GUIDELINES AND METHODOLOGY FOR APPLYING THE WOC SYSTEM

USAID SOUTH CAUCASUS WATER PROGRAM

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GUIDELINES AND METHODOLOGY FOR APPLYING THE WATER OBJECTS CODING (WOC) SYSTEM IN THE SOUTH CAUCASUS

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1. Background

Contact No USA/1367C-7FP-0002 (USAID-FP) signed between GEORISK Scientific Research Company, Armenia (hereinafter, *the Contractor*) and PA Government Services has envisioned development of water object coding guidelines highlighting the step-by-step process of water object coding of Georgia and Azerbaijan under the USAID-funded South Caucasus Water Program. The guidelines are expected to serve as an effective means of disseminating communications and allow for improved collaboration and coordination amongst water agencies of the riparian countries. As stated in the ***Request for Quotation (RFQ) USAI1358C-7FP-03*** for the said services, to develop the WOC Methodology the Contractor might consider as a technical reference the European Rivers and Catchment (ERICA) coding system developed in February 1997 and accepted by European Union. Based on these methodologies, the Contractor has already developed and tested Application of the Water Object Coding System in Armenia under the "Program for Institutional and Regulatory Strengthening of Water Management in Armenia" administered by PA Government Services Inc.

2. Introduction

As mentioned in the Work Plan of **USAID South Caucasus Water Program** implemented by **PA Government Services, Inc**, the goal of this activity is to increase regional cooperation in the management of shared water resources in an effective and sustainable way**.** In view of this goal, the activity will pursue the objectives of:

- Strengthening of the institutional framework and capacity for trans-boundary basin management and increasing of the technical understanding on key topics.
- Development of the scientific and analytical capacity needed to turn data into information, and promotion of its use for management.
- Strengthening civil society's participation to achieve stewardship and measurable social, economic, and environmental results.
- Promotion of regional and international discussion and cooperation amongst Armenia, Azerbaijan and Georgia on the issues pertinent to regional water management critical in the context of the South Caucasus [www. scaucasusater.org].

To achieve this goal, the availability of digital data on rivers and lakes and their drainage basins (catchments), including information on the characteristics of these entities, is important for the analysis of environmental pressures and their impact on water resources. Recent policies, such as the ***Water Framework Directive*** (***WFD***) require the setup of *Geographical Information Systems* on water bodies and drainage basins as a basis for the development of *River Basin Management Plans* and for the analysis and assessment of environmental impact.

These geo-information systems and related databases would be indispensable tools even in the solution of strategic tasks such as:

- Facilitating policy-making in international water resources management in the South Caucasus region;

- Characterization of the river basins to support the River Basin Management Plan according to the WFD;
- Tackling water quality issues: data on surface water quality monitoring (point and non-point sources of pollution) and pollutants from industries, agriculture and urban wastewater treatment plants;
- Cooperation on trans-boundary protected areas;
- Consideration of hydro-morphological changes related to operation of dams, hydropower plants, etc.

Moreover, it can be useful for a wide range of applications, including mapping, monitoring and modeling activities. A consistent database of river networks and catchment boundaries can support a variety of models of hydrology, ecosystems and climate. Analysis of river discharge, sediment and nutrient transport, biophysical attributes of drainage basins, and calculation of environmental pressure indicators can serve examples of such applications.

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3. Main Principles of the Coding

The *Regional Geographic Information System on Water Resources of the South Caucasus* needs to be as much accurate as possible, accessible, and easily interpretable. In other words, it must be an information system that incorporates the following data sets and features at the minimum:

- homogeneous data with a consistently high quality across the whole area of interest;
- a fully connected and hierarchical network of rivers;
- a nested set of catchments;
- a link between the various types of water bodies (rivers, lakes, transitional waters) and their respective catchments;
- a set of catchment characteristics useful for the calculation of proxy pressure indicators;
- locations of the national networks of stations in Armenia, Azerbaijan and Georgia and identification of the drainage basin for each monitoring station.

In their most basic forms, these datasets provide raw materials for presenting the spatial relationships between these features and other datasets such as land-use and topography.

To be operational, such system must have a capability for entry of additional data depending on the task solved. To link the additional data with existing datasets, each water object must be assigned a unique code. Considering that the code must also indicate the position of the considered water object in space, it is important to decide codes of what objects must be considered basic.

3.1 Catchment as a Working Unit

Selecting a working unit for the coding, it is important to bear in mind that surface hydrology is rather changeable in response to both natural factors, such as climate, and human impacts. In this respect, catchment would be comparatively stable unit to consider.

Catchment is defined as a part of the land surface that is drained by a unitary drainage network. Its boundary is defined as the line linking the points of greatest height between separate drainage networks, and thus this line separates their surface runoffs.

Another consideration to bear in mind is that tools designed for trans-regional water management must not be based on the national boundary principle. Terrain, soil type, geology and climate all play their roles, but none of these observe political boundaries. Some national boundaries are defined by major watersheds but many are not. Some, on the contrary, are defined by a river - the boundary being the center-line. For a region such as the South Caucasus, the hydrology of its area of interest must be seen as continuous and free from political boundaries.

In order to obtain impartial, reliable and complete information at a regional scale, it is necessary to use a 'natural' hydrological unit - **catchment.**

In Richards (1982), the term 'drainage basin' is used in place of 'catchment', but the meaning is the same.

Drainage basin forms a fundamental spatial accounting unit in hydrological studies, since it represents an open system [Dooge, 1968] within which moisture inputs, outputs and storages can be monitored to define the water balance equation:

Input	=	Output	+-	Storage changes
[Rainfall]	=	[Streamflow+Evapotranspiration]	+-	[Groundwater and soil moisture storage changes]

[Penman, 1950]

However, there will be times, for example when a pollution incident occurs, when it is necessary to identify which state a particular river stretch is in. This can be achieved by using the facilities offered by GIS to overlay a suitable national boundary dataset. To be suitable it must be consistent with the drainage system, i.e., where a river line is coincidental with a national boundary, these lines are identical. A hydrologically suitable national boundary dataset is available at SCWP website. http://www.scaucasuswater.org/index.php?article_id=24&clang=0

3.2 Catchment Derivation Methods

The next step is to decide on the method of catchment basin derivation.

Clearly, catchment boundaries can be identified if data on drainage network and elevations are accessible.

There are 2 methods to identify catchments:

- **automated DEM –** a software that utilizes DEM to identify a watershed, or

- **manual drafting** by interpretation of elevation and drainage information available on paper-maps.

When catchments are drawn manually, hydrologist uses simple, straightforward rules, e.g., catchment boundary must cross map contours at right-angles and touch river network at river stretch outflow point only.

The automated recognition of catchment boundaries is made by WATERSHED module available in most of the raster GIS.

In our experience of river coding for Armenia, we assessed the quality of the automatic definition of catchment basin boundaries as compared to the accuracy of manually digitized ones. For this purpose, we checked the data on the Voghchi River basin developed on the basis of 1:25,000 scale topographic maps against the data we derived from the 90 m SRTM data (a scale of ~1:100,000). Figure 3.1 shows the outcome of the comparison between catchment basin areas produced by the two methods.

The statistical analysis performed for 76 sub-catchments has demonstrated that the average standard deviation measures 0.54 km^2, correlation factor is 0.98 and the slope of graph approaches 45°. In the three of 4 cases showing large deviation from the average, national boundaries were disregarded by the automatic basin generation, but considered in manual digitizing, which explains the divergence. In one case, manual digitizing error was the cause.

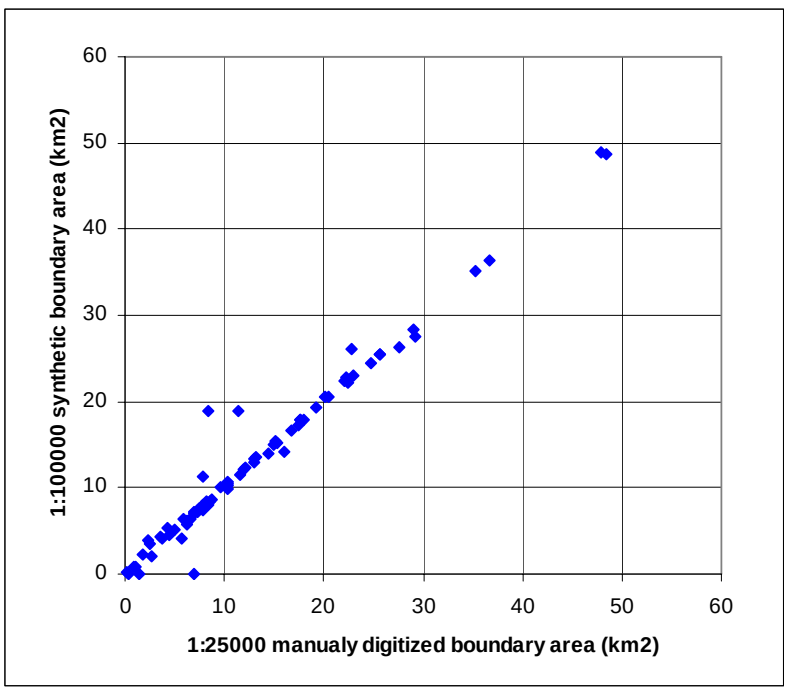

Fig. 3.1: Comparison of manually digitized and automatically derived catchment boundary areas

It is important to keep in mind that the accuracy of either manually digitized or automatically derived catchments eventually depends on that of the basic source data used. As long as the determined catchment boundaries are consistent with the source data they are not '*wrong*'. In the meantime, derived catchments are always approximations, hence this should be borne in mind

when, for example, differences are discovered between “official” catchment areas and those derived by the geo-information system.

3.3 Selection of the Coding System

Many systems are available for hydrological object coding worldwide, but they base on diverse principles. The differences are determined by the specificity of geography, climate and socio-economic conditions of each country. Therefore, the choice from the existing systems of one that would be optimal for a vast region like the South Caucasus, with versatile natural and socio-economic conditions, is a difficult task.

The main purpose of a regional coding system of hydrographic features, encompassing areas of the South Caucasus states, is to create unique identifier for geographic and hydrological features.

In general, the coding should be applied to all hydrological features reported within the Water Framework Directive (WFD). In addition, it should be flexible enough to allow for extensions to other additional features in future or in the context of other applications. The following water object types will be identified using a unique feature code (Table 3.1)

Table 3.1 Water objects reported within the WFD

##	Water Object Type	Water Object Code
1	River (sub) basins	RB
2	(Main) Rivers	RR
3	River Segments (reaching from confluence to confluence)	RR
4	Lakes	LE
5	River water bodies	RW
6	Lake water bodies	LW
7	Coastal water bodies	CW
8	Transitional water bodies	TW
9	Ground water bodies	GW
10	Artificial water bodies	AW

The code will serve as a common identifier and provide a link between the regional and the national information systems. The coding system will assist end users in identifying the consistency of the datasets being exchanged and it will form a basis for an automated data infrastructure, in which data related to hydrological objects are exchanged between computer systems. One of the tasks of these *Guidelines* is to define a coding system that will meet the following requirements:

- ***Uniqueness***
  Each hydrological feature should be uniquely identifiable via its code.
- ***Topological Code***
  Geographic features should be assigned with a structured hydrological code, i.e. coding should be done in relation to the hierarchy and topology of the river network and of its related catchments. The topological component of the code facilitates access to specific data for end users’ enabling them to by-pass the access to the geographical component of the data it relates to.

- ***International***
  Trans-boundary features are identified with one unique code avoiding management of several national codes.
- ***Comprehensive Coding System***
  The coding system has to cover all hydrological features and geographical features that are related to hydrological features addressed in the Water Framework Directive.
- ***Functionality***
  Within the general principles, codes must be functional and easy to process. They must be as short as possible and nevertheless informative enough to ease error checking.
- ***Top-down Approach***
  Coding should be done from the largest to the smallest feature. With this approach, coding could always be extended to higher resolutions, ensuring flexibility for code extension.
- ***Management of Codes***
  The codes should be managed, when relevant, on the lowest possible level, i.e. by international organizations for international river basins, by national organizations for features that are located entirely within a country. This principle should also be valid for sub-features, e.g. national tributaries to international river systems. Through geometrical coincidence these codes can be transferred to other systems.

The application of a common regional coding system should establish a stable link between the national and the regional level and enable adequate reporting and analysis of the data on regional level.

Main coding systems presently applied in the world are named in the report prepared by P. Britton as a part of WFD GIS Working Group Guidance [Britton, P., 2002]. The report provides a detailed description of 10 different coding systems, and a comparative analysis indicating both positive and negative features of each of the systems. Below we cite the summary table from this report that compares the 5 best systems by 11 basic parameters (Table 3.2).

Table 3.2 Comparison of key river and catchments coding structure

##	Coding system	Topology captured	Structured nested coding	Easy to understand	Extra digit(s) assigned per level of hierarchy	Information in digits enables direct analyses	Hydro logical catchments	No. of nested sub-catchments	No. of tributary catchments	Indicate catchments size	Consistent treatment of coastal areas	Starts with marine code
1	Pfafstetter	Y	Y	Y	Y	Y	Y	9	4	*	Y	*
2	ERICA	Y	Y	Y	Y	Y	Y	99	49	Y	Y	Y
3	LAWA	Y	Y	Y	Y	*	Y	9	4	*	*	*
4	REGINE	Y	Y	*	*	*	*	33	*	*	*	*
5	Finish	Y	Y	*	Y	Y	Y	*	100	Y	Y	*

The Table shows that the ERICA system (European Rivers and Catchments) designed for the European Environment Agency by a group of researchers from leading European universities and institutes matches the greatest number of parameters [R.W. Flavin et al., 1998]. In our view, it represents the most suitable system that, with small modifications, can be successfully applied for water object coding in the entire region of the South Caucasus. Below we provide detailed description of this system.

4. Description of the ERICA System

4.1 Overview

ERICA provides explicit information as to areas draining to a given sea/ocean or coastal stretch. It allows straightforward identification of all areas above or below a given point, thus providing an indication of position within a larger water system. It denotes the size of a catchment within pre-designated bands thus promoting comparison of like with like. It can implicitly show the size of the river system in relation to other systems draining to a sea/ocean and clearly differentiate between river catchments, coastal catchments and inter-catchment areas. ERICA aims to use the best points from existing methods (a number of which are from the German and Norwegian systems) and combine them with other internationally recognized systems, i.e., sea/ocean coding, to produce a system tailor-made for the EEA and its operations.

The system uses a faceted code that has:

- a marine code to identify the sea that the catchment drains to,
- a marine border code for the mouth or coastal stretch draining to the sea of interest, or sea/ocean adjoining that sea,
- a series of nested catchments, and
- a catchment size indicator.

The system is flexible in that it can accommodate additions to the catchment or river dataset and allow an indefinite depth of catchment coding. However, it is advisable to decide before implementing the system, how many levels suit the requirements of the end-user.

The final facet of the coding system provides an item of schematic data - an indication of catchment size. This is essential when wishing to compare catchments of similar size at an international scale.

The code, therefore, looks like this.

MM BBB N1 N2 N3 N4 A

Where MM = a two-digit marine code, BBB = a three-digit marine border code, N1 -N4 = two-digit nested catchment codes, and A = a single character area band

4.2 Marine Code

This is a two digit-code that identifies the recipient sea/ocean. The coding system for this is the widely used International Hydrographic Bureau system of 1953. Codes for seas/oceans in Europe are listed below in Table 4.1.

Table 4.1 European seas and oceans from the International Hydrographic Bureau system

Number	Sea	Number	Sea
01	Baltic Sea	19	Irish Sea and St. George's Channel
02	Kattegat	20	Bristol Channel
03	Skaggerak	21	English Channel
04	North Sea	22	Bay of Biscay
06	Norwegian Sea	23	North Atlantic Ocean
07	Barentsz Sea	28	Mediterranean Sea
08	White Sea	29	Sea of Marmara
18	Seas of the West Coast of Scotland	30	Black Sea

4.3 Marine Border Code

This is a three-digit code that identifies the coastal position of the area drained. This can be:

- **water-to-water -** where a true river mouth meets the sea or another sea/ocean borders the sea. These are indicated by an even number.
- **land-to-water -** a stretch of coast between river mouths or sea/oceans. These are indicated by an odd number.

The 499 (the total number of even numbers between 1 and 999) most significant rivers are numbered sequentially starting from the north and moving south (2, 4, 6, 8, etc., up to 998). For stretches of coastline that map horizontally, numbering will move from west to east. The stretches of coast between significant mouths will take the odd numbers i.e. the coastal stretch between mouths '246' and '248' will be numbered '247'.

The key to this facet is being able to identify the 499 most significant rivers (minus the number of sea/sea or sea/ocean borders). If the data is available, this will be based on catchment area, however, if this is not available, it will be done on total stream length draining to each mouth. The outflow number gives no indication of size and no direct indication of location. The only information that is implicit is that a number in the sequence 2, 4, 6…998 is one of the 499 most significant rivers flowing to a given sea and that rivers with consecutive even numbers (e.g. 2 and 4) are adjacent 'significant' rivers. An example of the Marine Border Code can be seen in Figure 4.1. It shows a sea with three separate land masses draining to it and three other sea/oceans bordering it. Seventeen rivers drain to it (in reality, this would be many more but for clarity it has been limited). Notice that the sea/ocean borders are also given numbers. This allows identification of all inputs to seas, even if it is from another sea/ocean and it also preserves the odd numbering applying to coastal stretches.

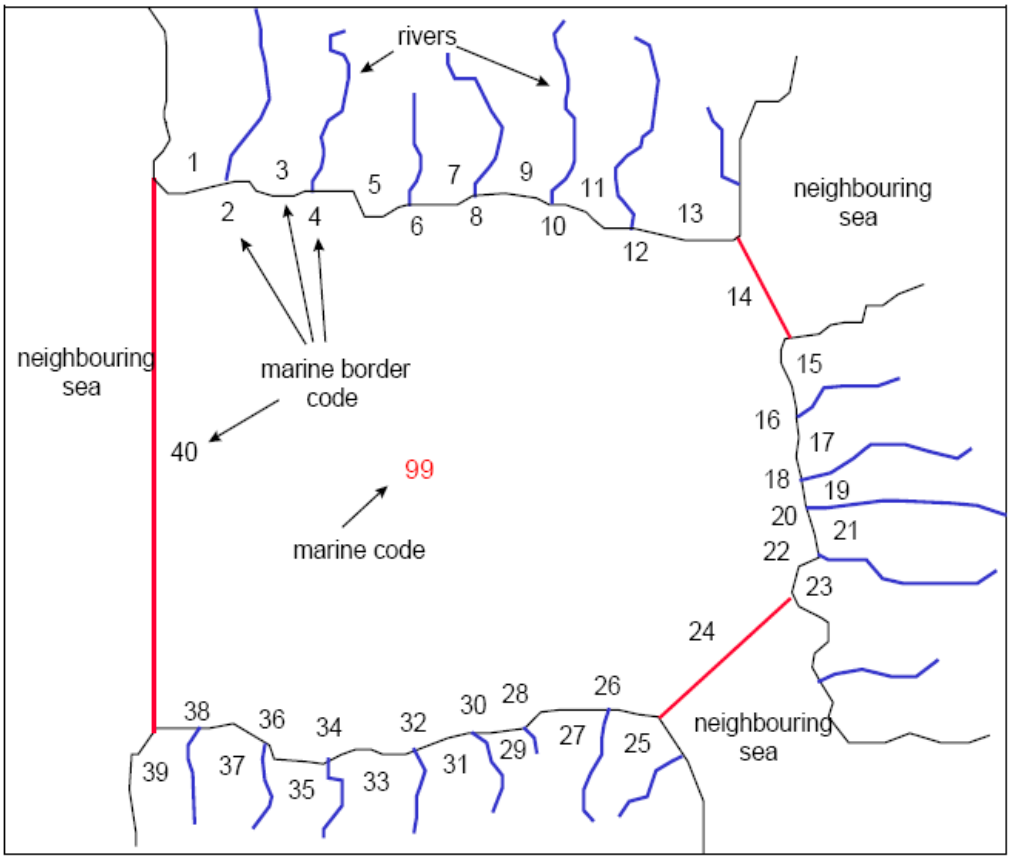

Figure 4.1 Example of marine border codes - note that water-to-water borders are even and land-to-water are odd.

4.4 Nested Catchment Code(s)

These are two-digit codes that identify nested catchments draining to the coastal border. The 49 (the total number of even numbers between 1 and 99) most significant tributaries are numbered sequentially starting from the exit point and moving towards the source. The inter-catchment areas between significant tributaries will take the odd numbers e.g. the inter-catchment area between tributaries ‘22’ and ‘24’ will be numbered ‘23’.

The key to this facet is being able to identify the 49 most significant tributaries. If the data is available, this will be based on catchment area, however, if this is not available, it will be done on total stream length draining to the exit point. The tributary number gives no indication of size and no direct indication of location. The only information that is implicit is that a number in the sequence 2, 4, 6…98 is one of the 49 most significant rivers flowing into a larger river and that tributaries with consecutive even numbers (e.g. 2 and 4) are adjacent ‘significant’ tributaries. An example of the first level coding can be seen in Figure 4.2.

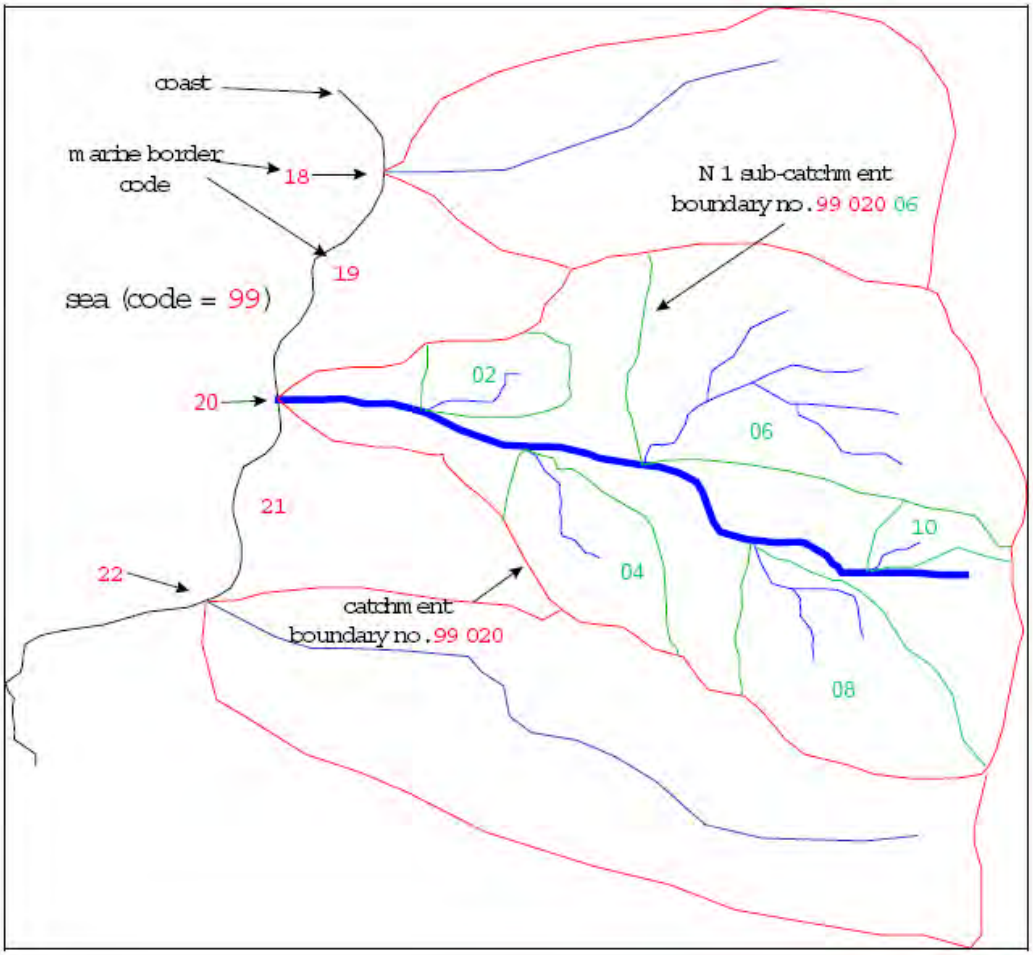

Figure 4.2 Numbering the most significant tributaries flowing to the main river

Once the most significant tributaries have been numbered and their catchments defined, the inter-catchment areas can be defined by completing the catchments immediately below the confluences. They can then be assigned odd numbers. An example is shown in Figure 4.3.
Each nested catchment can be further broken down. There is no theoretical limit to the number of 'N' levels. However, the computing resources available may impose limits. It is recommended that careful thought is given to the maximum number of 'N' levels required by the end-user. An example of second level 'N' can be seen in Figure 4.4

The default setting for nested catchments codes is '00'. The N2 level of inter-catchment coding is as for N1. N2 catchments can be further broken down using the same system.

In drainage systems with more than 49 tributaries, some inter-catchment areas will themselves contain tributaries. Figure 4.5 shows an exploded view of N1 inter-catchment 99 020 07 that contains two small tributaries. These are given the codes 99 020 07 02 and 99 020 07 04. This sub-division produces further inter-catchments which would receive the codes 01, 03 and 05

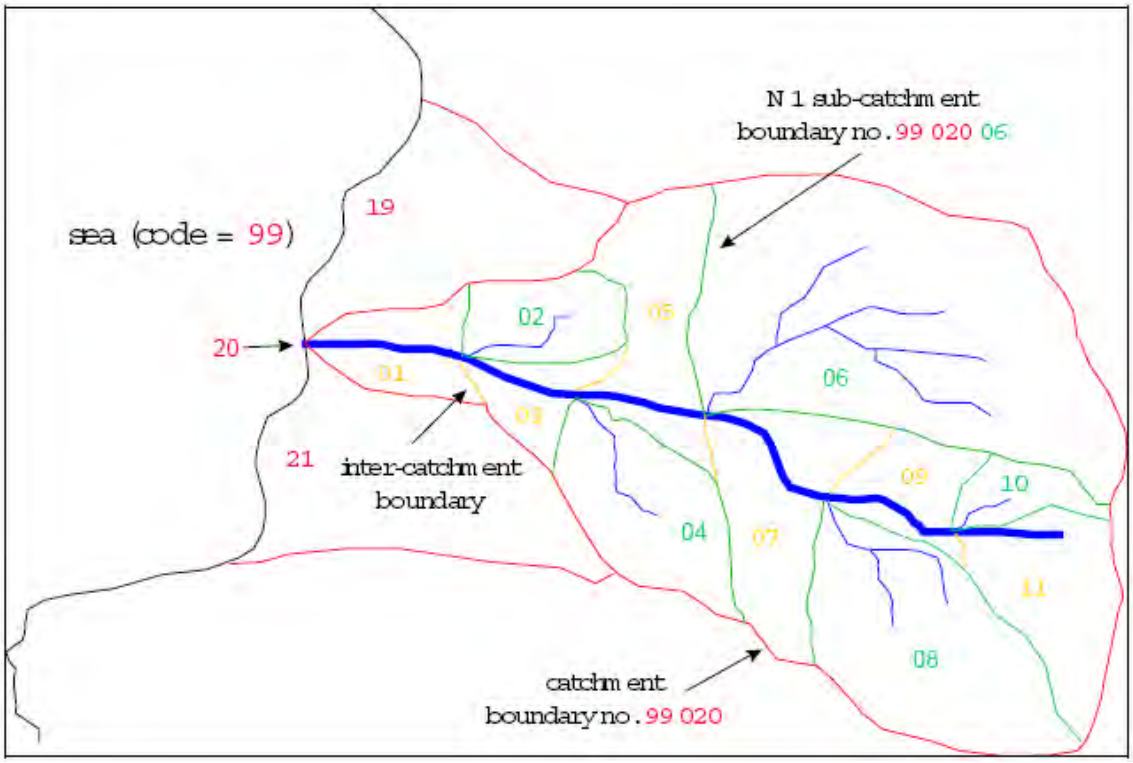

Figure 4.3 Defining and numbering the inter-catchment areas

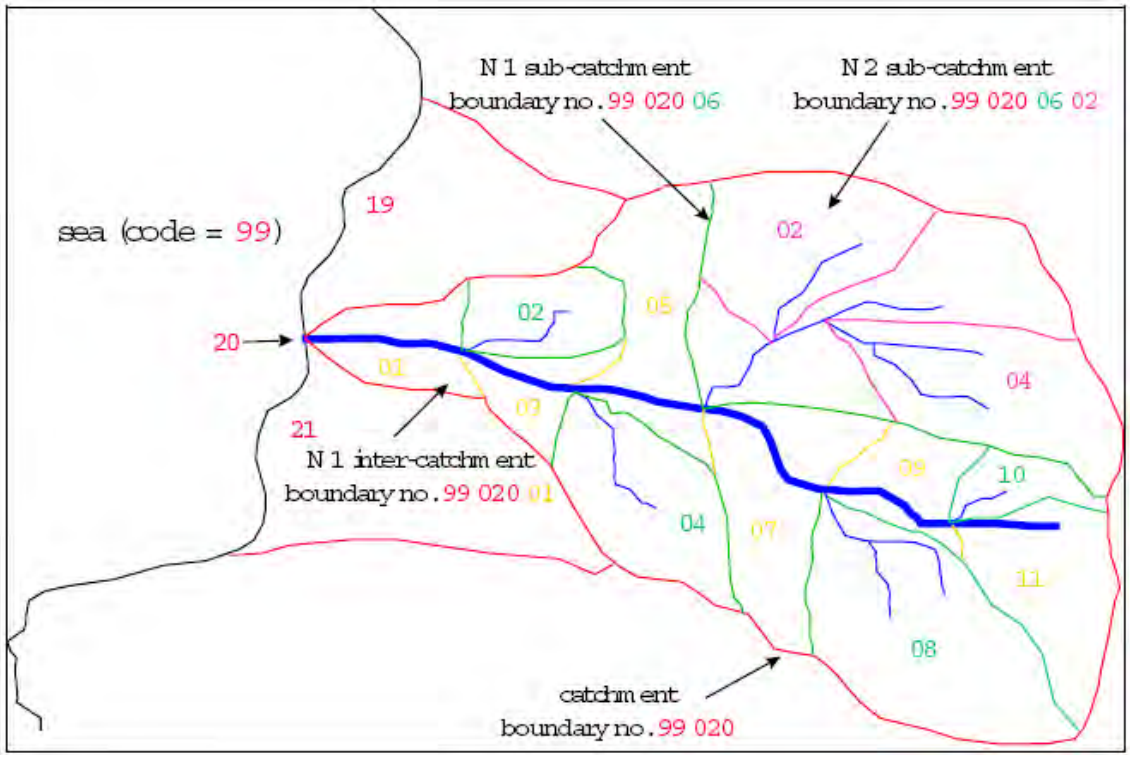

Figure 4.4 Example of a second-level tributary coding

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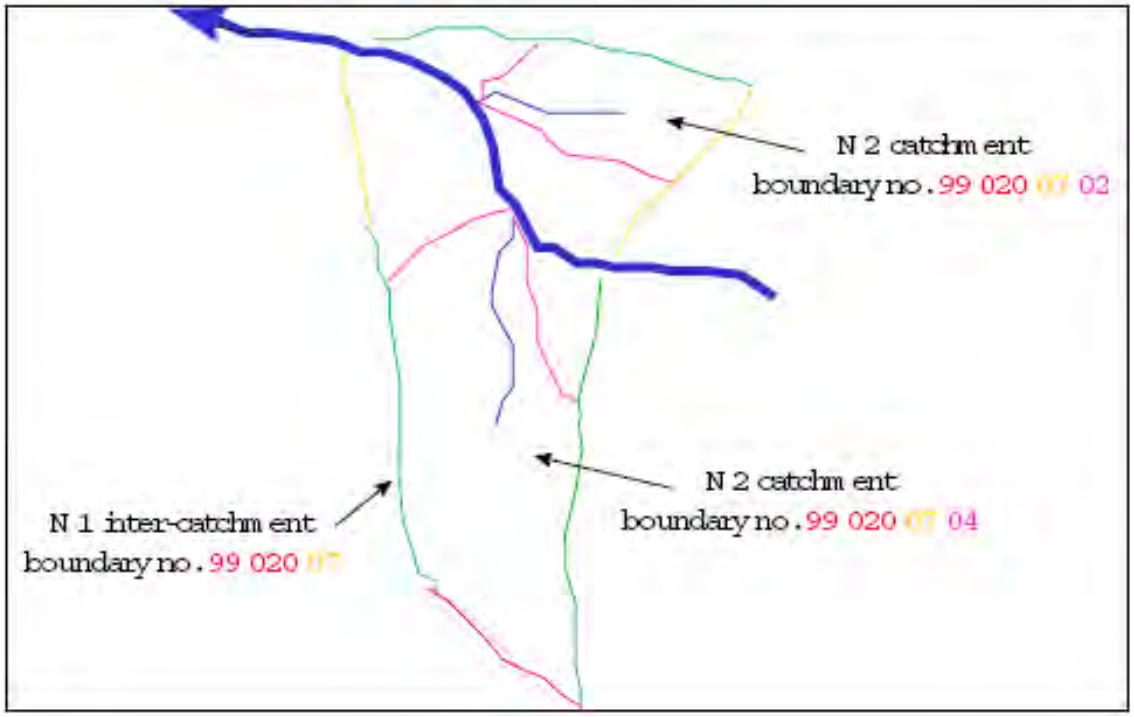

Figure 4.5 Sub-division of inter-catchment areas

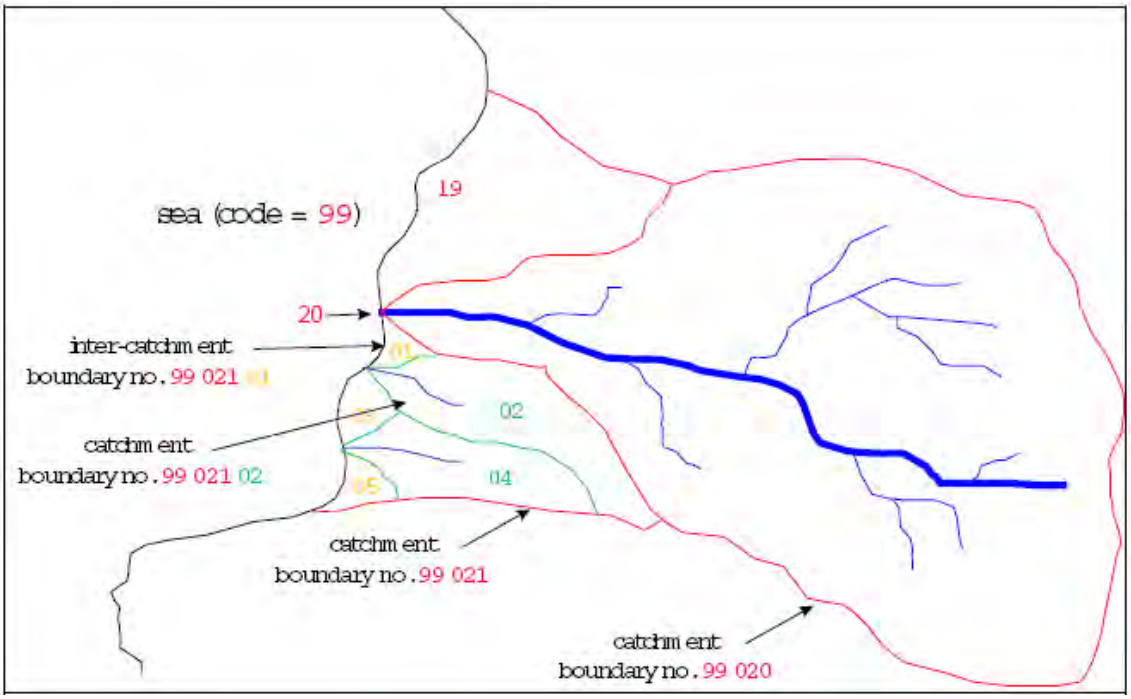

Figure 4.6 Sub-division of coastal catchments

In seas/oceans with more than 499 rivers draining to them, some coastal catchments will themselves contain rivers. Figure 4.6 shows an exploded view of coastal catchment 99 021 that contains two small rivers. At the N1 level, these are given the codes 99 021 02 and 99 021 04. This sub-division produces further coastal-inter-catchments which would receive the codes 01, 03 and 05.

4.5 Area Band Code

This is a single character code indicating the size of the catchment - essential for comparing like-with-like at a regional scale. This will always be available because a catchment code is only applied to catchments that have been derived.

Table 4.2 Area code banding

Band	Lower bound (km2)	Upper bound (km2)
A	0.0	1.0
B	1.0	10.0
C	10.0	25.0
D	25.0	50.0
E	50.0	100.0
F	100.0	250.0
G	250.0	500.0
H	500.0	1000.0
I	1000.0	2500.0
J	2500.0	5000.0
K	5000.0	10000.0
L	10000.0	25000.0
M	25000.0	50000.0
N	50000.0	100000.0
O	100000.0	250000.0
P- Z	not yet assigned	not yet assigned

4.6 Summary

ERICA adheres to well-proven methods to identify coastal and nested catchments. It is consistent and, during application in the pilot study areas, proved straightforward. The logical numbering along coasts and then from mouth to source make it easy to understand. This numbering system also provides a means of identifying the network that exists downstream as well as upstream of a given point.

Its one weakness is that catchments at the same level of ‘tributary’ hierarchy can vary greatly in size. However, this is rendered insignificant by the catchment-area-indicator facet of the code.

5. Application of the ERICA for the South Caucasus Region

Considering the above, the ERICA system would be the most convenient one for the coding of hydrological objects in the South Caucasus region, as it was developed for the entire area of Europe and takes into account the majority of hydrological and hydrographic features that can be encountered in the process of coding. In the meantime, we must consider that while a huge amount of accurate and reliable digital materials and databases are readily available for Europe, in the South Caucasus countries the situation in this respect is much worse. Ready-for-operation digital materials are not available or, if available, do not contain references to the source of information, or an assessment of the rate of accuracy and credibility of the source information. Therefore, before using such data, one should check and/or improve the accuracy of the information, which entails considerable financial expenses and time loss. The available hard-copy maps or other materials are out-of-date, or not accessible.

The experience of applying the ERICA system in Armenia revealed a series of problems, part of which were resolved. In this Chapter, we dwell on the discussion of these problems, suggest ways that could help to resolve them and indicate possible changes that need to be incorporated in the ERICA system in order to apply it for the South Caucasus region.

5.1. Digitizing River Network

The digitizing of river networks shall be accomplished up to the maximum possible level of detail and accuracy as this is important for the estimation of river length through GIS. For the entire area of the South Caucasus, 1:25,000 topography maps of the General Staff of the USSR (GenShtab) provide the greatest level of detail: these maps need to be scanned and geo-referenced. Our experience indicates that these maps display some shift as compared to SRTM DEM and Landsat 7 ETM+. Hence, it would be better first to enter all maps into GIS in their initial projection: this will ensure exact overlap of individual sheets. At the next stage, the ready shape-file of river network can be converted into Geographic Coordinate System Lat/Long WGS84 and then adjusted.

The continua of water channels, flowing into and out of lakes, are modeled according to the principle of shortest distance using cost-surface functions. If necessary, the main water channel that crosses a lake is digitized with the help of main flow directions, deeps and other local knowledge using the principle of shortest distance (Figure 5.1.). This alternative seems the most practical one, although local adjustments will probably have to be made in any case. In doing so, the order of tributary coding is preserved. River names must be entered into the database concurrently, as digitizing moves on.

It is important to bear in mind that Soviet maps at the scale of 1:25,000 were issued in 1953-1974, therefore the information they contain is rather out-of-date. This is specifically related to man-made canals and irrigation systems, dams and water reservoirs.

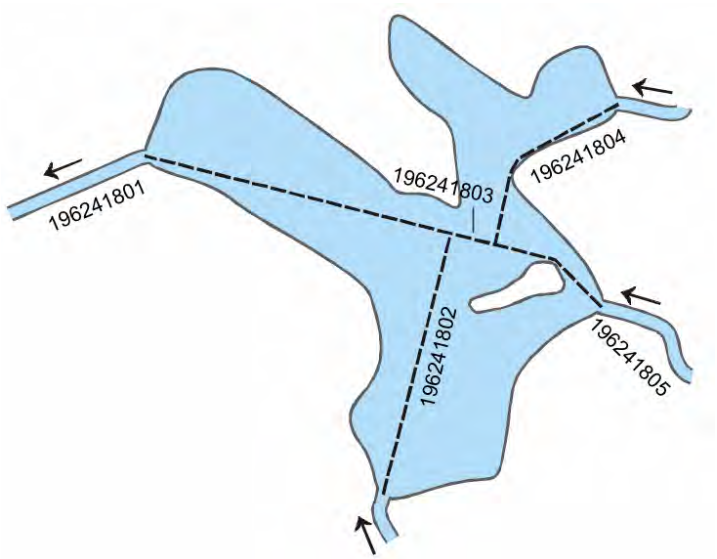

Figure 5.1 River network coding in lake area

5.2 Catchment Derivation

In order to determine the boundaries of hydrologic units, the first step is to create watersheds from DEM by applying Jenson and Domingue's D8 algorithm [Jenson, S. and Domingue, J., 1988]. The implementation of the algorithm can be found in the *Hydrological Modeling* extension of *ArcView 3.2*, *Hydrology Tool of Spatial Analyst* in *ArcGIS 9.1*, *Flow Module* of *IDRISI*, etc. In this algorithm, a single downstream cell among its eight neighbors is defined for each grid cell, so that the descent slope is the steepest. Once the flow directions are determined, the number of cells located upstream of each cell is calculated as a measure of flow accumulation. Applying a threshold value to these flow accumulation values and selecting the cells with accumulation values higher than the threshold yields a uniquely spanning drainage network. This network represents the paths of the DEM-based watershed flow system, the drainage density of which can be controlled by changing the threshold value. In order to determine the boundaries of the watersheds, the intersection points of the drainage reaches can be used as the outlets of watersheds, above which the contributing areas are determined. A threshold value other than the one used to define the drainage network can be used to determine the watersheds, if one-to-one correspondence of drainage reaches and watersheds is not required or if a watershed should contain more than one drainage reach. Low threshold values result in enormous number of small watersheds that do not have hydrologic meaning, while high threshold values result in very large watersheds that are not very useful to create a nested-level hierarchy. Therefore a try-and-error approach is required to determine an optimum threshold value.

Flat areas by definition have no defined flow direction and these areas require particular attention to assign the most realistic flow direction. The solution of the flow problem through flat areas is of great interest when the object of the study is a basin that includes a large floodplain, lakes or wetlands.

The D8 algorithm approach constrains the flow path within the flat area and allows multiple outlets. However, it often produces unrealistic, parallel flow patterns.-In such cases, the real river network pattern - as digitized from topography maps or satellite images - must be used with the procedure known in GIS as "*burning in*". A digital DEM is used in combination with a dataset of

digital drainage network. The vector drainage network is converted to a grid and overlain on the DEM. Grid values on the DEM that are coincidental with the drainage network grid are reduced by a set value, e.g., 50 m. This provides exaggerated valleys. Using this processed DEM as input, another grid, showing the flow direction of every cell, is created. The "*burning in*" of the drainage channels encourages neighboring grid cells to flow into the known drainage network. The flow direction grid can then be used as an input grid for hydrological functions in a GIS. These allow derivation of catchment boundaries.

Some of the watersheds among the initially produced watersheds can be artifacts created by raster-to-vector conversion and they must be deleted. Very small watersheds that are produced due to the topography of the land must be combined with the neighboring watersheds for generalization.

It is important to consider that such method of catchment derivation may create water catchment basins that would not include any water objects in the present (if, for instance, the rivers have been intercepted by man-made canals, or if the lakes have been drained). As the ERICA coding system has a hierarchical structure, it allows presence of such basins. If additional hydrological information permits so, such basins can be joined to the neighboring ones. If no supplementary data is collected, these basins shall be coded in the normal course.

5.3. The Coding

For Armenia, a country that has not an outlet to the sea, where all rivers can be related to the basins of either the Kura River or the Arax River, the code would look like as follows:

ABC N1, N2 ....,

where A is the water object code that is equal to **1** for rivers, **2** for lakes and **3** for channels,

B is the regional code from the Soviet coding system, corresponding to **9** for Armenia;

C is the code of one of the two large rivers, into which all rivers of Armenia flow (**2** –code for the Arax River, **4** – code for the Kura River);

N1, N2 ..., correspond to a two-digit code indicating the place taken by each river section in the river network hierarchy, where even numbers code tributary catchments, and odd numbers code inter-catchment areas.

The results of the coding were introduced into the attribute table of shape files, which had the following attribute fields (Name, WOT (Water Object Type), Region, Basin (Kura_Araks), R_Basin, Level_1, Level_2, Level_3... Level_n, WOC, Length (m)).

In the *Scope of Work for Water Objects Coding Application Services in Georgia and Azerbaijan* [http://www.scaucasuswater.org/index.php?article_id=42&clang=0] this form of attribute table has been kept valid. In the meantime, it does not take into account some specific features of the entire region of the South Caucasus. In particular, it does not consider that the region is washed by two international seas. The experience of water objects coding for Armenia was not considered either. Therefore, below we describe the changes we propose to incorporate in the coding system designated for the entire region of the South Caucasus and in the relevant attribute tables.

5.3.1 Marine Code

Rivers in the South Caucasus region all belong to the basins of the Black Sea or the Caspian Sea: hence, their codes shall start with the relevant marine codes. As one can see from Table 4.1, the code of the Black Sea assigned to it by the International Hydrographic Bureau System is **30**, but the Caspian Sea is not assigned a code provided that it has not an outlet to an ocean. Another problem is that the Marine Code is based on IHO 1953 standard, which provided a 2-digit code for marine and sea areas. This standard has been recently replaced by an updated IHO standard, which uses an extendible decimal sub-classification code, which would be harder to implement within a catchment coding system. Therefore, we propose to apply the system of coding of European seas offered in the *Proposal for a European Coding System for Hydrological Features* made by the coding group (chaired by A. Wirthmann) and presented on Figure 5.2.

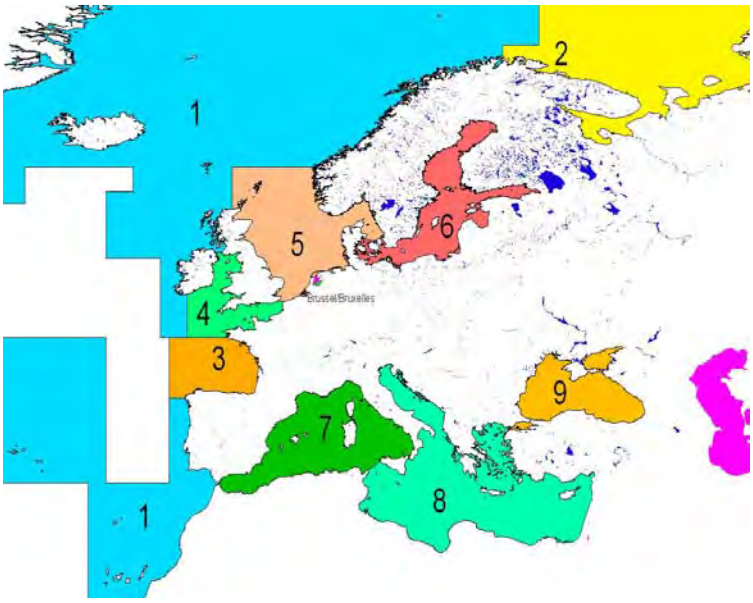

Figure 5.2: Sea coding around Europe using Pfafstetter inspired logic.
The ocean (outlet) is coded 1 whilst the Sea most distant from the Ocean is coded 9

They propose to code the seas ***9*** to ***1***, following the Pfafstetter logic; meaning that the Sea most distant from the Ocean is coded ***9*** and the Ocean is coded ***1***. Then, we can decide to code as follows: **9** - Black Sea, **8** - Eastern Mediterranean Basin, ***7*** - Western Mediterranean Basin, ***6*** - East Sea, ***5*** - North Sea, ***4*** - Celtic Sea and Channel, ***3*** - Bay of Biscay, ***2*** - White Sea and Barents Sea, ***1*** - Atlantic Ocean. Code ***0*** can be reserved for the Caspian Basin.

In such a manner, sea code would contain 1 digit instead of 2 provided for in the ERICA system. In other words, codes of any river in the Black Sea basin would start with ***9*** and in the Caspian Seas basin with ***0***.

5.3.2 Marine Border Code

Marine border coding must start from a national boundary and proceed from the south to the north and from the west to the east. Three (3) digits are provided for Marine Border Code under

the ERICA system, enabling coding of up to 499 rivers flowing into a sea – this is two great a number for our region. It is possible to limit to two digits for the Black Sea coast of Georgia and the Caspian Sea coast of Azerbaijan: this will allow coding up to 49 large rivers flowing into the sea.

5.3.3 Nested Catchment Code(s)

Our experience of ERICA system application in Armenia has demonstrated that the core problem related to the use of this system (which is equally true for most of other systems) is determination of 49 most important hydrological basins, a task requiring availability of accurate and reliable hydrological information such as hydraulic characteristics, flow rate and seasonality of the streams. This supplementary data is necessary for the expert judgment and satisfactory selection. In the meantime, information of this kind in the South Caucasus countries is either out-of-date or not easily accessible. The ERICA system suggests selecting across a catchment basin area or along a river length. In the experience of coding for Armenia, 5 km or longer rivers were coded. Other approaches can be chosen for Azerbaijan and Georgia.

5.3.4 Water Object Type

As mentioned in Chapter 3.3, the Water Framework Directive provides for 10 hydrological objects subject to coding and denoted with two letters (Table 1.1). Therefore, we would suggest to use designators accepted in the WFD for the database field *WOT* (*Water Object Type*) and for the code. Specifically, (*CW*) can be used for *Costal borders*, (*CB*) for Costal catchments, (*RB*) for *River (sub) basins* and (*RR*) for *(Main) Rivers and River Segments* (reaching from confluence to confluence).

Therefore, eventually the code can look like this:

OO M BB N1 N2 N3 N4 ... Nn A

where OO = a two-character water object type, M = one-digit marine code (**9** – for the Black Sea, **0** – for the Caspian Sea), BB = a two-digit marine border code, N1–Nn = two-digit nested catchment codes, and A = a single-character area band.

5.3.5 Attribute Table

In compliance with the changes in the coding system, relevant changes must be introduced into the database structure. Specifically, two letters shall be placed instead of one digit in the *WOT (Water object type)* field, *Region* field must be replaced by *Sea* field *(Marine code)*, and *Basin* field will be changed to *M_border (Marine border)*

Besides, as mentioned earlier in this Chapter, information available on the existing topography maps is out-of-date. The same is true for the names of rivers and lakes. In the meantime, it is very important to keep the old names in the database so that available archive data could be later linked to them. Hence, we suggest creation of two fields in the database: *Name_Old* and *Name_New*.

Eventually, the finalized attribute table would have the following structure: *Name_Old, Name_New, WOT, Sea, M_border, R_basin, Level_1, Level_2, ... Level_n, Area_band, WOC, Length.*

5.3.6 Quality Control

The quality control shall be performed at the end of each working stage for each river basin.
There are four stages of Quality Controlling for a spatial dataset. These are:

- checking completeness - ensuring that data that should be there is, and that spurious lines and polygons are not,
- checking positional accuracy - ensuring that lines and polygons are the correct shape and in the right place,
- checking attribute accuracy, and
- checking logical consistency - ensuring connectivity of networks, integrity of polygons and conformity between layers.

6. Step-by-step Procedure for the Water Objects Coding

6.1 Gathering Digital Data

The following input data are necessary for river coding:

- Topography maps at the scale of 1:25,000 are used for digitization of river network. If available as hard copies only, these maps should be scanned. It is better to scan each sheet as a single piece using a large-format scanner (A2 or larger) to avoid distortions that can be introduced when the parts are joined one to another.
- 3 second arc SRTM DEM is used for calculation of catchment boundaries. The data can be obtained at no charge from the NASA web site
  Version 1 – ftp://e0srp01u.ecs.nasa.gov/srtm/version1/
  Version 2 –ftp://e0srp01u.ecs.nasa.gov/srtm/version2/
- *LANDSAT 7 ETM+* is used to check and verify the results of digitizing. Six color imagery files - N-37-40_2000, N-37-35_2000, N-38-40_2000, N-38-35_2000, N-39-40_2000 and N-39-35_2000 are available at the SCWP. These files are in MrSID format The compressed sid files are also available free of charge at https://zulu.ssc.nasa.gov/mrsid/

6.2 Georeferencing

The scanned topographic maps must be then geo-referenced. The geo-referencing is realized using *Georeferencing Tool*. If Soviet maps (*Genshtab)* are used, *Gauss-Krueger Projection* shall be applied (6 degree zones: Zones 7-8 – for Georgia, Zones 8-9 - for Azerbaijan) and Pulkovo 1942 datum.

The input SRTM data are represented in geographic coordinates (Latitude/Longitude, datum WGS 84).

LANDSAT is in UTM projection (Zones 37N-38N for Georgia, Zones 38N-39N for Azerbaijan) in WGS 84 coordinate system.

Eventually, all data must be converted into UTM Projection and WGS 84 coordinate system in compliance with the *Scope of Work*.

6.3 Digitization of the River Network

The next step is digitization of river network. This procedure is realized by on-screen digitizing of geo-referenced topographic maps or using special software (*Carta Linx, Didger*) or immediately in *ArcGIS* by its *Editor* tool.

To avoid incidental omission of a tributary, all rivers must be digitized. To make network analyses possible, the digitizing must follow with the stream and layer topology must be duly considered. Using *ArcGIS* for topology check-up and editing, *Topology Tool* can be applied.

6.4 Identification of Main Rivers

At the next step it is necessary to identify the main rivers subject to the coding. In Armenia, all rivers 5 km long or longer were coded. Our experience shows that this is the minimum river length (with very few exceptions) that is justified from the standpoint of both hydrology, and economy. The selection of 5 km-long and longer rivers is performed in the shape file manually, through the *Editor* tool. Moving from the source to the estuary of a main river, minor tributaries are excluded and main river stretches are connected (i.e., unlinked nodes are excluded). To determine the length of each stretch, the following procedure can be used. *New Personal Geo-database* is created in *Arc Catalog*, into which the shape file of digitized river network is exported. Along with this, *Shape_Length* field is created in the database, where lengths of river stretches are recorded automatically. These lengths can change, again automatically, while the shape file is edited.

Identifying main rivers, it is also possible to use *Flow Accumulation* layer, which is calculated from DEM using *Hydrology Tool* (see the next section) and which identifies main rivers clearly. Besides, information available on topography maps must be used, river names for instance. Main rivers mostly have names, by secondary tributaries are nameless.

The attribute table linked to the layer would have the following structure: *Name_Old, Name_New, WOT, Sea, M_border, R_basin, Level_1, Level_2, ... Level_n, Area_band, WOC, Length.* Table fields must be all of *Text* type, excluding *Length*, which must be of *Double* type.

After the layer of rivers that are ≥ 5 km long is created, the number of tributaries for large river basins shall be assessed roughly. If this number is more than 49, the longest 49 must be selected. In the Armenian project, the number of tributaries was greater than 49 in one case only (the Debed River basin).

6.5 Catchment Derivation

The next step is *Catchment Derivation*. To accomplish this task, SRTM DEM must be imported into *ArcGIS*. *3dem* software, freely available at http://www.visualizationsoftware.com/3dem.html is used for this purpose. After SRTM data are opened in *3dem*, they must be converted into GEOTIFF format, in which form the data can be opened in *ArcGIS* and saved as GRID file.

After that *ArcToolbox* ⇒ *Spatial Analyst Tools* ⇒ *Hydrolo*gy is launched and then the stepwise procedure to follow is:

- ⇒ *Flow Direction* – the GRID file generated from the SRTM data is used as **Input surface raster**
- ⇒ *Flow Accumulation* – the output file produced by the preceding operation is applied as **Input flow direction raster**
- ⇒ *Snap Pour Point* – the shape file of rivers, for which catchment areas must be calculated, is used as **Input raster or feature pour point data;** the output file of *Flow Accumulation* procedure is applied as **Input accumulation raster**.
- ⇒ *Watershed* – the output file of *Flow Direction* procedure is applied as **Input flow direction raster;** the output file of *Snap Pour Point* procedure is applied as **Input raster or feature pour point data**. The resulting raster file of catchment areas must be converted into a vector file (polygons). This operation is made by means of *Spatial Analyst (Spatial Analyst* ⇒ *Convert* ⇒ *Raster to feature).*

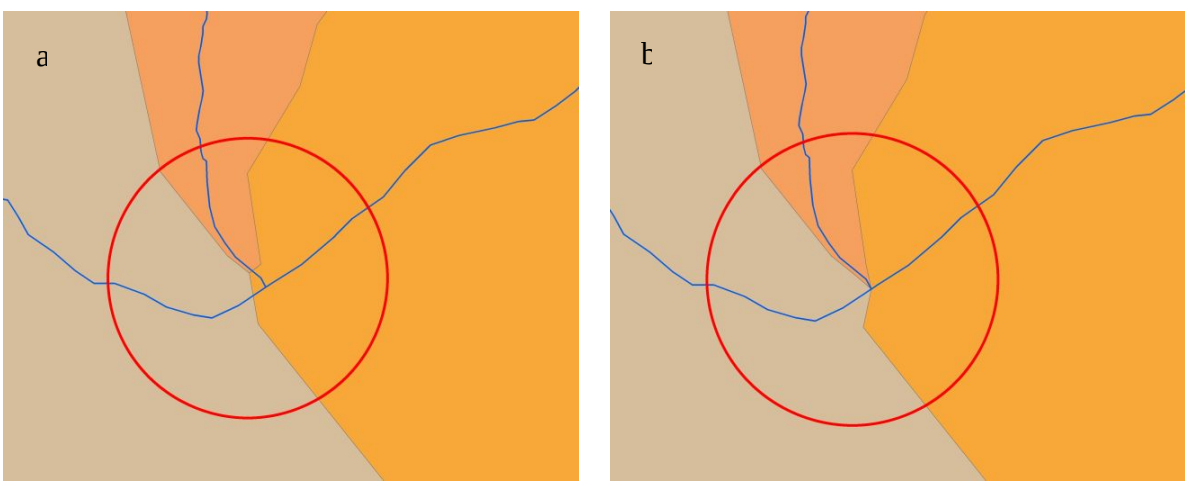

Figure 6.1 Adjustment of boundaries for automatically calculated catchment basins:
a –before the adjustment, b –after the adjustment

As far as SRTM DEM has a spatial resolution of 90 m, automatically calculated basin boundaries are not always strictly coincident with tributary estuaries. Therefore it might appear necessary to correct the catchment basin polygons (Figure 6.1). The correction is realized manually by means of *Editor* tool.

After the basin layer is created, area of each basin is calculated and recorded in the *Attribute Table*. Basin areas are calculated automatically by the same technique as used for river length calculations (see paragraph 6.4). Additionally, *Area Band* field must be created in the *Attribute Table*, where letter code corresponding to each basin area will be recorded in accordance with Table 4.2.

Catchment derivation can be performed also by means *ArcHydro Tool*, downloadable from ESRI website http://downloads.esri.com/support/datamodels/Hydro/_ArcHydro9_1.zip along with detailed documentation on the use of the program. We have not applied this program for river coding in Armenia.

6.6 The Coding

The next step is the coding of basins and rivers. The principle of coding is described in detail in Section 4 of this report, and illustrative examples of the coding of nested catchments of diverse hierarchic levels are provided in Figures 4.1-4.6.

In this section, we will just comment that it is more convenient to start the coding first on the shape file of main rivers (>5 km long), and then assign these codes to relevant basins. Rivers are coded manually – from the estuary to the source - with concurrent entry of the code into the *Attribute Table's* field of adequate level (*Level_1, Level_2, ... Level_n*). Moreover, *WOT, Sea, M_border, R_basin* fields must be filled in for any river basin. After this is done, *Field Calculator* is used to calculate *Water Object Code* field in the *Attribute Table* window *(WOC = [WOT]&[Sea]&[M_border]&[R_basin]&[Level_1]&[Level_2]& ...&[Level_n]&[Area_band]).* The final form of the code is shown in section 5.3.4 of this report.

Then these river codes are assigned to corresponding basins by means of *Join* function and automatically stored in the *Attribute Table* of catchments.

It is important to keep in mind that if any tributary important in hydrological or socio-economic aspect is omitted in the course of the digitizing or coding, it is possible to code it later, at the next hierarchy level, without changing the coding that has been realized already. The technique is described in section 4.4 and illustrated in Figure 4.5.

6.7 Final Deliverables

Upon completion of coding activities for each river basin, a unique ArcGIS project is created (*.mxd), which includes the following layers:

- All digitized rivers - Polyline shapefile
- Main rivers (more than 5 km long) - Polyline shapefile
- Catchment basins - Polygone shapefile
- Hillshade relief - GEOTIFF raaster file
- Isohypses at an interval of 100 m - Polyline shapefile

7. Recommendations

ERICA adheres to well-proven methods to identify coastal and nested catchments, and with slight modifications can be successfully applied for water object coding in the South Caucasus region. It is consistent and proved efficient during application in Armenia. The logical numbering along coasts and then from mouth to source make it easy to understand. This numbering system also provides a means of identifying the network that exists downstream as well as upstream of a given point. One weakness of this system is that catchments at the same level of 'tributary' hierarchy can vary greatly in size. However, this is rendered insignificant by the catchment area indicator facet of the code.

It would be reasonable to start the coding from the regional level and then proceed to lower hierarchy levels consistently with the tasks each individual country is facing. However, it is important to consider that the coding has been already completed in Armenia, and is still to be launched in Azerbaijan and Georgia in the format of separate activities. Therefore, it would be extremely important to convene a meeting of all project participants after the works are completed everywhere, in order to improve and join the databases one to another, develop a single regional-scale database and elaborate mechanisms to use, update and supplement it.

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