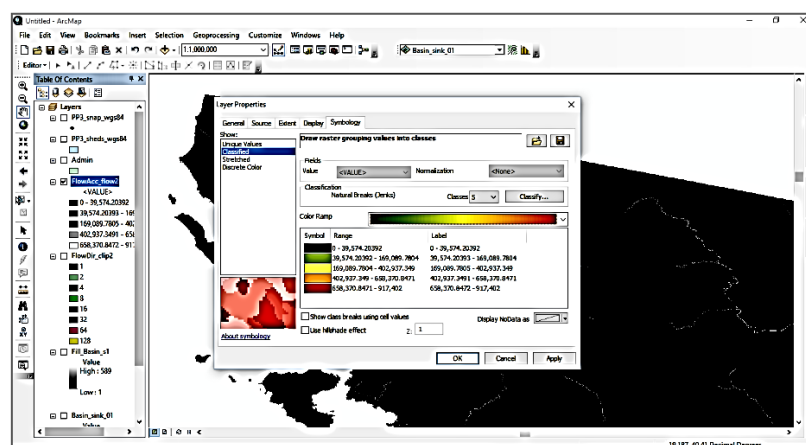

Figure 8. Changing the color ramp and putting the thresholds during accumulation step.

The first break value was specified as a threshold, according to the data for the Vjosa catchment. (See the range and the label for the 5 classes in the Figure 15, for the Vjosa project). The green color

was chosen for the first class, and red for the fifth one. At this point, we were able to pinpoint the areas of low or high accumulations in the Vjosa river.

It is therefore possible to compare the actual stream network with accumulated flow, because in the Vjosa study they are perfectly lined up. In any case the flow accumulated should well correspond with the watercourse data as it is displayed in the Figure 16. Flow accumulations enable the user to understand and then determine where to locate cells with high flow, which normally may be streams, channels, etc. Every cell has a pour point, that shows the placement of the cell where the water flows out from the cell. Pour points are named even outlet points.
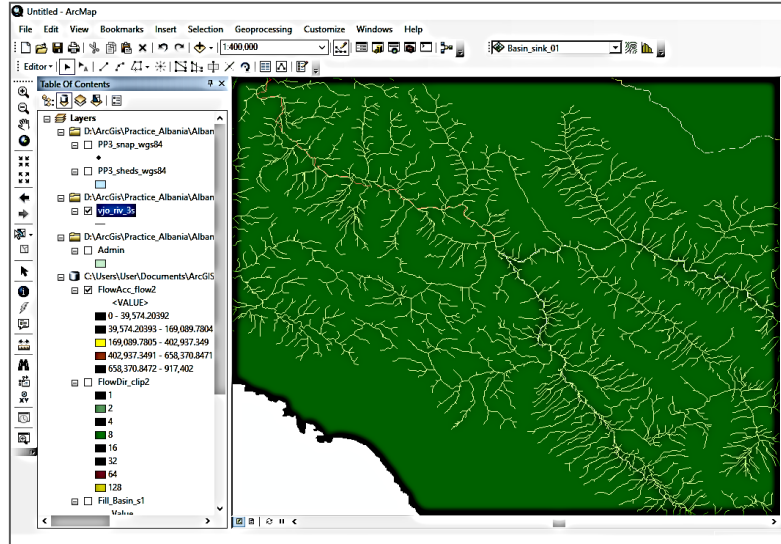

Figure 9. Final flow accumulation raster. The red color indicates the cells with bigger flow accumulation, eventually, in the lower altitude.

II.   *Building of the pour points*

Determination of the pour point location was a crucial phase of the basin delineation. A pour point should be placed in an area with a high flow accumulation, and it is used to assess the total contributing flow at that point of the cell. On this basis the pour points in the Vjosa project coincide with the Hydrometric stations; in other cases, even sampling sites or other data sources can select. Pour points can be built even manually.

III.   *Snapping pour points*

The meaning of the Snap pour points was related to snapping of the pour points created in the previous step to the closest cell with a high accumulation flow, in order to ensure that the placement done previously was correct. It converts the pour points to raster format, serving as input to the watershed tool also. So, by browsing the Snap pour point at Hydrology tool, we set the parameters as below:

- Set the Input raster or feature pour point data to the pour point loaded in the step V as in Figure 17.
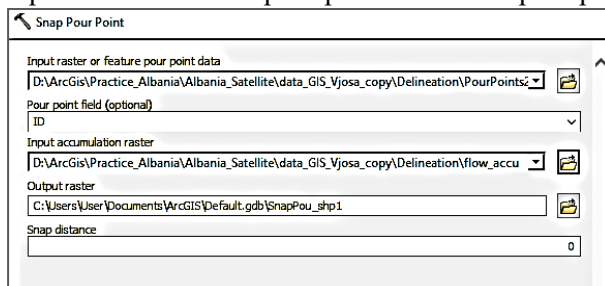

Figure 10. Snapping pour points.

- Set the Input accumulation raster to the accumulation raster created in the step IV
- Set the output raster with a meaningful name (Figure 17)

- The Snap Distance (with the same unit as the map) shows the distance used by the tool to search around the pour points for the cell that has the highest flow accumulation value. It should be dependent on the resolution of the data, and sometimes several trials are needed to find the best value. In the Vjosa case the exact location of the hydrometric stations was accepted, so the snap distance was set to 0 (Figure 17).
- At the Environmental settings/Raster Analysis Settings, after ensuring that the cell size is the same as that of the accumulation layer, the tool was run. The output is a raster of the pour points added to the map document (Figure 18).
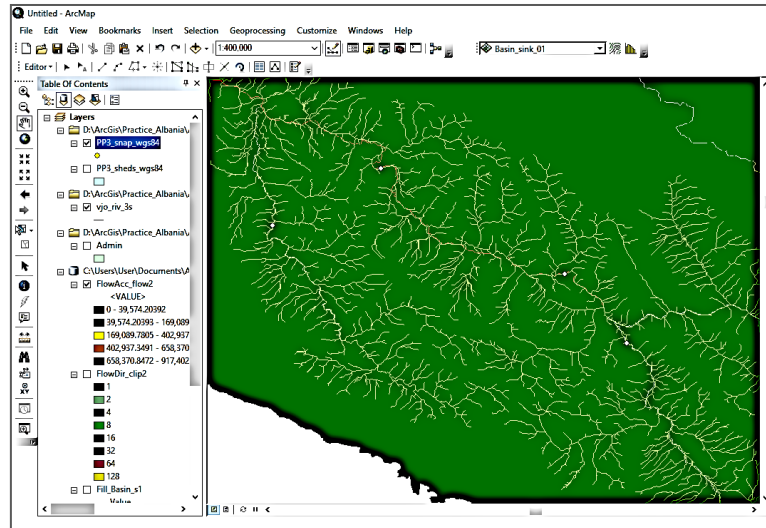

Figure 18. View of the snapped pour points (yellow dots).

IV. *Basin Delineation*

At the Watershed tool under the Hydrology tool, set the parameters as below:

- Set the Input flow direction raster as Flow Direction Raster created in step III.
- Set the Input raster or feature pour point data as the raster pour point file created in the step VI.
- Set the output raster with a meaningful name (Figure 19). Run the tool and after the run is complete a new raster will be created in the document map (Figure 20).
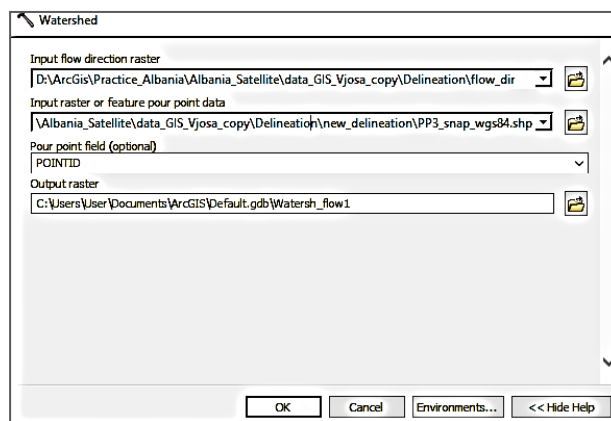

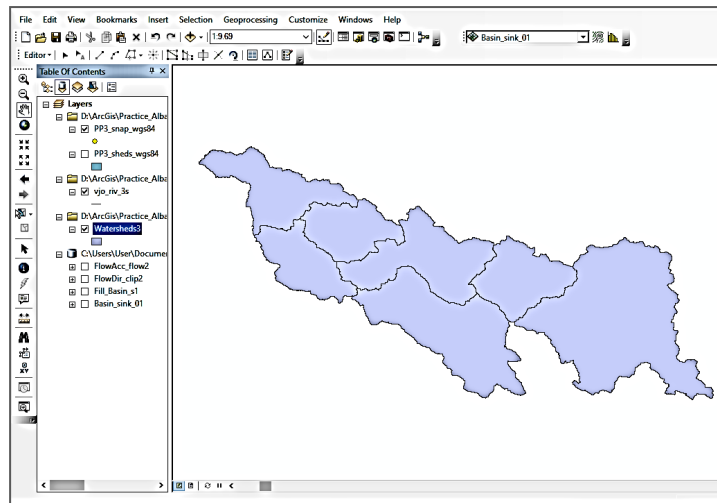**Figure 19.** Setting the parameters during the basin delineation process.

Figure 11. View of the Vjosa watersheds raster.

V. *Convert Basin Raster to Polygon*

For further analyses or geoprocessing, it is more useful to use vector files rather than raster files. To implement conversion QGIS provides Raster to Polygon tool, browsing in Toolbox/Conversion tool/From Raster (see Figure 21).
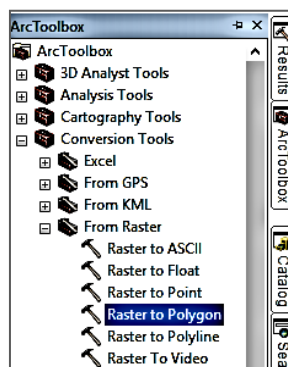

Figure 12. Browsing the Raster to Polygon tool in QGIS.

The parameters of the dialog box were changed as below:
- The input raster will be the watershed raster created in step VII.
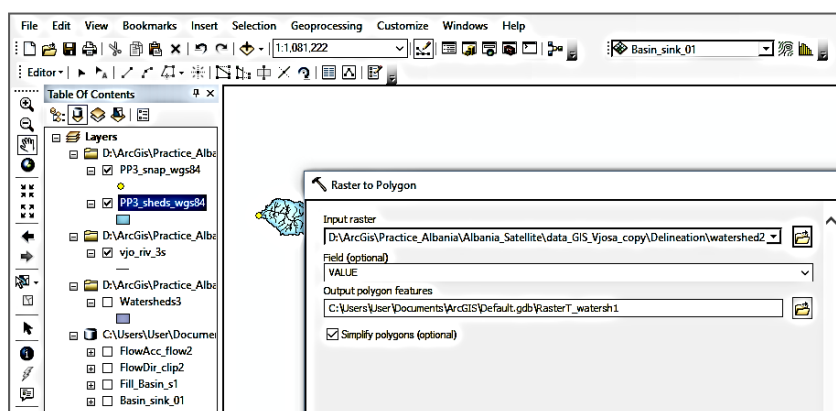- A meaningful name was selected for the output as shown in Figure 22.

Figure 13. Setting the parameters during conversion from raster to polygon in GIS environment.

A new polygon file will be displayed and the Vjosa watersheds and is finally added in the document map (Figure 23).
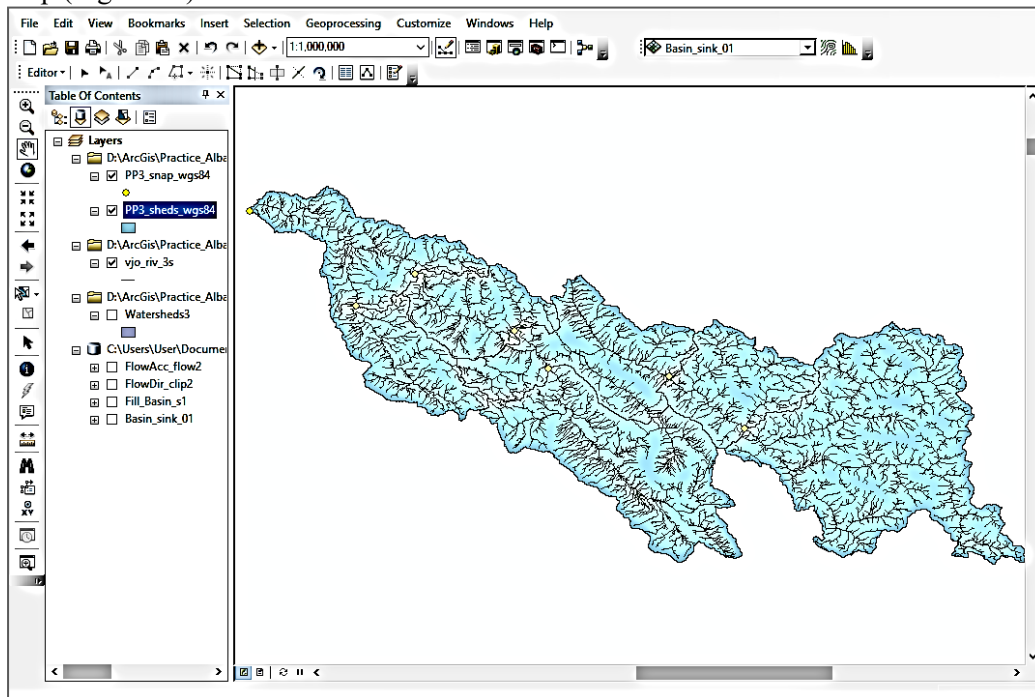

Figure 14. Delineated sub-basins for the six discharge stations that had data available for the WEAP model.

     VI.   Calculate Area of the Watersheds.

The Area calculation in QGIS is performed by using the Basin Layer shape file, at Attribute Table, adding a field (Area), and at the Field Calculator tool, writing the below calculations to convert (m^2) of the Raster file in (km^2). This conversion was needed because the Raster was in (m^2). For it, this formula was executed:

$$[COUNT]*90^2/1000^2, \text{ in } (km^2)$$

Where,
[COUNT] – is the number of pixels
90 m - is one pixel
Step IX completes the watershed delineation of the Vjosa river, basin making use of the QGIS software.

Results and Discussion

     The sub-basins of the Vjosa WEAP model were determined on the basis of the streamflow gauges (hydrometric stations) used for calibration points. These delineations divide the production of water within WEAP (in catchment nodes) into the areas that correspond to the catchment areas (or sub-basins) above the respective streamflow gauges. This strategy allows for direct water flow comparison in the current model of Vjosa river with the historic data observed at the gauging stations.

Considering the Permet streamflow gauge as an example, the tan region on the map represents the area where precipitation flow would be directed into the river section between the upstream gauge in Carshova and the Permet streamflow gauge. The water measured at the streamflow gauge in Permet can be derived through the following equation:

Flow at Permet
     = Upstream Gauge Values (river flow at Carshova)
     + Immediate Upstream Additional Streamflow (Permet catchment inflow)
     − Immediate Upstream Consumption in Demand Sites

Where "immediate upstream" means WEAP nodes physically located in the tan catchment area upstream of the Permet stream gauge (Figure 24).
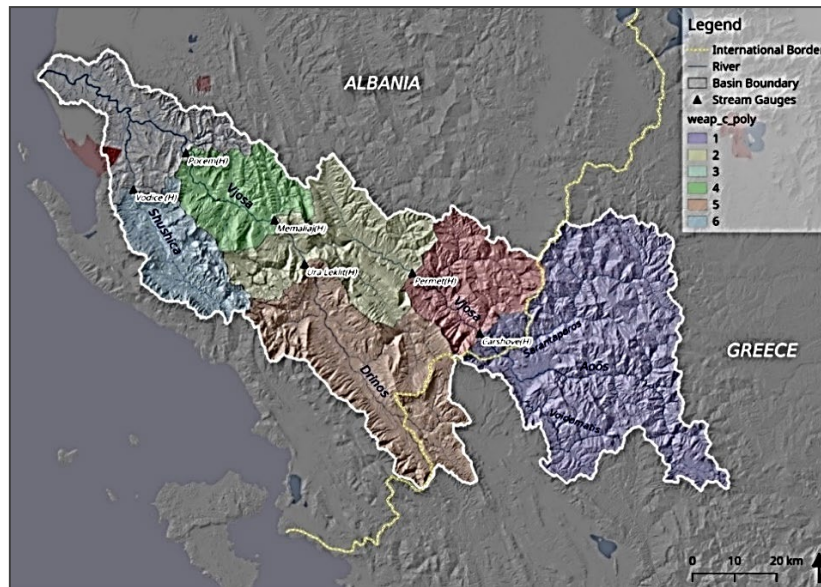
Research Paper

Figure 154. Vjosa delineated catchments for the WEAP model.

The catchment was delineated using a GIS software with the Hydro Tools extension and a digital elevation model (DEM), resulting in the final Vjosa watersheds shape files that have been used in the WEAP model for further analysis (Figure 25).

Figure 25. WEAP model schematic (Wickel et al., 2017).

The GIS shapefile was projected in the WGS 1984 coordinate system in order to display in WEAP. The completed WEAP schematic (Figure 25) shows the Vjosa catchment and demand site nodes within the seven subcatchment areas, named for the streamflow gauge directly downstream from them (or in the case of the two tributaries, Lumi i Shushices and Drinos). Therefore, using QGIS software, the locations of the streamflow gauges and the digital elevation model (DEM) of the region enabled the delineation of the Vjosa basin into seven catchments conventionally named according to the names of the streamflow gauge stations. The catchments are: Carshove (including a large area in Greece), Permet, Ura Leklit (including a small area in Greece, also referred to as the Drinos catchment, since it marks off the boundaries of the Drinos tributary), Memaliaj, Vodice (also referred to as Lumi i Shushices, because it is the Lumi i Shushices tributary), Pocem and Lower Basin (the outlet of the river to the sea, no gauging station available) (Figure 24).

Thereafter, all the model parameters are calibrated for the period during which there are historic records for both meteorological data (temperature and precipitation) and streamflow gauge data. For the Vjosa, the calibration period is from 2002-2008.

Figura 26 shows the observed and simulated streamflow for each of the stations following the calibration activities. These activities involve the land use characteristics for catchments upstream of the three monitoring stations used to calibrate the model. The calibrated stations are Permet (upstream catchments: Permet and Carshove), Ura Leklit station on the Drinos tributary (upstream catchment:

Drinos) and Pocem (upstream catchments: Pocem and Memaliaj). The two uncalibrated catchments: Lower Basin and Lumi i Shushices is assumed to have the same land use parameters as Pocem and Memaliaj, since those are the closest geographically (see Figure 5).
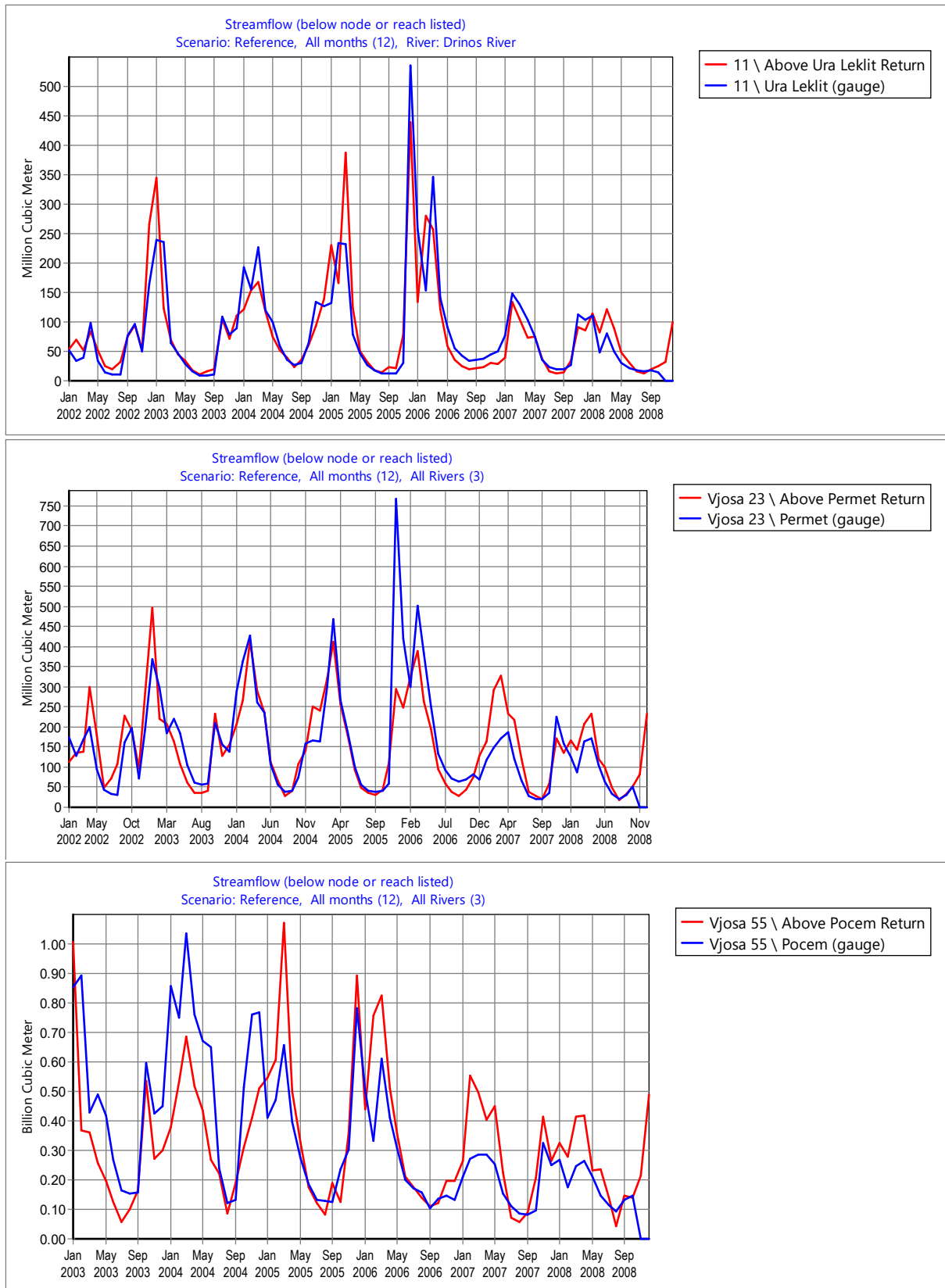

Figure 26. Streamflow comparison for Drinos, Permet and Pocem hydrological stations (Wickel *et al.*, 2017.

Conclusion

The thorough protocol provided here can be usually followed in delineation of other river basins as well. Nevertheless, it is important to stress that this guide incorporates details combined with specific characteristics of Vjosa River, therefore in applying this strategy for the study of other basins decisions should be taken according to the typical data needed and the kind of analysis that the users would like to perform. Vjosa River Basin has been divided into seven sub-basins for the purpose of including as many gauging stations as possible in the delineation model, in an attempt to avoid large sub-basins. The WEAP model results will have a certain level of accuracy and applicability depending directly on the available specific data that describe the Vjosa WEAP system (Yates et al, 2005a and Yates et al, 2005b).

References

Balázs B, Bertalan L, (2017) *Hydrology in Practice.* Departament of Physical, Geography and Geoinformatics, University of Debrecen, Hungary.

CNR Ingénierie, (2015) *Water Resources Management Plan in the Vjosa basin.* CEREG International, Diagnosis and analysis of sectoral patterns: Interim report. Agence de l'eau Rhône-Méditerranée Corse 2-4, allée de Lodz 69 363 LYON CEDEX 07, FRANCE.

INSTAT, (2011) *Statistical Yearbook, Census in Albania.* INSTAT, Tirana, Albania.

Lata, L., Bart AJ. Wickel., Galaitsi, S., Samper Hiraldo A, Bruci E, (2018) *First assessment of the impacts of climate change and development on the water resources of the Vjosa River, Albania.* Proceedings of ICOALS. Conference date: May 07-09, 2018. Agricultural University of Tirana.

Mucaj L, (2016) *Report on climate change scenarios for the Vjosa River Catchment area.*

Seferlis M, Laco T, Papadimos D, (2008). *Identification of human pressures and impacts on the surface waters of Aoos/Vjosa watershed.* The Goulandris Natural History Museum - Greek Biotope/Wetland Centre. Thermi, Greece. 70pp.

SEI, (2016), *WEAP Tutorial*: https://www.weap21.org/downloads/WEAP_Tutorial.pdf

Sergio Perez, (2012) *GIS for Water and Environment Management* Watershed delineation using ArcGIS Model Builder | GIS for Water and Environmental Management (wordpress.com)

UN-Water, (2019) *Integrated Monitoring Guide for SDG 6 Targets and global indicators*. Step-by- step monitoring methodologies for different proposed indicators, ex. 6.4.2 on water stress.

Wickel B, Lata L, Galaitsi S, Hiraldo AS, Bruci E, (2017) *Assessment of Hydro-Ecological and Socio-Economic Systems of the Vjosa River*, under the EU Flood Protection Infrastructure Project – FPIP.

Yates D, Sieber J, Purkey D, Huber-Lee A, (2005a) *WEAP21- A Demand-, Priority-, and Preference Driven Water Plan. Mod.:* Part 1: model characteristics. Water Int., **30**(4), 487-500.

Yates D, Sieber J, Purkey D, Huber-Lee A, (2005b): *WEAP21— WEAP21—A Demand-, Priority-, and Preference-Driven Water Planning Model:* Part 2, Aiding Freshwater Ecosystem Service Evaluation. *Water Int.*, **30**(4), 501-512.