CCM2 and ECRINS files use for Water Framework Directive (WFD) water body delineation and River Basin characterisation in the Vardar/Axios River Basin

François Baudry
Contracted in 2014 -2015 by the International Office for Water
Currently : Rhine-Meuse Water Agency/ Rozérieulles – B.P. 30019
57161 Moulins-lés -Metz
f.baudry16@gmail.com

Abstract

The 25 000 km² Vardar/Axios River Basin is shared by Kosovo, Serbia, the Republic of Macedonia and Greece. Water body delineation and River Basin characterisation are initial steps of the Water Framework Directive (WFD). For this purpose, shape files representing rivers and catchments are necessary. In riparian countries Digital Elevation Models (DEM) are regularly updated using aerial photos, satellite imagery and other sources. The accuracy of the DEM derived shape files is an issue. From the CCM2 (Catchment Characterisation and Modelling) of the EU Joint Research Centre (JRC) was derived the ECRINS (European catchments and RIvers network System) shape files for River Systems, Lakes and Elementary Catchments. They offer interesting information River Basin characterisation and mapping. However, when delineating water bodies in flat areas many errors of confluence were detected in the ECRINS river features. Therefore, in the Republic of Macedonia, more accurate River and Catchment shape files were produced in June 2015, by using a 5 meter resolution national DEM. These files were introduced in a Water Information System (WIS). River segments were attributed Pfafstetter codes for the Vardar River Basin within the territory of the Republic of Macedonia. The precise River and Catchments files serve as basis for Water Body delineation. But, as the GIS files of riparian countries do not match between them, ECRIN files were used to map transboundary watersheds in border areas. More accurate CCM2 and ECRINS files would enable correspondence with rivers and catchments for better water management within transboundary River Basins.

Keywords: River Basin, GIS resolution, Transboundary, Water Body Delineation

1 WFD objectives achievement and Water Body delineation

The Water Framework Directive (WFD) [1] requires delineating surface and ground water bodies and characterizing them. During the process of development of the River Basin Management Plan (RBMP), environmental objectives have to be set on water bodies (WB). Natural conditions, technical difficulties or disproportionate costs may be advocated by each E.U. Member State to postpone the deadline of objective achievement to 2021 or 2027. Even less stringent objectives may be set, under particular circumstances. The impact of anthropogenic pressures and the resulting expected status of the water bodies have to be taken into account in the WB delineation process. Achieving the WB environmental objectives is an important commitment of the Member States.

The WB delineation process is therefore, the basis on which is constructed many WFD elements: the delineated water bodies are the foundation bricks of WFD processes, as explained in the guidance document on water bodies [2]. Hence, the selection of the GIS file sources to be used for delineating has far-reaching and strategic implications.

2 - GIS files available for delineation

Delineating the surface water bodies includes the production of sufficiently accurate Geographical Information System (GIS) files of the water bodies (usually shape files). In this regard, the availability and quality of the existing GIS files of the rivers network and their catchments are critical.

To represent the WFD International River Basin Districts on maps, it is necessary to put together GIS files of the rivers network of several riparian countries. In each of the States, Universities, Institutions or Projects have developed Digital Elevation Model (DEM). These are usually produced and regularly updated by using aerial photos, satellite imagery, Google or OpenStreetMap and other sources, such as 1/25000 topographic maps.

The derived DEM GIS files, which are useful for WFD, include Rivers segments, Lake Polygons, Nodes of rivers confluences and the boundaries of rivers and streams drainage basin (catchment). Each State uses country specific geographical projections and DEM.

Since the resolution of the DEM and their accuracy vary, the GIS files derived from them vary also. As a result, it is not easy to put together riparian Rivers and Catchments files to produce a common GIS file for a whole International River

Basin District. Moreover, as far as River Basin Management (RBM) data are concerned, depending on the riparian country, the tables of attributes of the Rivers and Catchments GIS files are more or less rich in characterisation data.

3 - Files covering international River Basin in Europe: CCM2 and ECRIN files

The EU Joint Research Centre (JRC) produced files on rivers systems in the frame of the Catchment Characterisation and Modelling Project (CCM2). Under the European Catchments and Rivers Network System (ECRINS) Project, GIS shape files were derived from the CCM2 and other sources to facilitate the use of the information for WFD implementation. The CCM2 and ECRINS files cover an area larger than Europe.

The CCM2 shape files are freely downloadable on the web (http://CCM2.jrc.ec.europa.eu/ and the ECRINS files on the European Environmental Agency website (EEA). They can be used with, for instance, the free OpenSourceSoftware QGIS. Hence, without any payment, maps can be easily produced by non-specialists to represent hydrological features such as river network systems for various Strahler number, lakes or 'mosaics' of Functional Elementary Catchments (FEC) for particular areas.

The CCM2 and ECRINS shape files are particularly interesting to map water related information for International River Basins. They cover many countries and along border areas, by using them, there is no need to put together heterogeneous GIS files from different countries to represent Transboundary Rivers, Lakes and their watersheds.

The methodology and the attribute tables of CCM2 and ECRIN GIS files are described in a report prepared by the EU Joint Research Centre (JRC) [3]. The descriptors in the fields in these attribute tables are relevant for River Basin characterisation, as described in section 5.

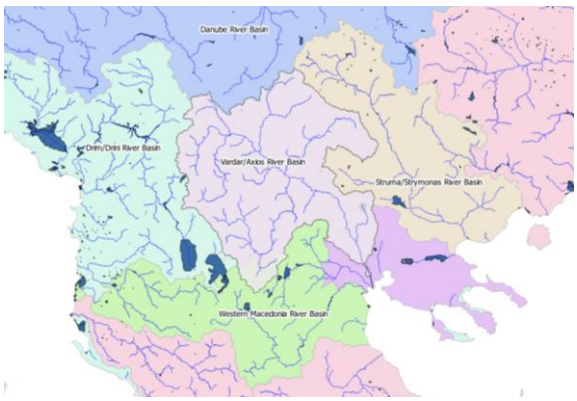
However, the features of the ECRINS shape files representing River Network and Catchment do not have a resolution better than 100 m. In 2014, while attempting to delineate Surface Water Bodies in the Vardar sub-basins, errors of representation of the River Network System were identified. Consequently, the accuracy of the ECRIN shape was considered as an issue in flat areas, as described in the section 6.

4 - The international Vardar/Axios River Basin

The Republic of Macedonia is aiming at accessing to the European Union. In this connection, the EU funds projects to assist the Ministry of Environment and Physical Planning (MoEPP) and other water institutions to implement the WFD. The Project entitled: "Technical assistance for strengthening the institutional capacities for approximation and implementation of the environmental legislation in the area of water management in Macedonia" (EuropAid132/08/D/SER) was implemented jointly by Ramboll (Denmark), and the Office International for Water (France) from January 2014 to December 2015.

The Project main geographical area was the Vardar River Basin in the Republic of Macedonia. The Vardar River is called 'Axios' when entering into in Greece.

Figure 1: Location of the Vardar/Axios River Basin among the WFD River Basin Districts in South Europa



Source: ECRINS shape files, EEA; CCM2 shape files, E.U JRC.

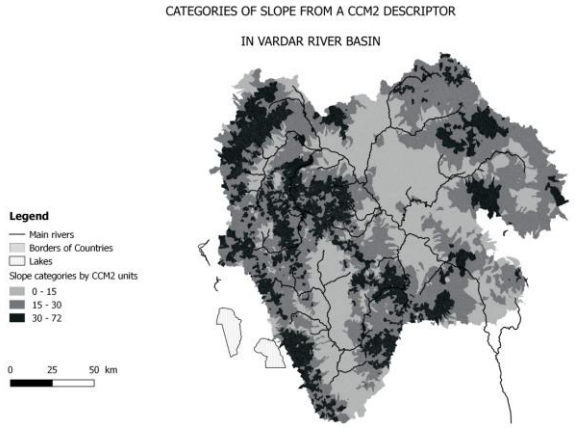
The Vardar/Axios River Basin is an international River Basin. The riparian countries are Serbia, Kosovo, Macedonia and Greece (see Figure 2 and 3 in the Annex: maps). It expands over a rather mountainous territory (see Figure 4). Its average elevation is about 790 m. This River Basin covers about 25,000 km² of which around 20600 km² are in the Republic of Macedonia. The total length of the Vardar/Axios River is 389 km, with 87 km being in Greece. The transboundary Lake Dojran/Doirani is located in the Vardar/Axios River Basin. It is shared by the Republic of Macedonia and Greece.

5 - The use of CCM2 and ECRIN files for mapping and characterising the Vardar/Axios River Basin

For mapping on an A4 format, basins and sub-basins of the Vardar/Axios the accuracy of the shape files representing the River Network system of CCM2 and ECRINS files is of satisfactory quality. This is why, these shape files were often used during the above mentioned EU funded Vardar Project to represent the river systems, other main geographical features of the Vardar/Axios River Basin. Hence, many maps were produced to give a general picture of this River Basin and its sub-basins (see Figure 2 and Figure 3 in Annex). In this regards, the number of Strahler is very useful to make distinction between the small and large rivers for instance to represent on a map only the large ones. During the Project, when accuracy was not an issue, thematic maps of the basins and sub-basins, were produced using particular ECRINS and CCM2 descriptors for pedagogical and communication purpose (Figures 2, 3, 4, 5).

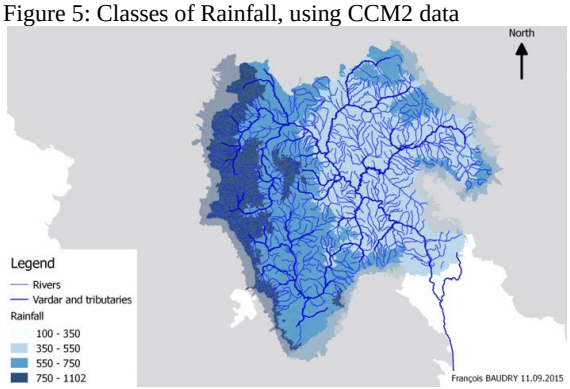
The CCM2 shape files included indicators such as the slope, the altitude, the rainfalls and Pfafstetter code. They are relevant for the description of surface water bodies. Classes of slope and classes of rainfalls were mapped for the Vardar River Basin (see Figures 4 and 5).

Figure 4: Classes of slope using CCM2 data



Source, CCM2, EU –JRC, EU 'Vardar Project 2014-2015'

Figure 5: Classes of Rainfall, using CCM2 data

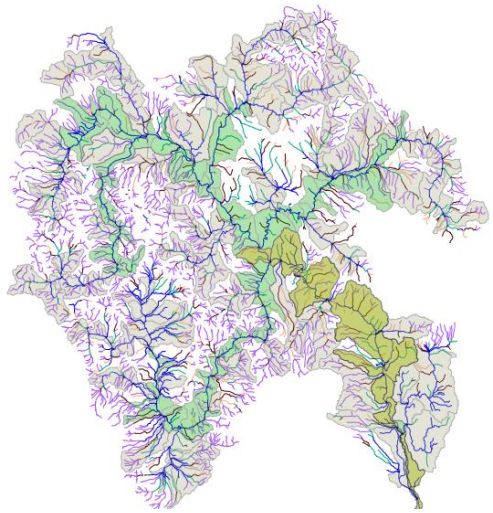


Source: CCM2, JRC, EU 'Vardar Project 2014-2015'

One of the WFD steps for characterising Surface Water Bodies is to define a typology [2], [4]. As per WFD, under system A and B, various descriptors have to be utilised, these are: altitude, geology, size of the river basin and the WFD ecoregions.

The tables of attributes of the ECRINS shape files include fields that appeared interesting also to map and characterise the surface water bodies. The fields regarding 'surface' and 'altitude" of the ECRINS files Functional Elementary Catchment (FEC) enable to characterise the River Basin by classes of size and altitude (Figure 6). During the above mentioned EU funded Vardar Project 2014-2015, the ECRIN shape file were used also to explain the delineation methodology to the staff of the Macedonian water institutions (see Figures 6 and 7).

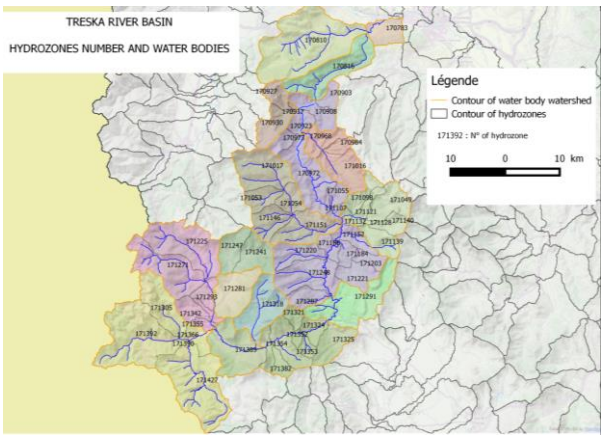
Figure 6: Use of the field size of the River Basin of the ECRINS Catchment GIS files



Source: ECRINS files, working map of EU 'Vardar Project 2014-2015' (Legend: over 1000 km² below 10 000 km², above 10 000 km² green-yellow, blue Large River, red small rivers).

A first water body delineation test was performed in July 2015 by using the ECRINS GIS files for the sub-basin Treska. As this basin is mountainous, the FEC seemed appropriate to delineate water body catchment by merging the FEC, where appropriate.

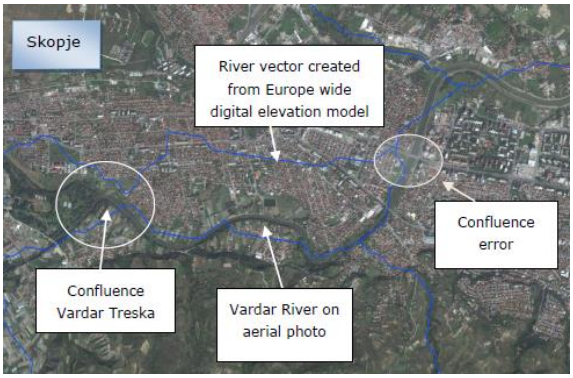
Figure 7: First delineation of water bodies by merging elementary unit FEC (called hydrozones in the map).



Source: ECRINS file, (EEA), EU 'Vardar River Basin 2014 -2015'

But, when checking the location where the Treska River merges with the Vardar River, it became apparent that the geometry of ECRINS River network shape file need to be corrected. In plains, the ECRINS shape file appeared of insufficient accuracy to be used for the Surface Water Body delineation (see Figure 8). This was explained in a first report on delineation submitted to the Macedonian Authorities [4].

Figure 8: Identification of an error in the river network as featured on the ECRINS files (confluence Treska River /Vardar River)



Source: ECRINS River Network and Typology report from the EU 'Vardar Project 2014-2015' and its Typology report [4].

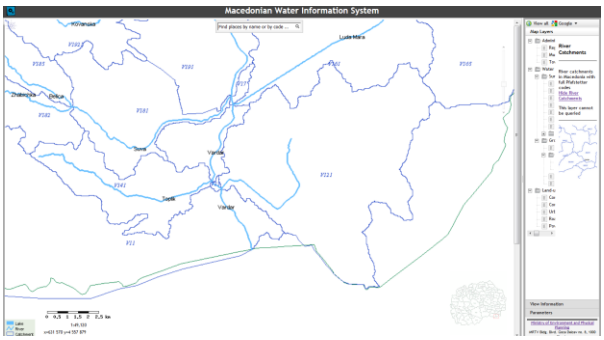
In August 2014, it was assumed that it might be possible to correct the ECRINS GIS files, in flat areas. To this end, it was proposed to use other geographical sources of information such as OpenStreetMap, Google maps, topographic maps or existing DEM. But, in December 2014, it became clear that it was not the best option. Beginning of 2015, the use of ECRINS shape files for Water Body (WB) delineation was abandoned. It was decided to create a more accurate River Network for the whole Vardar River Basin by using high resolution DEM of the Republic of Macedonia. The best national DEM available had a resolution of 5 m.

A very detailed River Network was derived from this DEM by Ivan Mincev, a consultant of the Vardar Project. It was decided also to produce the corresponding River catchment shape file by creating a River catchments of above 10 km². Each catchment should have only one river segment inside. Each river segment was given the name of the river or streams figuring in the corresponding 1/25000 paper topographic map.

Finally, two precise shape files were completed in July 2015. One was for River segments and the other for the corresponding River Segment Catchments. The quality check of the shape files went on in July 2015. When the two shape files for rivers and catchments were of sufficient quality, the Water Bodies were delineated and the pressure and impact analyses could be launched and were carried out from August to October 2015.

The corrected River and Catchment shapes files and other water related data were uploaded on a web mapping tool designed by Henning Mejer, a consultant of the Vardar Project. They are now part of the information system of the Ministry of Environment and Physical Planning (MoEPP) http://wis.moepp.gov.mk/# (Figure 9). It is called "Macedonia Water Information System" (MWIS). This tool includes many user friendly functions. Many water related datasets prepared and checked during the Vardar Project were uploaded in the MWIS and they can be displayed in graphics and maps. The datasets are freely downloadable. The staffs of the water institutions were trained to the use of the web mapping tool and participated to the creation of the datasets and select options for the design of the MWIS.

Figure 9: River segments and their catchments as displayed by the Macedonia Water information System (MWIS).



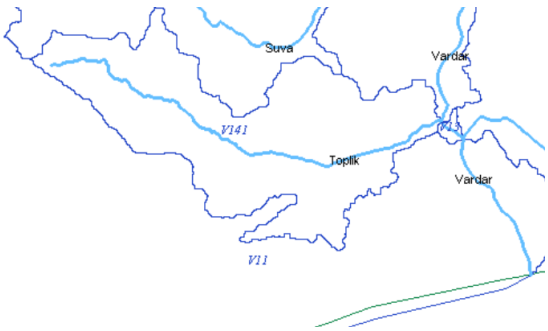
Source: http://wis.moepp.gov.mk/# Henning Mejer, creator of the web mapping tool. Ivan Mincev, producer of the Rivers and Catchments Shape file derived from 5 m resolution national DEM of the republic of Macedonia.

Each river segment was attributed a Pfafstetter code. The code was generated automatically after the logical tree of the river network in the Republic of Macedonia has been completed and carefully checked. The code in the Macedonia Water Information System (MWIS) does not take into account the downstream small tributaries of the Axios (see Figure 10 in Annex). The Pfafstetter code in MWIS is therefore specific to the Republic of Macedonia.

As for the CCM2, the Pfafstetter coding of the delineated catchment units and the corresponding river segment has been done differently (Figure 11 in Annex). The CCM2 coded river tree includes all the rivers and streams in all the riparian countries. However, due to the insufficient resolution, it is likely that it contains errors.

The coding of the MWIS is for the whole country, as they are several River Basin the river segment code in the MWIS includes two elements, on for the River Basin, the other for the Pfafstetter code. For instance, the river segment 'Toplik' was attributed the code "V141", with 'V' standing for Vardar, and '141' for its Pfafstetter code (see Figure 12)

Figure 12 : River Segment named "Toplik" and its catchment and Pfafstetter code as displayed on the web by MWIS.

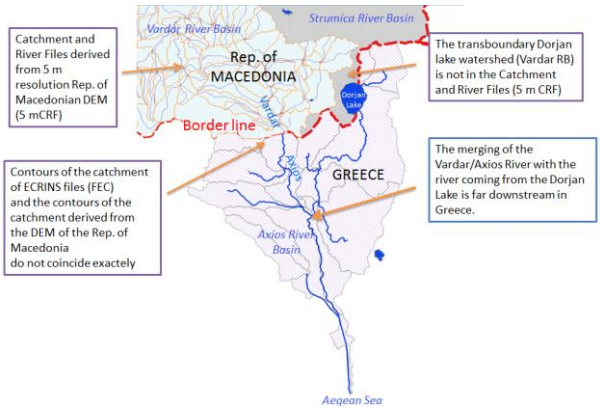


Source: http://wis.moepp.gov.mk/# , designer and producer of the web mapping tool Henning Mejer. Shape file produced with the Rep of Macedonia DEM by Ivan Mincev in 2015.

In the borders areas, a country specific high resolution DEM does not enable a full representation of Transboundary Rivers and their Catchments. To be able to do so, it is necessary that GIS data be shared between riparian countries. Transboundary cooperation has to be organised in order to facilitate such exchange of GIS files. This can be a long process.

Therefore, for the WFD related maps in transboundary areas, GIS files covering Greece and the Republic of Macedonia were needed. In this connection, the ECRINS files were useful for mapping in the border areas. In these areas, two GIS shape files, one being ECRN files , the other the high resolution DEM derived GIS files were superposed to create maps representing transboundary Rivers and Lakes as well their entire catchments (see Figure 13 and Figure 14 and 15 in the Annex : maps). This representation is not completely satisfactory as the vectors of the two shape files do not correspond exactly. It would be better to have accurate shape files, with the same geographic projection over border areas.

Figure 13: Coverage by ECRINS Rivers and Catchment files of transboundary areas.



Source: ECRINS River and Catchment files and high Resolution River and Catchment Files of the Rep. of Macedonia.

For calculating the surface of the transboundary catchments, the ECRINS field 'surface' of the FEC file was used. For each transboundary sub-basin of the Vardar/Axios Basin was distinguished (see table 1):

- the surface of the sub-basin within the Republic of Macedonia,
- the surface of the whole sub-basin including the surface in riparian countries.

Table 1: Estimation of Sub-basins surface with ECRIN file and with the high resolution DEM of the Rep. of Macedonia

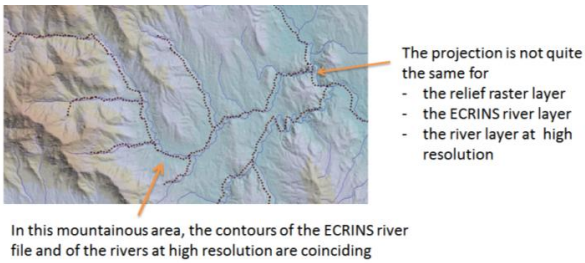
Sub-basins of Vardar/Axios River Basin	Surface for the sub-basins within the Rep. Maced. (km²)	Surface for the whole sub-basin (km²)
Upper Vardar	1616	1629
Middle Vardar	2570	2577
Vardar downstream	2822	3122
Bregalnica	4320	4322
Crna Reka	5044	5180
Pcinja	2058	2878
Treska	2071	2071
Lepenec	133	831
Total	20634	22608

Source: ECRINS (EEA) and 5m resolution DEM derived GIS files from the Rep. of Macedonia.

6 - The insufficient accuracy for delineating Surface Water Body in flat areas

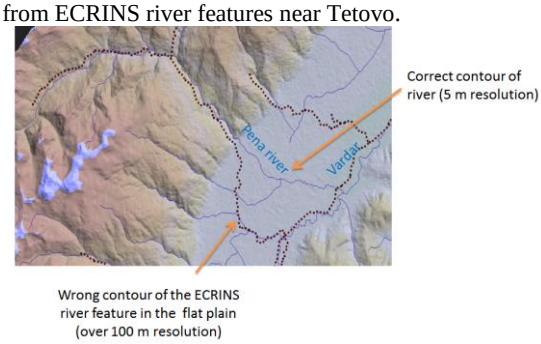
In mountainous areas, the ECRINS shape file contours correspond to the more detailed one deriving from a 5 meter resolution DEM (see Figure 16).

Figure 16: Case 1 - satisfactory corespondance between the ECRIN files and the rivers contours in Treska sub-basin.



Source: ECRINS file, EAA, and high resolution river network derived from national DEM of Republic of Macedonia.

Figure 15: Case 2 - Error in the contour of the rivers derived from ECRINS river features near Tetovo.

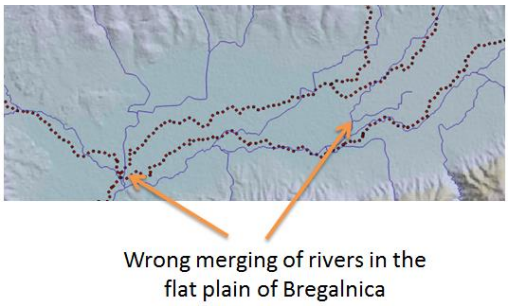


Source: ECRINS file, EAA, and high resolution river network derived from national DEM of Republic of Macedonia.

In flat areas, on the contrary, the resolution of the ECRINS shape file is not sufficient. For instance, near the town of Tetovo in the upper Vardar River Basin the contour of the rivers are not correct. During the preparation of the ECRINS file preparation the junction between rivers, which are close from one another, was forced. In reality, these rivers are not connected. In this case, the confluence between the Pena River and the River Vardar, as per ECRINS file, is at the wrong place (see Figure 15).

In the Bregalnica sub-basin, a Project has already proceeded to the delineation of Surface Water Bodies, using a DEM. In mountainous areas, it was possible to replicate the same delineation with the ECRINS files but in flat area it is not the case (see Figure 16).

Figure 16: Case 3 - Error in the contour of the rivers derived from ECRINS file in the Begalnica River Basin near Kochani.



Source: ECRINS file and high resolution river network (RoM).

To estimate the magnitude of the errors in a whole River Basin, it is possible to calculate the part of the flat areas within the River Basin where errors occur. A threshold for a class of slope can be defined and then the areas affected by errors can be mapped by using for instance the CCM2 slope descriptor.

The ECRINS file can be used also in transboundary area in EU member state where the EU water Directive are implemented or for other water management purpose. A test was performed in administrative area of the Rhine-Meuse Water Agency. The aim was to see the correspondence between the WFD delineated Water Body catchment and the ECRINS catchments. As a matter of fact, they were only few catchment units from the two files which were corresponding. In the future, it would be interesting to be able to have a better correspondence between the ECRINS and CCM2 units and the countries 'official' river network and their delineated catchment units.

7 - Conclusions

During the EU funded 'Vardar Project 2014-2015', the CCM2 and ECRIN shape files were used extensively for general mapping and characterisation. They were especially precious in borders areas around the Republic of Macedonia. For communication and training, when accuracy was not a main concern, the files were very interesting and gave good results.

The files served also to assess particular situation, in places where it was known that the errors are minor, such as in mountainous areas or when the ECRIN or CCM2 descriptors give the best information available.

To better benefit from the ECRINS and CCM2 advantages, the challenge would be to use more precise DEM over the countries covered by CCM2 in order to create more accurate shape files at international level. It would be better if they correspond, as much as possible to the official rivers and catchment shape files in the countries.

If not yet available, it will be also interesting to refer, in the CCM2 and ECRINS files to the codes of the existing delineated water bodies in countries. The corresponding Pfafstetter code and the national Water Bodies codes could be introduced in downloadable new versions of the CCM2 and ECRIN shape files. This issue concerns not only relatively small transboundary river basins like the Vardar/Axios one, but also large ones expanding over many countries, such as the Rhine, Meuse and Danube River Basins,

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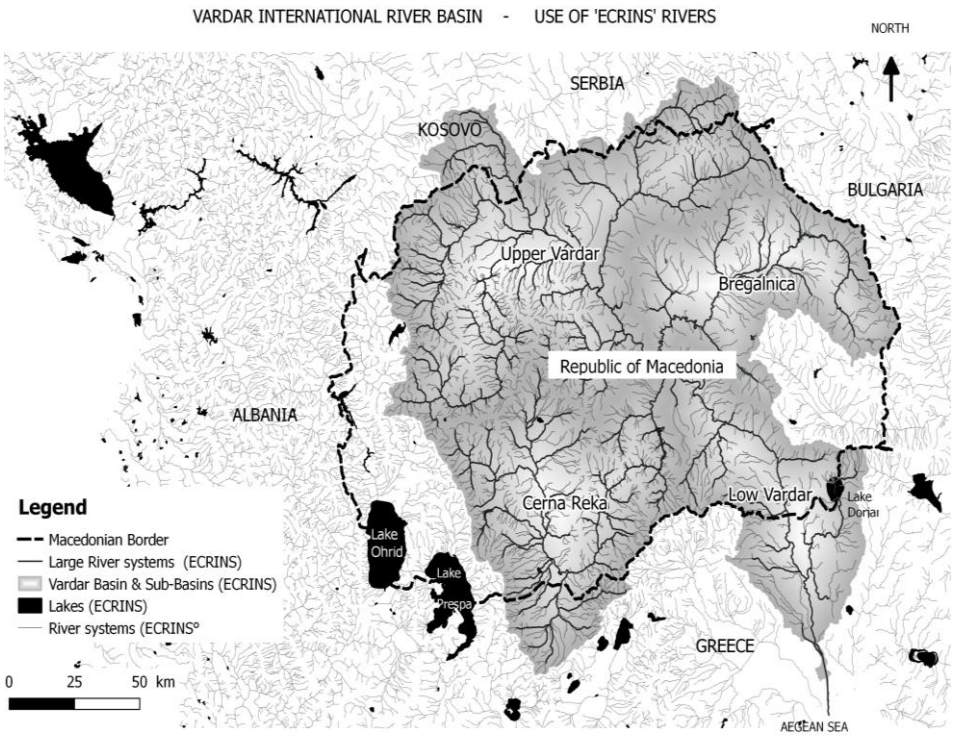
ANNEX: Maps of Vardar/Axios River Basin

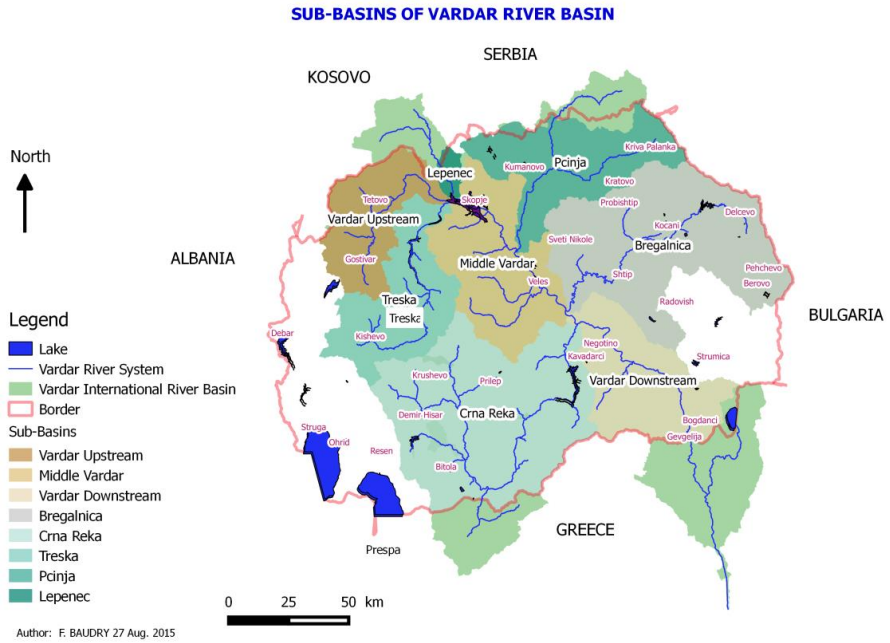
Figure 2: Use of ECRINS file for general description of Vardar /Axios international River Basin

Vardar/Axios River Basin with ECRINS shape files



Source: ECRINS GIS Files (EEA), produced with QGIS

Figure 3: Use of ECRINS files for general description of the Vardar /Axios Sub-Basins



Source: ECRINS GIS files (EEA) and city files from the MoEPP – Rep. of Macedonia, produced with QGIS

Figure 10 : Pfastetter code of River Segment in the Vardar River Basin within the Republic of Macedonia

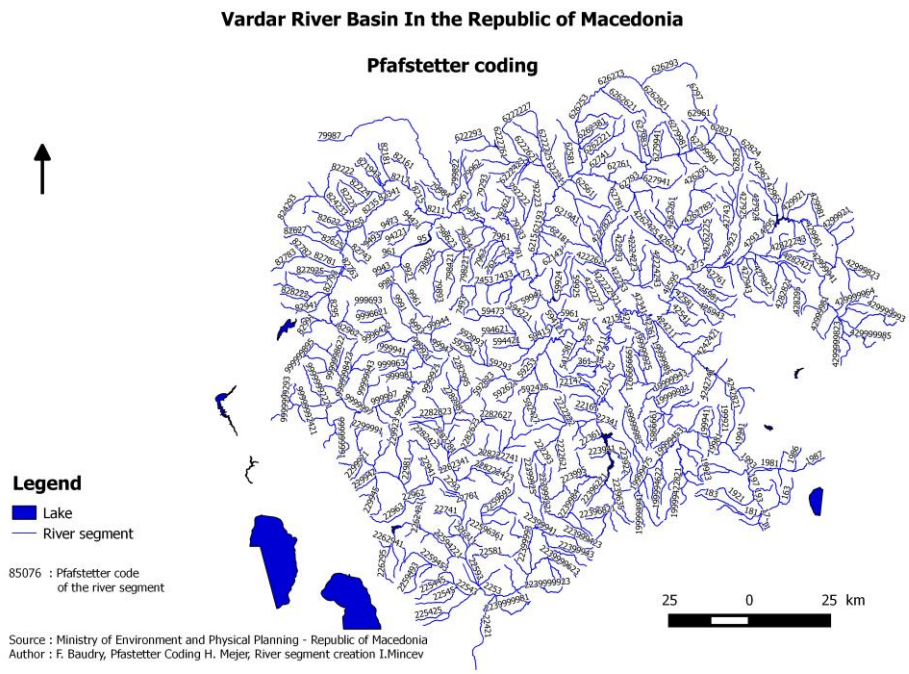
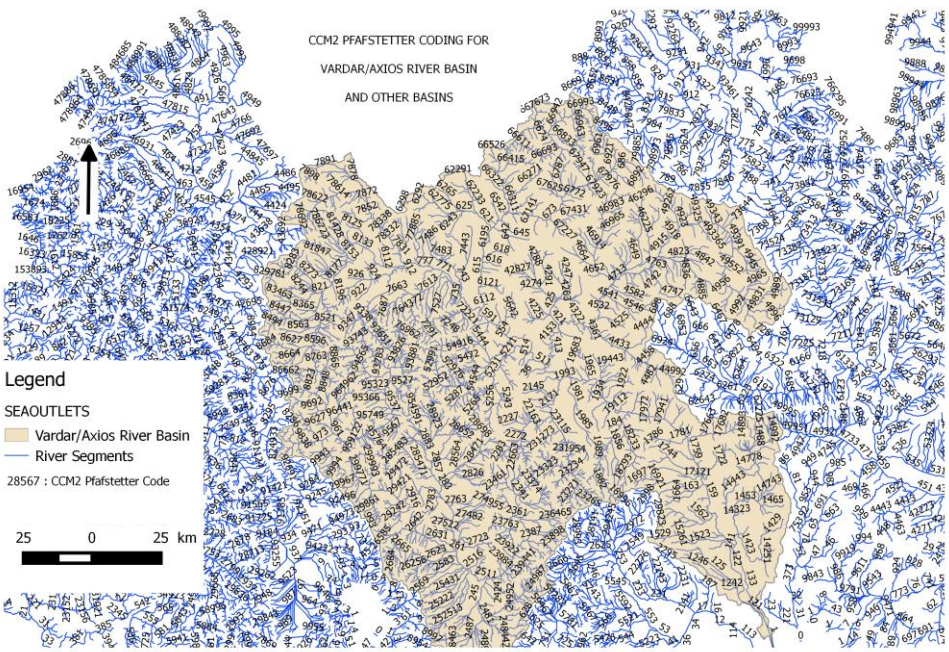
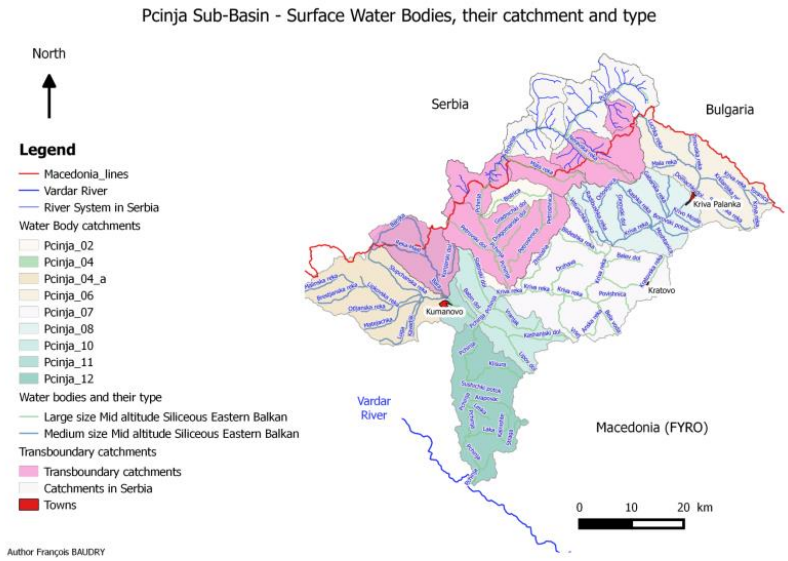


Figure 11 : CCM2 Pfafstetter Coding for Vardar/Axios River Basin and other Basin



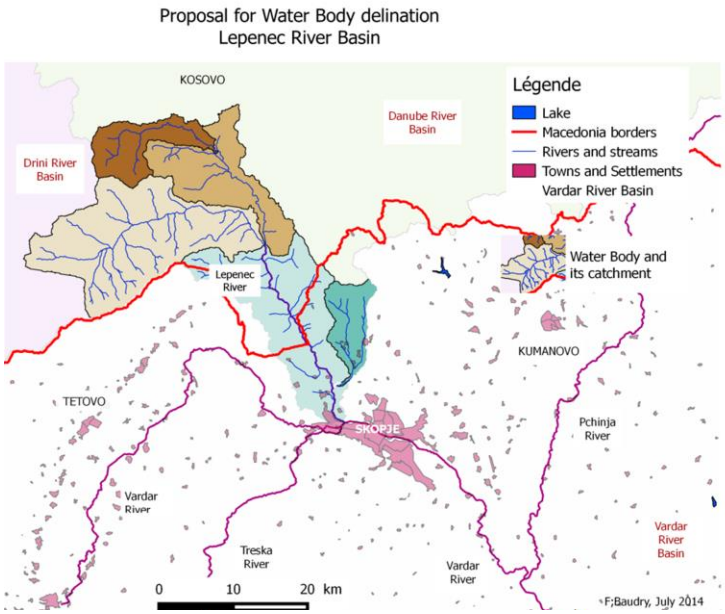
Source: CCM2, JRC – E.U

Figure 14 : Use of ECRINS files in the border areas : identification and mapping catchment areas (Pcinja sub-basin)



Source : EU funded 'Vardar project 2014 -2015' for the Ministry of Environment and Physical Planning of the Republic of Macedonia.

Figure 15 : Use of ECRINS files in the border areas : identification and mapping catchment areas (Lepence sub-basin)



Source : EU funded 'Vardar project 2014 -2015' for the Ministry of Environment and Physical Planning of the Republic of Macedonia.