Small-scale, low-cost, environment friendly irrigation schemes: sites selection and preparation of full work tender dossier

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TRAINING WORKSHOP —
“WATER ACCOUNTING PRACTICES AND RIVER BASIN MODELLING using RIBAMAN-5”

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1 INTRODUCTION TO SYSTEMATIC RIVER BASIN PLANNING

1.1 DEVELOPING AN ANALYTICAL FRAMEWORK FOR OBJECTIVE ASSESSMENT

"Water balance" management is at the critical centre of effective water management policy, implemented through Permits and Programmes of Measures. This essential quantitative approach is not well understood by MoEPP, MAFWE and many operators at this time. The following sections are intended as a simple primer.

1.1.1 WATER QUANTITY AS A FINITE NATURAL RESOURCE

Water resources within a river basin (commonly referred to as the annual (or seasonal) renewable resource ("runoff" or ARR)) are finite. Over the long-term, the natural quantity of water replenished is a function of the primary physical water balance of the river basin:

Annual Runoff = Precipitation – Evapotranspiration (units may be mm (depth), m^3/s (rate) or Million m^3 (quantity).

Seasonal Runoff = Precipitation (rain + snow) – Evapotranspiration – Δ Storage (snowpack, soil reservoir, groundwater, reservoirs, lakes)

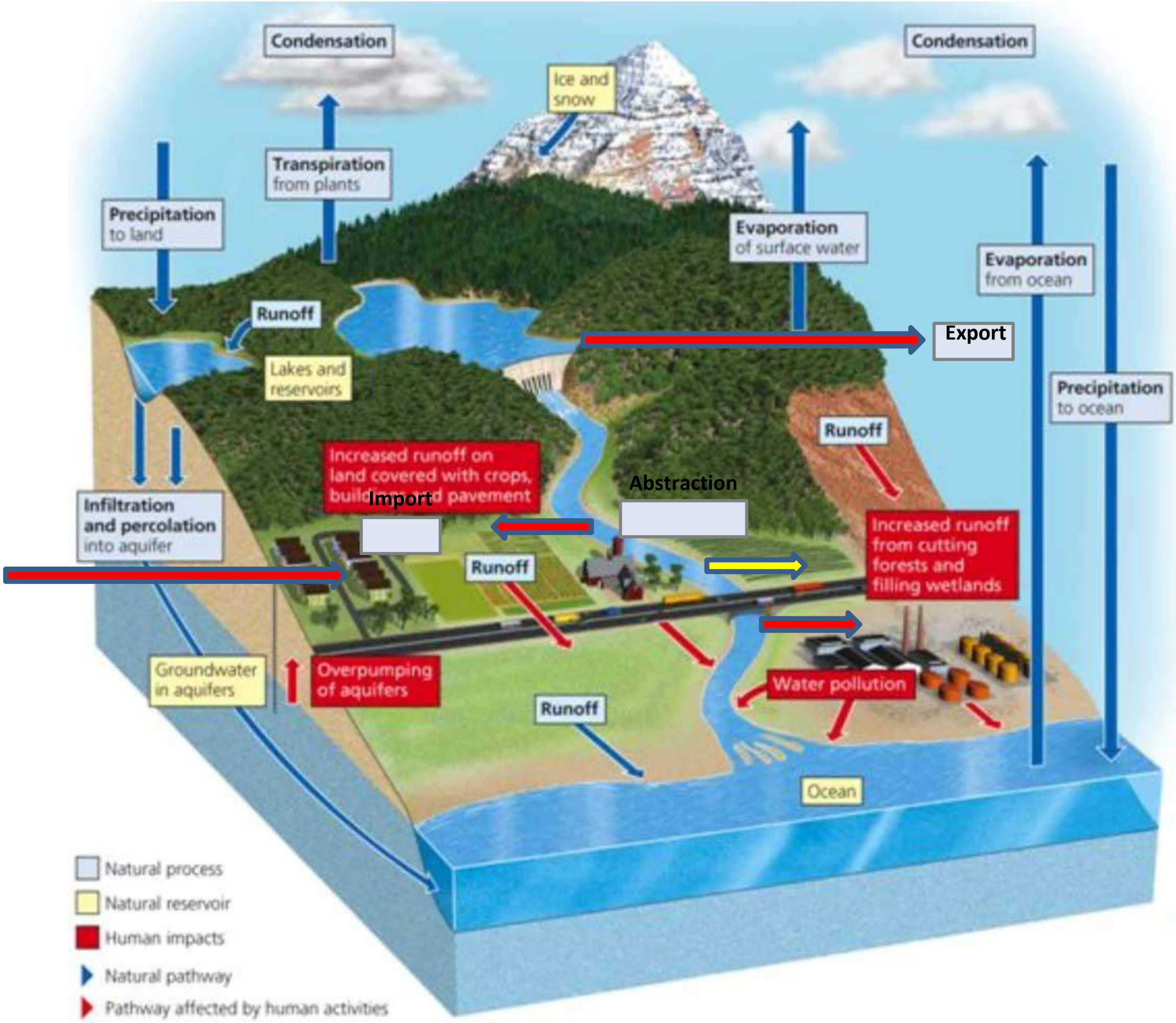
This is typically defined as the 'unmodified' or 'reference' condition. However, in practice virtually all river basins exhibit modified behaviour due to **artificial influences**. These influences mainly include abstractions, consumption and return of water by the principal economic sectors (municipalities, agriculture, energy and industry). These influences and their impacts may change significantly across seasons.

Therefore in addition to the natural characteristics of river basin runoff, for effective policy formulation it is also necessary to measure, control and account for all these artificial influences. The modified seasonal water balance of a river basin is thus more complex, and is further refined as:

Seasonal Runoff = Precipitation (rain + snow) – Evapotranspiration – Δ Storage (snowpack, soil reservoir, groundwater, reservoirs, lakes) – [Abstractions (municipal, irrigation, hydropower, industry) + Exports (surface, reservoirs, groundwater)] + [Returns (municipal, irrigation, hydropower, industry) + Imports (surface, reservoirs, groundwater)].

Clearly water balances and water interactions become potentially very complex at the seasonal level, and therefore it is essential to approach this decision making problem within a systematic framework, such that all river basins are analysed in the same objective, analytical manner.

Figure 1-1 – Concepts of Hydrological Cycle, Water Balance and Artificial Influences



1.2 USING WATER ACCOUNTING PRINCIPLES

1.2.1 UN SYSTEM OF ENVIRONMENTAL-ECONOMIC ACCOUNTING FOR WATER

The United Nations System of Environmental-Economic Accounting for Water (SEEA-Water) is a sub-system of the SEEA applied to water-related information. It provides a conceptual framework for organising the hydrological and economic information related to water in a coherent and consistent framework AND for monitoring progress towards water policy objectives, commonly referred to as 'water accounting'[1]. The UN, World Bank, FAO, OECD, EC and IMF are all signatories to this approach.

'Water Accounting' integrates physical (hydrological) and economic information related to water consumption and use, to achieve equitable and transparent water governance for all water users and a sustainable water balance between water availability, demand and supply.

Figure 1-2 – Example of Water Accounting According to UN SEEAW

	EA.131. Surface water				EA.132 Groundwater	EA.133 Soil water	Total
	EA.1311 Artificial reservoirs	EA.1312 Lakes	EA.1313 Rivers	EA.1314 Snow, ice and glaciers			
1. Opening stocks	**1 500**	**2 700**	**5 000**	**0**	**100 000**	**500**	**109 700**
Increases in stocks							
2. Returns	300	0	53		315	0	**669**
3. Precipitation	124	246	50			23 015	**23 435**
4. Inflows	1 054	339	20 137		437	0	**21 967**
4.a. From upstream territories			17 650				**17 650**
4.b. From other resources in the territory	1 054	339	2 487	0	437	0	**4 317**
Decreases in stocks							
5. Abstraction	280	20	141		476	50	**967**
6. Evaporation/actual evapotranspiration	80	215	54			21 125	**21 474**
7. Outflows	1 000	100	20 773	0	87	1 787	**23 747**
7.a. To downstream territories			9 430				**9 430**
7.b. To the sea			10 000				**10 000**
7.c. To other resources in the territory	1 000	100	1 343	0	87	1 787	**4 317**
8. Other changes in volume							**0**
9. Closing stocks	**1 618**	**2 950**	**4 272**		**100 189**	**553**	**109 583**

Figure 1-3 – Example of Water Accounting According to RIBAMAN-5

SURFACE WATER BALANCE		Upstream Inflow	Catchment Inputs								
		R1	PMX	SNP	QBF	ΣMR	ΣHR	ΣIR	ΣAR	IMP	SRO
CATCHMENT A0	OND	155.60	107.6			0.1	155.6	0.1		0.05	
	JFM	233.00	80.7			0.1	233.0	0.1		0.05	
	AMJ	242.34	84.3			0.1	189.9	0.1	2.1	0.05	1.3
	JAS	83.17	62.1			0.1	83.2	0.1	0.5	0.05	1.0
	TAV	714.1	334.7			0.2	661.6	0.3	2.7	0.19	2.3

SURFACE WATER BALANCE		Catchment Losses					Surface Abstractions and Returns								Storage Volumes			Runoff	
		ETA	EVP	SRC	GRC	EXP	SMI	SMR	SHI	SHR	SII	SIR	SAI	SAR	SS	RS	GS	CVO	CQO
CATCHMENT A0	OND	-22.4	-26.5	-49.0		0.0	-0.1	0.0			-0.3	0.3			42.2			187.72	23.62
	JFM	-16.4	-1.9	-32.9		0.0	-0.1	0.0			-0.3	0.3			58.7			278.99	35.88
	AMJ	89.7	49.2	35.1		0.0	0.1	0.0			0.3	0.3	0.7	0.1	19.0			245.22	31.19
	JAS	-37.6	-33.2	-21.7		0.0	-0.1	0.0			-0.3	0.3	-0.9	0.0	21.9			90.95	11.44
	TAV	-166.1	-110.9	-138.7		0.0	-0.3	0.1			-1.4	1.2	-1.7	0.1				802.9	25.53

[1] United Nations, Department of Economic and Social Affairs, Statistics Division (2012) - System of Environmental-Economic Accounting for Water (SEEAW)

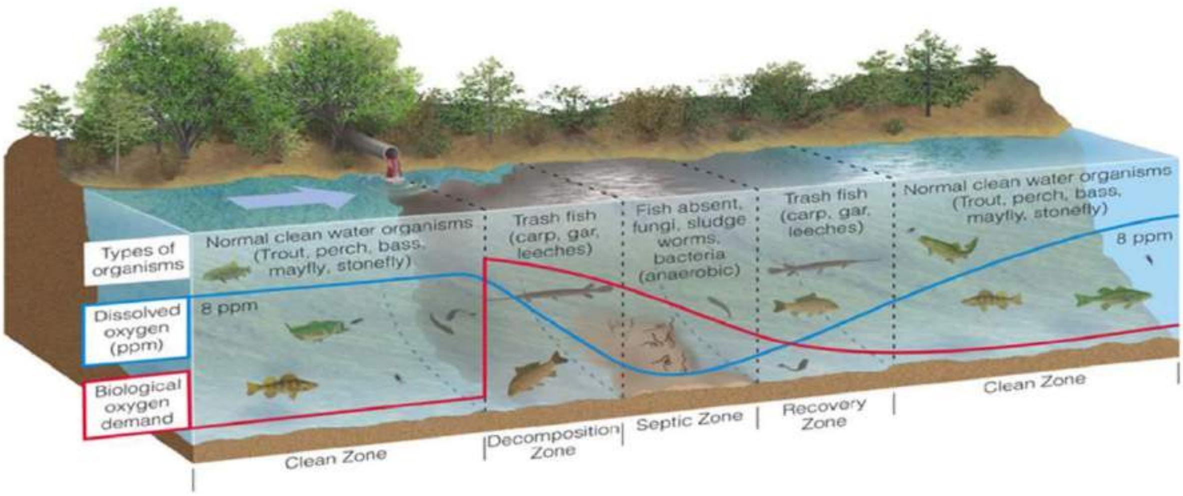
1.3 PRACTICAL EXERCISE – EXAMPLE OF THE FRAMEWORK – WWTP PRIORITIES

1.3.1 OXYGEN CONSUMPTION IN RIVERS (BOD)

Municipal, agricultural and industrial activities discharge organic substances to rivers that deplete waterbody oxygen levels (measured by BOD_5, Figure 1-4). If the wastewater is untreated, and runs continuously e.g. municipal wastewater, at the point of maximum oxygen demand (septic zone) the river may become uninhabitable for all fauna other than anaerobic bacteria.

Prolonged depleted oxygen levels typically less than 6-8 mg/l will be harmful higher taxa such as fish. To achieve Good Ecological Status in any waterbody, a typical Environmental Quality Standard (EQS) for BOD_5 will be in the order of < 4 mg/l. Values > 15 mg/l are very likely to place the catchment waterbody into Bad Status.

Figure 1-4 – Example of Oxygen Depletion Downstream of Outfall



The level of oxygen in the waterbody is one of the most critical parameters for aquatic ecosystem health, and therefore BOD_5 is considered one of the most useful general measures of pollutant impact on water quality.

At the exact point of discharge, before complex deoxygenation and reaeration processes initiate, the resultant BOD_5 level in the waterbody is a simple mass-balance calculation based on the pollutant load of the wastewater + initial load in the river (g or kg) divided by the total volume carrying the load (m^3).

Load (g) / Volume (m^3) = Concentration (g/m^3 = mg/l)	

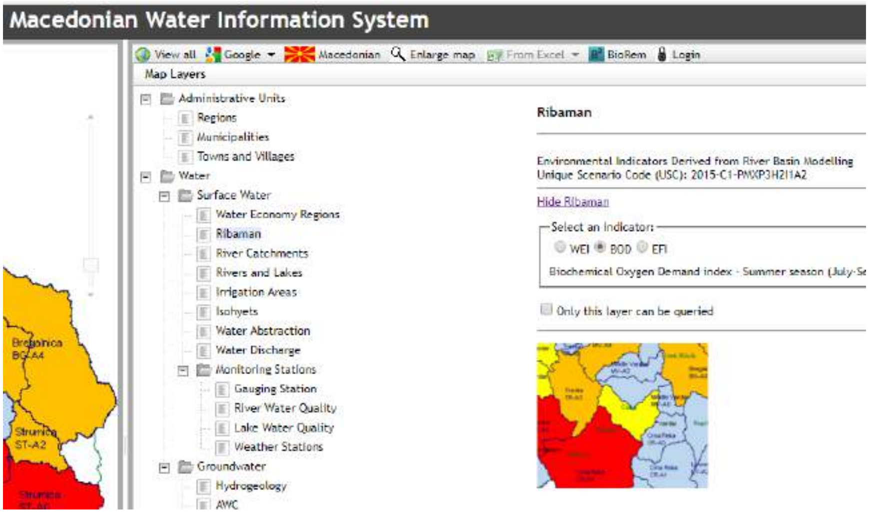
1.3.2 Practical exercise – Use the Framework To Select Priority WWTP Locations

In this exercise you will identify a short-list of priority catchments that require urgent BOD treatment with Wastewater Treatment Plants.

The example uses the **INDICATOR of BOD** to assist in the policy decision.

Method 1 *– Use the MoEPP Water Information System to Find Worst Case BOD*

1) Log on to www.moepp.gov.mk
2) Navigate to map layers\water\surface water\ribaman\ BOD



3) Identify all catchments with BOD > 15 mg/l.
4) Establish the exact BOD value in each case
5) Complete the data Table. Prioritise the areas for WWTPs

Catchment	BOD AMJ	BOD JAS	Priority	Other Comments

Method 2 *– Use the raw data from RIBAMAN-5 modelling of indicators*

1) Study the Tables and identify the BOD priority catchments
2) Highlight them.
3) Why is there a difference between BOD in spring and summer?

Catchment	BOD AMJ	BOD JAS	Priority	Other Comments

Table 4-1 Summary of Sub-basin Environmental Indicators

Western Macedonia
25.08.2017

Sub-Basins	Water Balance							Water Exploitation Index					BOD Index					Ecological Flow Index				
A	B	C	D	E			F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
Prespa	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	PR-A0																					
Ohrid - Drim	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	OD-A0	121.5	702	47.6	45.5	19.9	25.6	0.0%	0.0%	0.0%	0.1%	0.0%	0.3	0.2	0.2	0.3	0.3	0.92	1.00	0.90	1.75	1.14
Spilje Dam	OD-R1	13.1	777					104.1%	103.1%	88.5%	127.8%	101.6%	0.7	0.5	0.3	0.3	0.4	0.92	0.99	0.89	1.79	1.15
Catchment A1	OD-A1	313.2	777	46.1	42.3	22.1	20.1	0.2%	0.2%	0.4%	1.3%	0.4%	0.3	0.2	0.1	0.4	0.2	0.87	0.96	1.01	1.40	1.06
Catchment A2	OD-A2	831.1	941	15.0	13.0	5.9	7.1	1.0%	0.8%	0.5%	2.4%	0.8%	0.8	0.6	0.3	1.2	0.7	0.99	0.99	1.00	0.98	0.99
Globochica Dam	OD-R2	2.7	761					103.5%	115.7%	99.7%	86.3%	102.1%	1.1	1.0	0.8	1.2	1.0	0.81	0.94	1.02	1.81	1.15
Catchment A3	OD-A3	328.0	761	26.6	26.5	13.0	13.5	0.4%	0.3%	1.4%	4.9%	1.1%	1.2	0.9	0.8	1.2	1.0	0.78	0.81	1.02	2.10	1.18
Lake Ohrid	OD-R4	358.7	742					0.3%	0.3%	0.3%	0.7%	0.3%	1.2	1.2	1.2	1.3	1.2	0.75	0.79	1.03	2.64	1.30
Catchment A4	OD-A4	1405.7	742	21.6	20.2	16.8	3.3	0.8%	0.7%	0.8%	1.3%	0.9%	1.5	1.2	1.2	1.8	1.4	0.99	1.00	1.01	1.01	1.00
T-AV		3000	801					26.3%	27.6%	23.9%	28.1%	25.9%	0.9	0.7	0.6	1.0	0.8	0.88	0.93	0.99	1.69	1.12
Upper Vardar	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	UV-A0	136.59	654	26.5	22.36	12.58	9.78	10.3%	8.9%	6.3%	21.4%	9.7%	0.8	0.7	0.5	1.3	0.8	1.20	1.18	1.01	1.45	1.21
Catchment A1	UV-A1	383.57	723	23.7	20.53	11.17	9.36	0.6%	0.5%	1.7%	7.9%	2.0%	2.6	2.3	1.8	4.1	2.7	1.34	1.31	1.08	1.89	1.40
Catchment A2	UV-A2	206.59	972	3.4			0	4.7%	4.1%	3.3%	8.7%	4.4%	19.3	12.3	6.2	23.4	15.3	0.96	0.96	0.98	0.95	0.97
Catchment A3	UV-A3	497.59	856	16.0			0	23.3%	21.6%	35.6%	9.8%	26.5%	4.2	3.9	3.6	6.7	4.6	1.54	1.53	1.11	2.62	1.70
Catchment A4	UV-A4	392.12	806	12.2			0	-248%	-150%	-77%	-138%	-136%	3.9	3.2	3.3	5.0	3.9	3.48	2.50	1.81	2.43	2.55
T-AV		1616	810					-41.7%	-22.9%	-5.9%	-18.0%	-18.8%	6.2	4.5	3.1	8.1	5.5	1.70	1.49	1.20	1.87	1.57
Treska	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	TR-A0	190.4	671	22.4	20.8	7.7	13.1	0.0%	0.0%	0.0%	0.1%	0.0%	0.8	0.8	0.7	1.2	0.9	1.28	0.83	0.76	1.68	1.14
Matka Dam	TR-R1	0.3	672					75.6%	72.0%	69.1%	101.2%	77.8%	0.0	0.0	0.0	0.0	0.0	1.30	0.82	0.74	1.70	1.14
Catchment A1	TR-A1	13.9	672	20.5	19.0	7.0	12.0	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	0.0	0.0	0.0	0.0	1.30	0.82	0.74	1.68	1.13
Sv. Petka Dam	TR-R2	1.1	714				0.0	92.9%	22.8%	26.9%	99.0%	56.6%	0.0	0.0	0.0	0.0	0.0	1.34	0.81	0.72	1.85	1.18
Catchment A2	TR-A2	40.5	714	18.6	17.6	5.3	12.3	0.0%	0.0%	0.0%	0.1%	0.0%	0.0	0.0	0.0	0.0	0.0	1.35	0.81	0.72	1.85	1.18
Kojak Dam	TR-R3	14.2	755				0.0	137.0%	81.0%	72.2%	205.7%	99.6%	2.0	2.4	2.5	3.5	2.6	1.36	0.80	0.72	1.87	1.19
Catchment A3	TR-A3	924.6	755	18.4	15.3	7.7	7.6	0.2%	0.1%	0.3%	1.5%	0.3%	5.9	3.2	2.7	11.8	5.9	0.96	0.98	0.98	0.88	0.95
Catchment A4	TR-A4	888.4	759	9.8	7.8	3.5	4.3	7.0%	3.8%	6.0%	24.4%	7.2%	13.8	7.3	7.1	31.8	15.0	0.93	0.96	0.96	0.79	0.91
T-AV		2058	748					39.1%	22.5%	21.8%	54.0%	30.2%	2.8	1.7	1.6	6.0	3.1	1.23	0.85	0.79	1.54	1.10

Table 4-2	Summary of Sub-basin Environmental Indicators																					Central-Northern Macedonia 25.08.2017
Sub-Basins				Water Balance				Water Exploitation Index					BOD Index					Ecological Flow Index				
A	B	C	D		E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
Lepenec	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	LP-A0	121.0	661	10.8	9.1	3.9	5.2	-0.1%	0.0%	0.4%	1.2%	0.3%	1.1	0.9	0.6	1.6	1.1	0.97	0.98	0.99	0.95	0.97
Catchment A1	LP-A1	46.0	665	9.5	8.0	3.4	4.6	0.2%	0.2%	0.4%	1.0%	0.4%	0.4	0.3	0.2	0.6	0.4	0.97	0.97	0.98	0.94	0.97
Catchment A2	LP-A2	131.0	714	9.0	7.6	3.2	4.3	0.3%	0.3%	0.2%	0.5%	0.3%	1.0	0.8	0.5	1.5	1.0	0.97	0.97	0.98	0.95	0.97
Catchment A3	LP-A3	308.0	797	4.1	3.5	1.5	2.0	1.5%	1.1%	1.2%	3.8%	1.6%	4.8	3.6	2.4	6.9	4.4	0.99	0.99	1.00	0.98	0.99
Catchment A4	LP-A4	226.5	693	3.1	2.6	1.1	1.5	9.2%	8.0%	7.5%	14.5%	9.2%	35.9	30.5	17.5	50.1	33.5	0.93	0.94	0.96	0.89	0.93
T-AV		832.5	729					2.2%	1.9%	1.9%	4.2%	2.4%	8.7	7.2	4.2	12.1	8.1	0.96	0.97	0.98	0.94	0.96
Pchinja	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	PJ-A0	460.9	619	12.9	10.3	3.4	6.9	0.1%	0.1%	1.4%	6.3%	1.2%	0.6	0.3	0.3	1.4	0.7	0.95	0.98	0.93	0.73	0.90
Catchment A1	PJ-A1	378.0	647	1.3	1.1	0.5	0.6	16.8%	12.1%	12.1%	28.6%	16.9%	40.1	23.3	20.6	75.0	39.8	0.71	0.88	0.69	0.48	0.69
Glazhnja Dam	PJ-R2	1.0	761				0.0	0.0%	0.0%	45.0%	105.0%	37.0%	1.0	0.9	0.7	0.7	0.8	0.75	0.97	0.54	0.10	0.59
Catchment A2	PJ-A2	101.7	761	1.2	1.0	0.4	0.6	0.4%	0.3%	0.2%	0.7%	0.3%	0.9	0.6	0.4	1.4	0.8	1.00	1.00	1.00	1.00	1.00
Catchment A3	PJ-A3	1000.0	711	4.7	3.9	1.5	2.4	3.5%	2.1%	5.4%	20.6%	6.0%	16.6	9.6	7.6	27.2	15.3	0.97	0.98	0.96	0.83	0.93
Catchment A4	PJ-A4	928.2	716	5.3	4.6	1.5	3.1	0.6%	0.3%	1.2%	5.5%	1.2%	2.4	1.2	1.1	4.2	2.2	0.99	1.00	1.00	0.97	0.99
T-AV		2870	691					3.6%	2.5%	10.9%	27.8%	10.4%	10.3	6.0	5.1	18.3	9.9	0.89	0.97	0.85	0.69	0.85
Middle Vardar	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	MV-A0	182.5	593	94.5	84.8	44.8	40.0	0.0%	0.0%	0.1%	0.4%	0.1%	0.0	0.0	0.0	0.0	0.0	1.19	1.07	1.06	1.39	1.18
Catchment A1	MV-A1	614.3	682	4.2	3.2	1.2	2.0	0.2%	0.1%	2.3%	18.6%	2.4%	1.5	0.7	0.8	4.6	1.9	1.00	1.00	1.01	1.02	1.01
Catchment A2	MV-A2	396.4	681	77.6	69.8	36.8	32.9	0.1%	0.1%	0.2%	1.0%	0.2%	0.6	0.4	0.3	1.0	0.6	1.37	1.13	1.09	1.41	1.25
Catchment A3	MV-A3	436.1	677	74.9	67.3	35.5	31.8	0.0%	0.0%	0.1%	0.6%	0.1%	0.1	0.1	0.1	0.2	0.1	1.14	1.13	1.09	1.37	1.19
Catchment A4	MV-A4	965.3	660	62.7	56.1	30.7	25.4	-1.9%	-1.3%	-0.9%	-3.2%	-1.5%	7.5	5.3	4.4	11.9	7.3	1.22	1.18	1.14	1.61	1.29
T-AV		2594.6	667					-0.3%	-0.2%	0.4%	3.5%	0.3%	1.9	1.3	1.1	3.5	2.0	1.2	1.1	1.1	1.4	1.2
Bregalnica	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	BG-A0	1514.5	622		8.3	2.8	5.5	-0.1%	-0.1%	0.5%	2.9%	0.3%	6.0	2.5	3.4	7.5	4.9	0.62	0.87	0.89	1.90	1.07
Mantovo Dam	BG-R1	3.6	655					0.0%	0.0%	339%	1342%	244%	1.4	1.7	2.0	2.4	1.9	0.00	0.00	0.00	0.00	0.00
Catchment A1	BG-A1	189.2	655		0.4	0.2	0.2	2.6%	1.8%	10.1%	31.9%	9.4%	6.4	4.4	4.6	11.9	6.8	0.97	0.98	1.02	0.99	0.99
Catchment A2	BG-A2	1441.9	697		6.4	2.2	4.2	0.6%	0.3%	1.4%	7.0%	1.2%	9.0	3.7	5.1	9.7	6.9	0.58	0.86	0.86	1.80	1.03
Knezhevo Dam	BG-R3	0.8	838					13.3%	12.2%	9.7%	33.3%	14.0%	0.8	0.7	0.5	0.5	0.6	0.41	0.82	0.86	0.56	0.66
Catchment A3	BG-A3	52.2	838		0.8	0.3	0.5	6.4%	6.4%	4.8%	14.8%	6.9%	0.1	0.1	0.1	0.2	0.1	0.94	0.94	0.96	0.86	0.92
Kalamanci Dam	BG-R4	4.2	739					12.6%	50.7%	104.0%	320.9%	89.3%	2.3	2.4	2.5	3.4	2.6	0.13	0.74	0.75	1.79	0.85
Catchment A4	BG-R4	1122.1	739		4.5	2.0	2.5	2.2%	1.2%	5.1%	19.3%	4.9%	4.8	2.5	2.8	8.8	4.7	0.98	0.99	0.98	0.85	0.95
T-AV		4319.9	681					7.0%	14.2%	25.0%	79.1%	23.2%	3.4	1.9	2.2	4.5	3.0	0.61	0.87	0.88	1.17	0.88

Table 4-3 Summary of Sub-basin Environmental Indicators

Southern-Eastern Macedonia
25.08.2017

Sub-Basins	Water Balance							Water Exploitation Index					BOD Index					Ecological Flow Index				
A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	X
Crna Reka	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	CR-A0	517.2	647	24.4	17.9	3.0	14.9	0.0%	0.0%	0.3%	1.5%	0.2%	0.1	0.1	0.1	0.4	0.2	1.02	0.70	0.96	1.47	1.04
Tikvesh Dam	CR-R1		706					110.2%	72.3%	78.7%	242.0%	91.9%	0.7	0.4	0.2	0.2	0.4	1.02	0.66	0.95	1.52	1.04
Catchment A1	CR-A1	825.4	706	24.3	19.0	6.8	12.2	0.2%	0.1%	0.1%	0.4%	0.1%	0.0	0.0	0.0	0.1	0.0	0.91	0.91	1.01	0.84	0.92
Catchment A2	CR-A2	1606.6	734	22.2	16.7	5.9	10.8	0.4%	0.2%	0.2%	1.8%	0.3%	0.2	0.1	0.1	0.8	0.3	0.91	0.90	0.92	1.24	0.99
Strezhevo Dam	CR-R3		789					12.4%	-16.0%	58.3%	975.5%	52.5%	0.9	0.8	0.7	0.7	0.8	1.18	0.65	0.62	4.69	1.78
Catchment A3	CR-A3	155.6	789	2.1	1.6	0.4	1.2	0.3%	0.1%	2.8%	31.8%	3.2%	0.5	0.3	0.2	2.0	0.7	1.00	1.00	1.00	0.79	0.94
Catchment A4	CR-A4	2769.0	706	12.7	11.0	3.4	7.6	17.1%	12.9%	9.4%	32.3%	13.2%	15.2	6.9	8.5	46.6	19.3	0.86	0.84	0.87	1.48	1.01
T-AV		5874.0	711					20.1%	9.9%	21.4%	183.6%	23.1%	2.5	1.2	1.4	7.2	3.1	0.99	0.81	0.90	1.72	1.10
Lower Vardar	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	LV-A0	893.75	611	136.8	114.4	53.1	61.3	0.0%	0.0%	0.2%	1.1%	0.2%	0.3	0.2	0.2	0.5	0.3	1.02	0.96	1.01	1.27	1.06
Catchment A1	LV-A1	216.35	621	130.0	110.9	53.5	57.4	0.0%	0.0%	0.0%	0.2%	0.0%	0.0	0.0	0.0	0.0	0.0	1.02	0.96	1.01	1.28	1.07
Catchment A2	LV-A2	458.73	724	4.5			0.0	5.8%	3.6%	5.9%	17.7%	6.4%	0.4	0.2	0.3	0.8	0.4	0.94	0.96	0.99	0.93	0.96
Catchment A3	LV-A3	695.28	602	123.1	105.0	50.7	54.4	-0.5%	-0.1%	0.8%	-0.1%	0.2%	0.4	0.2	0.2	0.8	0.4	1.02	0.96	1.01	1.30	1.07
T-AV		2264.1	632					6.5%	3.4%	6.9%	50.6%	7.4%	0.8	0.4	0.5	2.1	0.9	0.99	0.92	0.98	1.30	1.05
Strumica	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	ST-A0	725.2	635	4.2	2.6	0.8	1.7	2.2%	1.1%	4.1%	43.2%	4.1%	9.8	4.6	6.8	39.1	15.1	0.79	0.79	0.78	0.97	0.83
Vodocha Dam	ST-R1	1.8	659					0.8%	0.6%	58.0%	2101%	56.9%	1.0	1.0	1.0	1.1	1.0	0.08	0.10	0.10	0.12	0.10
Catchment A1	ST-A1	71.8	659	0.2	0.1	0.0	0.1	0.8%	0.4%	10.8%	54.2%	12.2%	1.7	0.7	0.9	4.4	1.9	0.99	1.00	0.90	0.51	0.85
Turija Dam	ST-R2	1.8	734					33.3%	30.8%	55.0%	454.9%	65.2%	1.4	1.4	1.5	1.9	1.5	0.10	0.10	0.30	0.13	0.16
Catchment A2	ST-A2	210.6	734	1.1	0.8	0.2	0.6	-0.1%	0.0%	0.0%	-0.2%	-0.1%	3.5	1.6	1.8	9.4	4.1	1.00	1.00	1.00	1.00	1.00
Catchment A3	ST-A3	362.0	652	1.6	1.2	0.3	0.8	4.0%	2.1%	3.0%	19.5%	4.0%	17.5	8.8	9.7	43.6	19.9	0.97	0.98	0.99	1.10	1.01
Catchment A4	ST-A4	117.5	743	0.9	0.7	0.2	0.5	0.0%	0.0%	0.0%	0.0%	0.0%	0.0	0.0	0.0	0.1	0.0	1.00	1.00	1.00	1.00	1.00
T-AV		1487.2	663					5.9%	5.0%	18.7%	381.8%	20.3%	5.0	2.6	3.1	14.2	6.2	0.70	0.71	0.72	0.69	0.71
Dojran	ID	Area	P	MAF	Q50	Q90	WAU	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN	OND	JFM	AMJ	JAS	ANN
Catchment A0	DJ-A0																					
T-AV																						

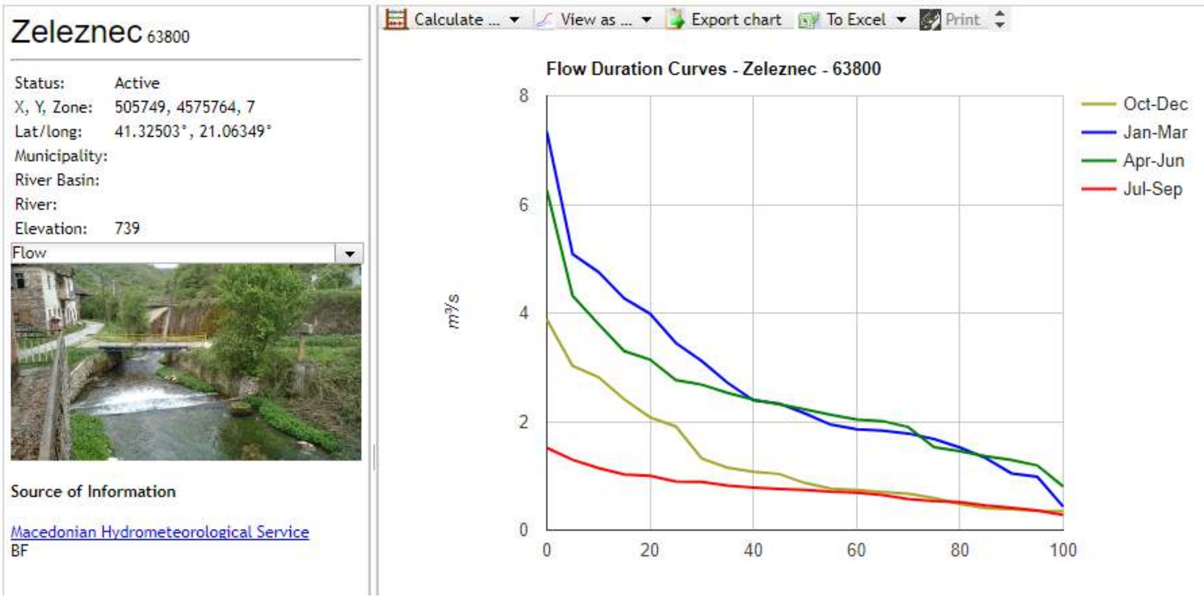
eptisa

2 CONCEPTS OF "ECOLOGICAL FLOW" AND "WATER FOR USE"

2.1 UNDERSTANDING AND WORKING WITH FLOW DURATION CURVES

Flow Duration Curves (FDCs) are one of the most essential and basic tools in water resource assessment and allocation. An FDC describes the proportion of time that a specific flow is equalled or exceeded within a period of record. FDCs can be prepared for any time period, most usually annual, seasonal and monthly. They are derived from a probabilistic assessment of long-term flows at a measurement location.

Figure 2-1 – Example of Seasonal Flow Duration Curves – GS Zeleznec, Crna Reka Sub-basin



In the example of Figure 2-1, the significant differences in seasonal flow regime are evident. The winter period (January-February-March) has the steepest curve, indicating a wider range of flow values. This reflects the higher variability of runoff in this period, which is probably related to differences in the timing of snowmelt.

The summer period FDC (July-August-September) is noticeably flatter than other seasons. This means that stable, low flows dominate the regime in this period. Typically this situation arises either because i) groundwater contribution (baseflow) dominates the river flow ii) there may be significant upstream abstraction e.g. irrigation.

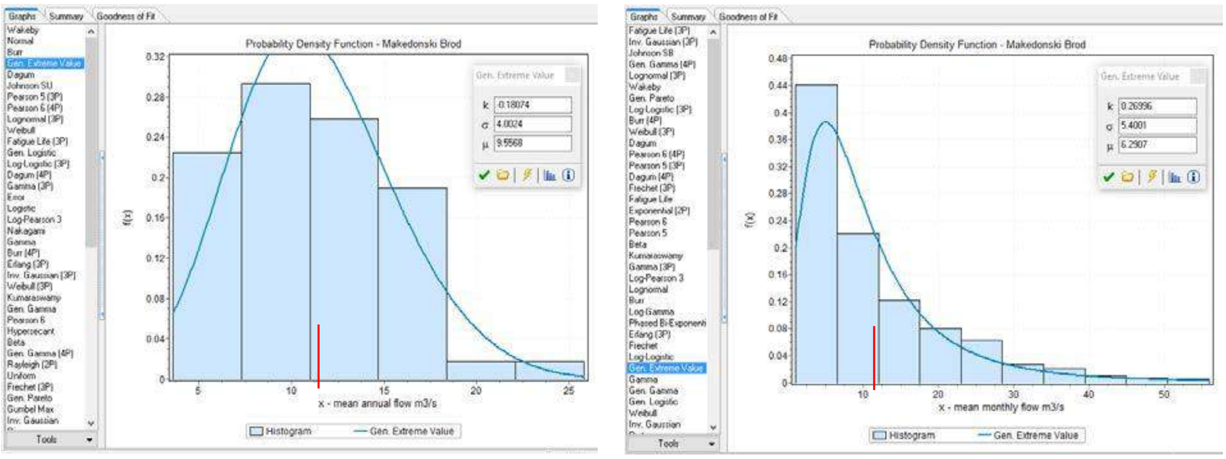
2.1.1 UNDERSTANDING THE DIFFERENCE BETWEEN Q_{MEAN} AND Q_{50}

In water resources planning and allocation, we are principally interested in reliable average quantities of water. Many water professionals assume that the mean flow is a sufficient indicator of ‘average’ flow condition. This is NOT the case, especially when we move to seasonal, monthly or daily flow data!

Use of the annual mean can significantly distort the correct representation of water availability or water use impacts at monthly/seasonal periods. This arises from the statistical properties inherent to the data interval used. Annual flow data (i.e. series of *n-year* values) tends to have a probability distribution that increasingly tends to near-normal i.e. the mean flow value is central to the distribution of all the annual flows.

In Figure 2-2 (left), annual statistics are shown. The most common annual quantity (the modal group) lies in the range 8-10 m³/s (the mean annual flow (red line) for Makedonski Brod is 11.4 m³/s), hence the data are considered ‘near-normally distributed’. This means that there are a similar number of annual quantities above the mean flow as below it. However, for monthly flow quantities, the situation is completely different (Figure 2-2, right). The majority of the mean monthly flow quantities are much less than the mean annual flow, counter-balanced by a few extreme quantities greater than the mean. This is typical of most world rivers i.e. monthly data tend not to be ‘normally distributed’ and are ‘positively skewed’.

Figure 2-2 – Example of Probability Distributions for Annual Data and Monthly Data



This statistical difference is of extreme importance in water allocation. For ANY data set (daily, monthly or seasonal) that is highly positively skewed, the arithmetic mean of that data set is NOT a reliable indicator of the ‘average’ value, because the mean is distorted by the (fewer) higher values. In these cases the better measure of the ‘average’ condition is the **median flow (Q50)**. The Q50 is the centrally occurring data value, and is therefore not influenced by the skew of the data set.

Since in water resource systems the requirement is to define and allocate a representative long-term average quantity of water, the Q50 is the more correct value to use. Typically the Q50 will be 10-20% less than the arithmetic mean. This is a significant quantity in water resource terms. The Q50 is directly obtained from the Flow Duration Curve.

2.1.2 PRACTICAL EXERCISE – DERIVE A FLOW DURATION CURVE AND IDENTIFY KEY PROPERTIES

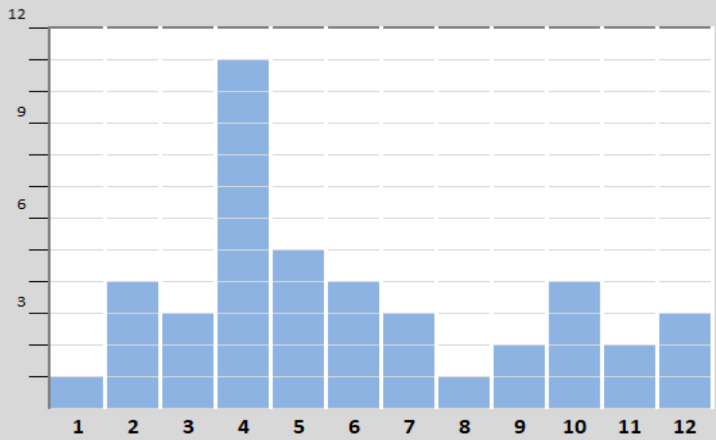
Use the template of Figure 2-2 to derive the Flow Duration Curve.

1) The annual hydrograph is plotted for you.
2) Rank the monthly data under <Flow>, highest to lowest. With identical values, just repeat them.
3) The plot position P (X > *x*) is already calculated, but convert this to a percentage.
4) Calculate the annual MEAN flow AND the annual MEDIAN flow
5) Repeat for seasons (1,2,3), (4,5,6), (7,8,9), (10,11,12)
6) Use the data to plot the Flow Duration Curve
7) Calculate the volumetric difference between the annual mean value (3.67 m^3/s) and the annual median value (3.0 m^3/s).
8) Based on the unit values given below, calculate how much error is possible with respect to water allocation quantities.

Volume	3.67 – 3.0 m^3/s	
Sector	Unit use ('cost of production')	Potential difference in output
Municipal water	Unit rate = 0.200 m^3/capita day	
Hydropower	Unit rate = 4,588 m^3/MWh	
Irrigation	Unit rate = 7,500 m^3/hectare	

Table 2-1 – Practical Exercise for Flow Duration Curve

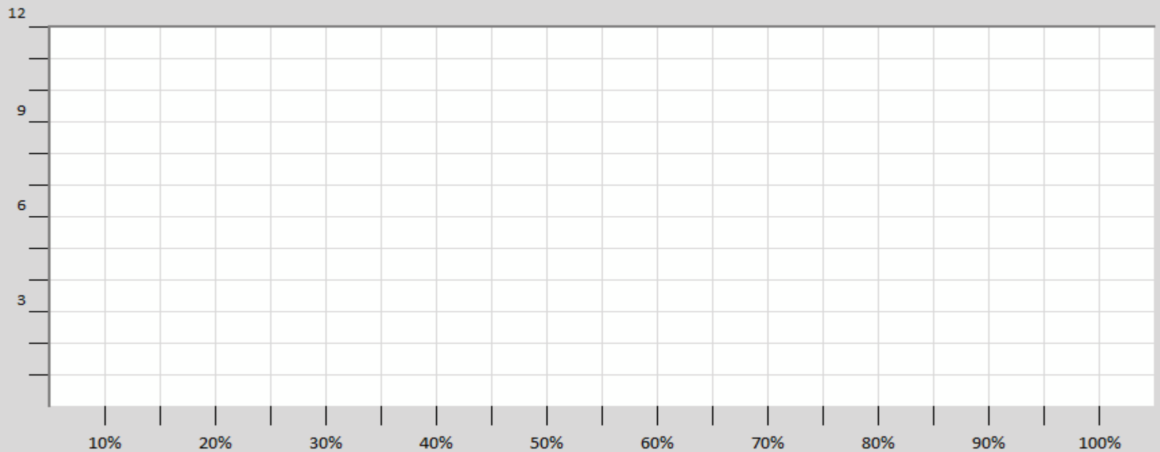
Hydrograph



Rank	Flow	P (X > x)	P (%)
1		0.083	8.3
2		0.167	16.7
3		0.250	25.0
4		0.333	33.3
5		0.417	41.7
6		0.500	50.0
7		0.583	58.3
8		0.667	66.7
9		0.750	75.0
10		0.833	83.3
11		0.917	91.7
12		1.000	100.0

	Mean	Q50
Annual		
1,2,3	*2.67*	*3.00*
4,5,6	*6.67*	*5.00*
7,8,9	*2.00*	*2.00*
10,11,12	*3.00*	*3.00*

Flow Duration Curve



Water Available

Q90	
WAU	**Q50 - Q90**
VOL	**3.67 - 3.00**
MW	**0.20 m3/c/day**
HP	**4,588 m3/MWh**
IRR	**7,500 m3/ha.**

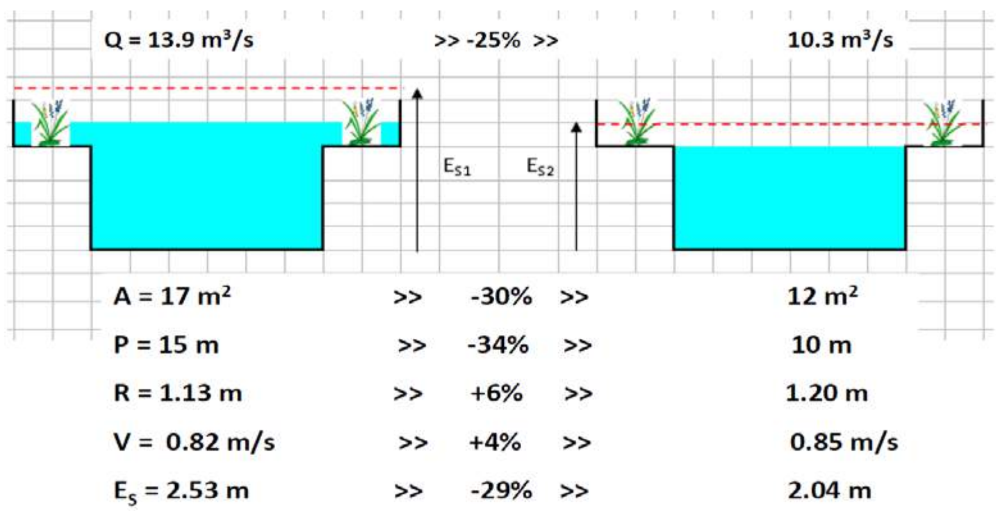
2.2 ECOLOGICAL FLOWS

2.2.1 WATER QUANTITY, ECOLOGICAL FLOW AND WATERBODY 'STATUS'

In recent years since the promulgation of the WFD, there has been recognition that in fact water quantity, not quality, plays the critical pre-eminent role in delivering waterbody 'Good Status'. First, quality is in any case always a function of quantity through the processes of dilution and concentration of effluents, secondly, because of several fundamental physical principles, even relatively small changes in waterbody quantity (± 25%) from the normal 'regime' of the natural flow can significantly and permanently impact adversely on aquatic species, irrespective of the water quality of the waterbody, [2].

It is often not well understood at the most fundamental level WHY ecological flow preservation is so important. Figure 2-3 illustrates that a modest reduction of river flow of only 25% has a significant impact on every aspect of ecological habitat parameters.

Figure 2-3 – Fundamental Physical Principles of Ecological Flow



The changing origin and quantity of water flowing in a river provides habitat and significantly influences water quality, temperature, nutrient cycling, oxygen availability, and the geomorphic processes that shape river channels and floodplains. Natural flow regimes display variability at a range of time scales, including seasonal and inter-annual. Native aquatic and riparian biotas are highly adapted to this variability. For this reason, the magnitude, frequency, duration, timing and rate of change of the natural flow regime are generally agreed to be the key elements central to sustaining and conserving native species and ecological integrity[3].

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[2] Faulkner, B.L. (2015), "Implementing Innovative Permit Procedures in EU pre-accession countries, with Special Reference to Environmental Flows – A case-study of hydropower in the Republic of Macedonia", in CIWEM National Conference "The Cutting Edge in Water Framework Directive Implementation, Birmingham, UK.

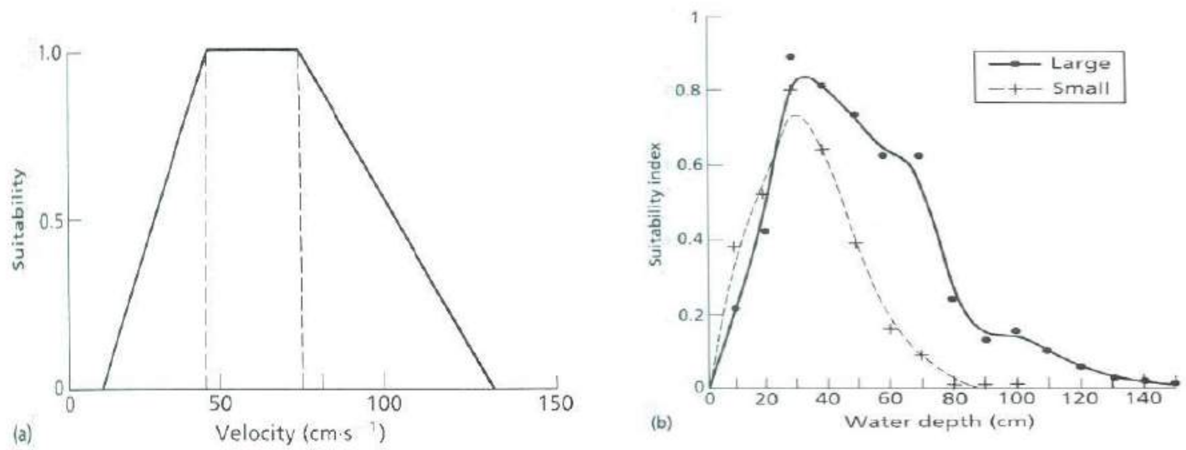
[3] European Commission (2015) Ecological Flows in the Implementation of the Water Framework Directive, CIS Guidance Report 31, Technical Report 2015-086.

When artificial influences (e.g. irrigation abstractions, hydropower releases) change the natural regime, very significant adverse effects on the aquatic biota are inevitable. Increases of flow are as likely to create adverse impacts as reductions in flow.

The sensitivity of waterbodies to artificial influences is assessed at a detailed ecological level typically in the form of **habitat preference curves**. These curves describe the habitat preferred range of the aquatic species, typically in the form of the flow depth and flow velocity. For example, Figure 2-4 illustrates that for salmonid fish, the optimum flow velocity ranges between 0.50 – 0.75m/s. Optimum depth for spawning lies between 0.30 – 0.50m. Evidently these are extremely small margins.

Major influences such as large scale irrigation abstraction or hydropower releases may change the physical properties of the waterbody by an order of magnitude +. Uncontrolled or at the inappropriate time, these influences can evidently completely disrupt or even destroy the aquatic ecosystem.

Figure 2-4 – Examples of Habitat Preference Curves for Salmonid Fish



2.2.2 Q90 AS A PROXY FOR MINIMUM ECOLOGICAL FLOW

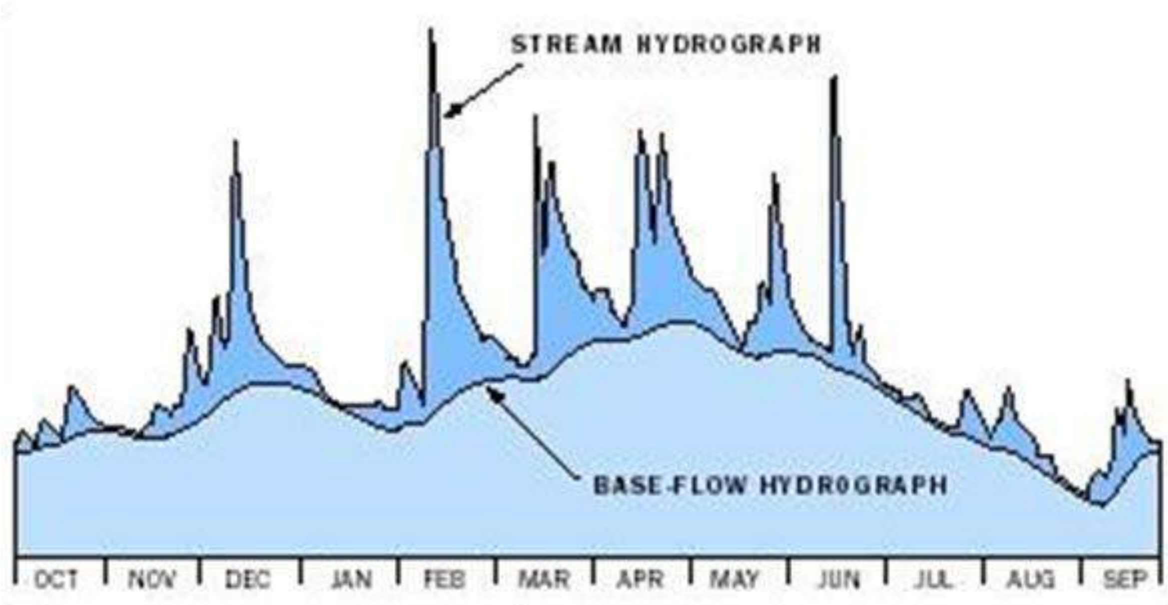
The Q90 index flow is of particular importance in ecological flow assessment. It is widely accepted as a good general indicator of the groundwater contribution to a stream or river (known as '**baseflow**'). Baseflow is usually heavily influenced by catchment geology which will also possibly have unique properties of temperature and chemical constituency different from surface water.

Of the total outflow hydrograph of any river basin, the baseflow typically constitutes 30-40%+ of the volume. More importantly, this part of the hydrograph is the stable, long-term component of the stream flow (Figure 2-5).

Because the baseflow dominates the time-period, it is conventionally accepted that most aquatic species will have adapted more closely to the baseflow regime than the surface runoff regime.

Therefore the Q90 is therefore widely regarded as a good indicator of the minimum ecological flow requirement for the time-period of interest, especially for ecosystem properties such as spawning, dispersion and migration.

Figure 2-5 – Baseflow and Runoff Hydrographs



2.2.3 *The Ecological Flow Index (EFI)*

The Ecological Flow Index (EFI) expresses for any specified time-period (month or season) the ratio of the modified flow to the original unmodified or reference flow. Obviously there are potentially many ecological flows within a single year (high and low) and whilst it will not be technically possible to match every point of the natural Flow Duration Curve, so-called 'index flows' provide a benchmark at various points on the FDC to measure the extent of ecological flow disruption.

Typically these benchmark flows will comprise either:

- The median monthly or seasonal flow Q50, 12 or 4x per year (RIBAMAN-5 utilises this approach)
- Selected index flows from the annual Flow Duration Curve (see Figure 2-7).

For example, the **Q90** benchmark EFI would be: whereas the **Q50** benchmark EFI would be:

Figure 2-6 – Definition of EFI Indicator

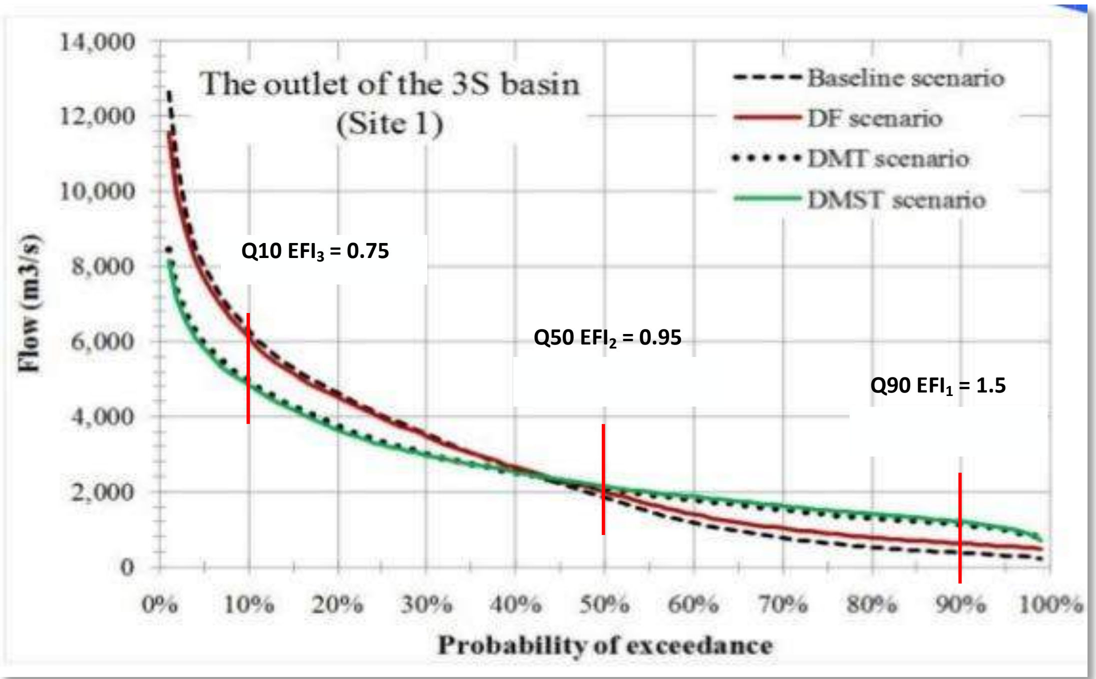
$$\frac{\text{Q90 Scenario } n \text{ Flow}}{\text{Q90 Reference Flow}} = \text{EFI}_1 \qquad \frac{\text{Q50 Scenario } n \text{ Flow}}{\text{Q50 Reference Flow}} = \text{EFI}_2$$

Therefore an EFI = 1.00 would show that the waterbody was at its natural or 'reference' state. The larger the difference from 1.00, the greater is the disruption to the original or target ecological flow.

Since artificial influences (e.g. reservoir storage in winter or irrigation abstraction in summer) may reduce flows below the original natural flow, the EFI can also be less than 1.00

The example of Figure 2-7 shows how a natural FDC (red line) may become modified as a result of artificial influences (green line) (e.g. reservoir storage of high flows in winter, increase of summer low flows due to hydropower releases). Figure 3-9 also shows the inadvisability of using a single annual 'average' index flow such as Q50. In this case Q50 appears to be at an acceptable value (0.95), BUT the high and low flows are actually significantly disrupted in opposite directions, hence the natural flow regime is significantly disrupted at the important extremes.

Figure 2-7 – Example of Ecological Flow Indices Superimposed to FDC



It is now widely accepted that EFIs in excess of 1.30 or less than 0.70 may be sufficient to disrupt the ecological status of a waterbody to 'less than good' (Table 3-1). EFIs > 1.45 or < 0.55 are very likely to place the waterbody into Bad Status, simply through the impact of excessive changes in flow regime.

It should be a general policy objective to achieve EFIs as close to 1.00 as possible for each season of the year in every sub-basin, catchment or waterbody where this is economically and technically feasible.

Table 2-2 – Example Thresholds for Ecological Flow Index and BOD Index

Waterbody Status	EFI Low	EFI High	Flow Modification	WFD	BOD mg/l
Reference Status	0.95	1.05	Minimal influences		≤ 2
Good Status	0.85	1.15			≤ 4
Moderate Status	0.70	1.30			≤ 7
Poor Status	0.55	1.45			≤ 15
Bad Status	< 0.55	> 1.45	Heavily Modified		≥ 15

2.2.4 *INDEXES OF FLOW VARIABILITY IN RELATION TO ECOLOGICAL FLOW*

With regard to the sensitivity of aquatic species to changes in flow regime, there are two important statistics of relevance:

Coefficient of Flow Variation (CV)

The CV value of any river is an expression of the variability of the catchment outflow around the central long-term mean flow, defined as:

$$CV = \frac{s}{\bar{x}} * 100\%$$

]

i.e. the standard deviation of the data set (annual or monthly) / long-term mean. Therefore higher values of CV represent a more variable flow regime. Typically rivers in the northern hemisphere tend to have annual CVs in the range 30-40%.

Values < 30% are typical of high baseflow dominated catchments with large (stable) contributions of groundwater. Values > 50% are indicative of high surface runoff catchments, with variable flow regimes and low proportions of baseflow.

The CV is calculated automatically within the Water information System for every Gauging Station in Macedonia.

Baseflow Index

The second index is the relative approximate measure of baseflow contribution as a proportion of long-term median flow, the so called Baseflow Index (BFI). The BFI is simply the ratio:

Q90 / Q50 (for any time period, but especially on an annual timescale).

Obviously the CV and BFI indexes are closely related. The higher the BFI value, the greater the groundwater contribution. BFI values > 0.4 are indicative of groundwater dominated flow regimes. One would also expect therefore that catchments with high(er) BFI values will have lower coefficients of variation.

How is this relevant to ecological flows?

Ecologists argue that when baseflow contribution to a river is high, this produces relatively stable flow regimes not frequently influenced by flash floods and surface runoff. Aquatic species have adapted to this stable regime and are less tolerant of sudden flow regime changes (such as will be created by hydropower discharges).

Therefore, if artificial influences substantially change the flow regime (as indicated by large change in the EFI), this will be more damaging in baseflow dominated catchments than surface flow dominated catchments. Aquatic species that have evolved/adapted to high flow variability will be more tolerant of flow regime change.

2.3 WATER AVAILABLE FOR USE

2.3.1 *FUNDAMENTAL PRINCIPLES*

This concept is not properly understood or applied in Macedonia, but it is critical to sustainable water allocation. There are two fundamental principles:

- **On a long-term basis, you cannot abstract more water from the river basin than is seasonally or annually renewed.**

  Therefore this value must be calculated both at seasonal and annual timescales, AND at sufficient spatial resolution so as to be relevant.

  Secondly, this finite quantity must be accounted formulation
  i.e. when some water has been allocated (by Permit), the amount that does NOT return to the source must be deducted from the original quantity. Otherwise there is a risk of 'over-licensing' i.e. allocating water that does not exist.
  This is why 'water accounting' is central to proper river basin management.

- **It is essential to safeguard (reserve) the ecological flow requirement at all times, otherwise the aquatic ecosystem is permanently damaged.**

  Therefore the value of the ecological flow must be calculated at seasonal and annual timescales.

  Secondly, once calculated, the ecological flow requirement must be subtracted from the long-term seasonal/annual renewable outflow (defined by either Q_{MEAN} OR Q_{50}):

  $Q_{OUTFLOW} - Q_{90}$ = Water Available for Use

2.3.2 *PRACTICAL EXERCISE – DETERMINATION OF WATER AVAILABLE FOR USE*

1) Return to Table 2-1.
2) Establish the 'water available for use' from the FDC.
3) Show it both as a flow rate (m^3/s) AND as an annual quantity (MCM).

As we will see in the PM session, RIBAMAN-5 follows all of these best practice concepts.

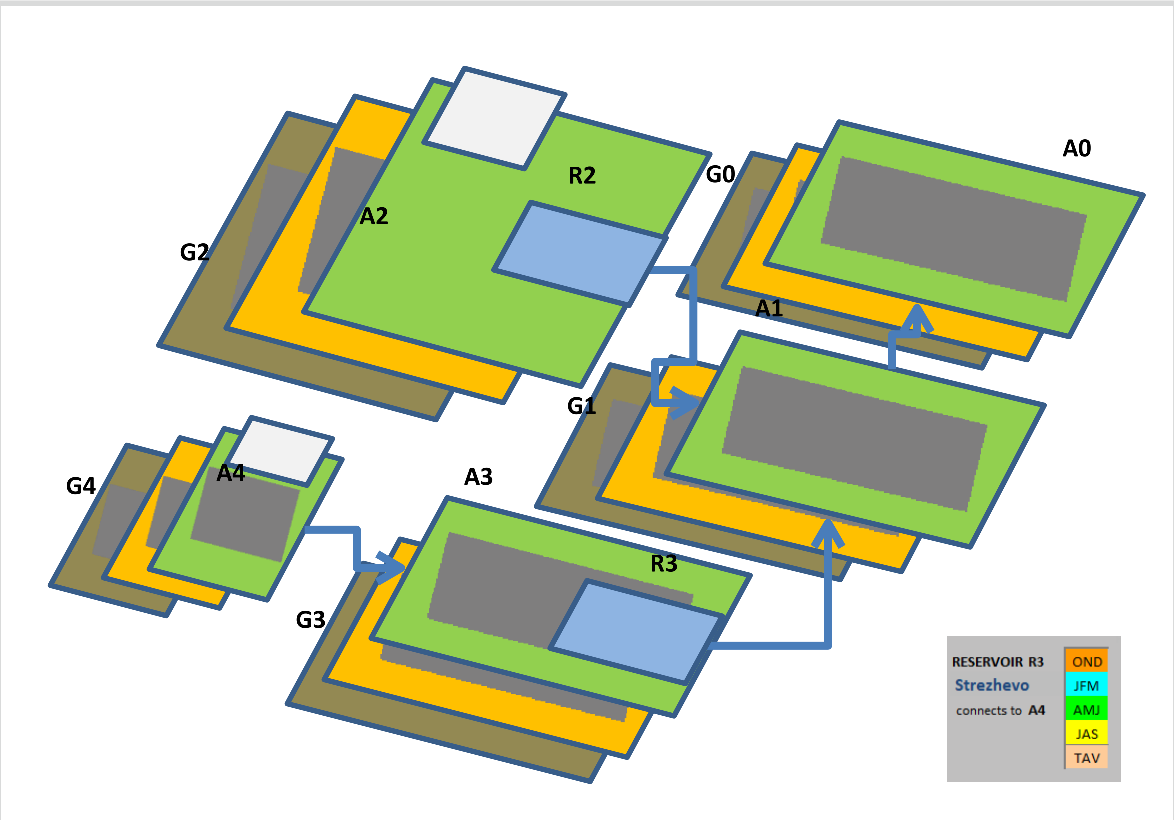
- Calculation of natural AND modified runoff at catchment and seasonal scale
- Calculation of ecological flow and water availability for use based on 'runoff – Q90'.

3 INTRODUCTION TO RIBAMAN- 5

3.1 RIBAMAN-5 STRUCTURE – RIVER BASIN, CATCHMENTS, RESERVOIRS, GROUNDWATER, DATABASES

3.1.1 *Basic Structure*

- RIBAMAN-5 is a catchment based water balancing model based on SEASONS.
- Each river basin has a maximum of five linked catchments (A0 to A5). Each catchment can contain a single reservoir (R0 to R5).
- Underlying each catchment is a linked groundwater zone (G0 to G5).
- Rivers, abstractions and discharges are not modelled as single nodes.
- All volume inputs and outputs are summed and balanced at catchment scale only.
- Volumes are input, stored, moved and balanced between various zones according to basic hydrometeorological principles (precipitation, infiltration, runoff, transpiration, evaporation) OR
- Artificial activities through abstraction, discharge, storage, imports and exports



3.1.2 WATER SOURCES

Furthermore, for each sector, water can come from three different sources:

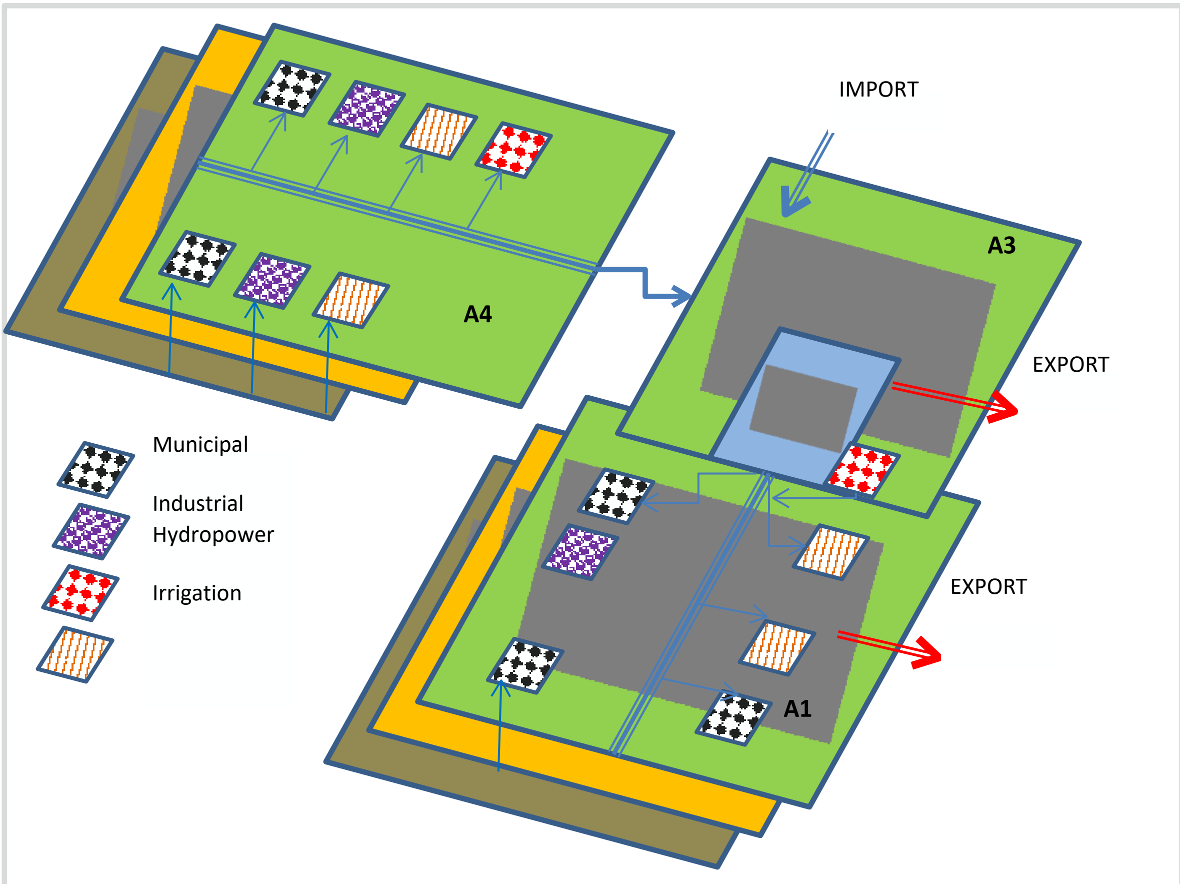
- Surface source (code S)
- Reservoir source (code R)
- Groundwater source (code G)

Water that is abstracted from groundwater that is not consumed returns to surface water. Any water not returned by any sector is assumed 'lost' back to groundwater.

3.1.3 MAIN SECTORS IN WATER DEMAND

Each of these sectors has its own data set:

- Municipal water (code M)
- Industrial water (code I)
- Hydropower water (code H)
- Irrigation water (code A)



3.1.4 *MAIN PATHWAYS*

RIBAMAN-5 uses a simple logic set to account for all water transfer. The terminology is as follows:

- Precipitation is the driving force of all water balance. Then follows various natural processes (infiltration, transpiration, evaporation) to create RECHARGE to the surface, snowpack, soil, groundwater and artificial reservoir units. RUNOFF is the volume that leaves the catchment to pass to the next catchment downstream.
- All artificial water use follows this basic logic:

  Water is ABSTRACTED and used as SYSTEM INPUT to the sector

  Water is then USED by the sector. Some water may be CONSUMED. This water is permanently lost from the river basin.

  Most water is RETURNED to the surface system. Water that has not been consumed or returned is 'LOST' to groundwater.
- The sectoral water balance is as follows:

  RETURN VOLUME = ABSTRACTION – CONSUMPTION – LOSS

3.1.5 *NAMING PROTOCOL FOR VARIABLES*

Most parameters in RIBAMAN-5 basically use a three letter acronym comprising:

SOURCE – SECTOR – PATHWAY

For example, the parameter SMU describes that this is SURFACE water supplying a MUNICIPAL system, and that the value describes the UNIT use of that water.

For example, the parameter GAI describes that this is GROUNDWATER source, supplying an AGRICULTURAL system, and that the value describes the INPUT volume.

For example, the parameter RIR describes that this is RESERVOIR source water supplying INDUSTRY, and that the value describes the RETURN volume (back to the surface system by default).

3.1.6 *WATER TAKEN FROM RESERVOIRS*

Water taken from reservoirs is a special case. There can only be a single reservoir in each catchment. Water taken from a reservoir by any sector is by default transferred to the connected catchment downstream of the reservoir.

After USE, all reservoir supplied water (municipal, irrigation, industrial or hydropower) is returned in the DOWNSTREAM catchment (minus CONSUMPTION and LOSS).

For ecological flow calculations immediately downstream of the Dam, hydropower releases are included, but municipal, irrigation and industrial releases are not.

3.1.7 BASELINE DATABASES

Each sector has its own 'smart' database, repeated in identical format for three sources of water. Data are easy to enter and to check. RIBAMAN-5 provides a lot of pre-processed information, especially with respect to unit rates, water use efficiency etc.

This allows you to make comparisons between different catchments within the same river basin regarding water use, unit rates, efficiencies, losses etc.

All data are always divided seasonally for every sector in every catchment.

Figure 3-1 – Example of Municipal Water Database (Surface Source S)

MUNICIPAL WATER ABSTRACTIONS (S) [Population Equivalent] [Mm^3/3 months] B9		October-November-December								January-February-March							
	ID	N	SMU	SMI	SMC	SMR	SML	SME	MBOD	N	SMU	SMI	SMC	SMR	SML	SME	MBOD
	A0	1,798	0.460	0.076	13%	35%	0.040	48%	149	1,794	0.470	0.076	13%	35%	0.040	48%	146
	A1	751	0.421	0.029	15%	23%	0.018	37%	167	751	0.431	0.029	15%	23%	0.018	37%	164
	A2	22,692	0.392	0.817	14%	30%	0.459	44%	178	22,692	0.400	0.817	14%	30%	0.459	44%	174
	A3	891	0.395	0.032	15%	19%	0.021	34%	179	891	0.403	0.032	15%	19%	0.021	34%	175
	A4	148,830	0.411	5.629	14%	17%	3.907	31%	169	148,830	0.420	5.623	14%	17%	3.901	31%	166
	T-AV	174,962	0.409	6.584	0.914	1.225	4.445	33%	170	174,958	0.418	6.578	0.914	1.225	4.439	33%	167

Values in yellow are data entered or changeable by the user. Values in green are automatically calculated by the model. In the example above, the terminology is as follows:

ID - the catchment identifier

N - the total population in the catchment supplied from SURFACE water sources

SMU - the equivalent unit rate of water supplied per capita (m^3/capita/day)

SMI - the total volumetric SYSTEM INPUT of water to municipal systems from surface sources only (MCM/season)

SMC - the amount of water supplied that is CONSUMED (%)

SMR - the amount of water that is RETURNED to the surface system (%)

SML - the volume of water not consumed or returned, therefore LOST (to groundwater) (MCM).

SME - an indicator of the EFFICIENCY of the water abstraction. Water that is either consumed and/or returned is considered an efficient use of water (%)

MBOD - this is the BOD concentration of the effluent based on a standard BOD load of 60 g/capita/day

Reservoir and groundwater sourced municipal supply follows the identical database format.

MUNICIPAL WATER ABSTRACTIONS (R) [Population Equivalent] [Mm^3/3 months] B10			October-November-December								January-February-March							
		ID	N	RMU	RMI	RMC	RMR	RML	RME	MBOD	N	RMU	RMI	RMC	RMR	RML	RME	MBOD
		R0																
	A0	R1																
		R2																
	A4	R3	33,530	0.483	1.490	12%	31%	0.846	43%	141	33,530	0.494	1.490	12%	31%	0.846	43%	138
		R4																
		T-AV	33,530	0.483	1.490	0.176	0.468	0.846	43%	141	33,530	0.494	1.490	0.176	0.468	0.846	43%	138

In the case of reservoirs, the default link is also shown. In this case it is Reservoir R3 that supplies municipal water to catchment A4.

			October-November-December								January-February-March							
MUNICIPAL WATER	B11	ID	N	GMU	GMI	GMC	GMR	GML	GME	MBOD	N	GMU	GMI	GMC	GMR	GML	GME	MBOD
ABSTRACTIONS (G)	A0	G0	4,008	0.466	0.172	12%	34%	0.092	47%	147	4,013	0.476	0.172	12%	34%	0.092	47%	144
[Population Equivalent]	A1	G1	16	0.393	0.001	16%		0.000	16%	182	16	0.400	0.001	16%		0.000	16%	179
[Mm^3/3 months]	A2	G2	11,154	0.389	0.400	14%	20%	0.262	34%	179	11,154	0.398	0.400	14%	20%	0.262	34%	176
	A3	G3	170	0.391	0.006	15%		0.005	15%	181	170	0.400	0.006	15%		0.005	15%	177
	A4	G4	28,622	0.376	0.990	15%	14%	0.697	30%	188	28,622	0.384	0.990	15%	14%	0.697	30%	184
		T-AV	43,969	0.388	1.568	0.229	0.283	1.056	32%	182	43,974	0.396	1.568	0.229	0.283	1.056	32%	178

Figure 3-2 – Examples of Hydropower Water Databases (Surface (S) and Reservoir (R)

			October-November-December							January-February-March						
HYDROPOWER	B12	ID	N	SHU	SHI	SHC	SHR	SHL	SHE	N	SHU	SHI	SHC	SHR	SHL	SHE
ABSTRACTIONS (S)		A0														
[MegaWatt Hours]		A1														
[Mm^3/3 months]		A2	76	9114	0.692		100%		100%	194	9114	1.773		100%		100%
		A3	2,837	1325	3.759		100%		100%	3,122	1325	4.136		100%		100%
		A4														
		T-AV	2,913	1528	4.451		4.451		100%	3,317	1782	5.909		5.909		100%

Surface water sources for hydropower are described as 'run of river' schemes. All hydropower output in the catchment and the water use are totalled to a single value.

In this case N represents the total MWh of energy produced in the season. Otherwise terminology is identical to that for municipal water.

			October-November-December								January-February-March							
HYDROPOWER	B13	ID	N	RHU	RHI	RHC	RHR	RHL	RHE	TBN	N	RHU	RHI	RHC	RHR	RHL	RHE	TBN
ABSTRACTIONS (R)		R0																
[MegaWatt Hours]	A0	R1	33,918	4588	155.603		100%		100%	4	50,788	4588	232.996		100%		100%	4
[Mm^3/3 months]		R2																
	A4	R3	1,386	10414	14.434		100%		100%	3	1,356	10414	14.123		100%		100%	3
		R4																
		T-AV	35,304	4816	170.037		170.037		100%		52,144	4739	247.119		247.119		100%	

In the case of hydropower generated at Dams, there is one additional parameter for control, which is the number of turbines that can be put into operation (TBN). The default setup is first created in the RESERVOIRS module, modified as necessary in the BASELINE module.

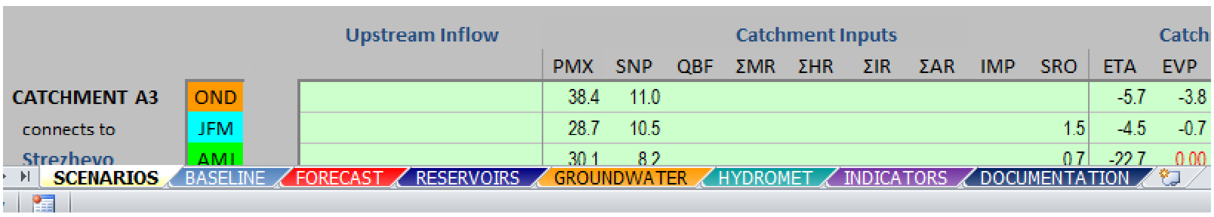
3.2 RIBAMAN-5 FUNCTIONALITY – SCENARIOS, MODULES, MODES

3.2.1 MODULES

RIBAMAN-5 currently has 8 modules.

- The SCENARIOS module is where scenarios are created, and all detailed output for CATCHMENTS is presented, including environmental indicators.
- BASELINE contains all the baseline catchment characteristics, hydrometeorological data and the quantities for municipal water, population, industry, hydropower and irrigation.
- FORECAST contains all the planned quantities for each sector by type, source of water and RBMP period
- RESERVOIRS contains all relevant technical data for reservoir characteristics AND the scenario outputs for each reservoir model
- GROUNDWATER contains all relevant technical data for groundwater characteristics AND the scenario outputs for each groundwater model
- HYDROMET contains factual data on all relevant meteorological and flow gauging Stations that may be relevant to the river basin
- INDICATORS is a user-template that can be used to fill in indicator summary for any specific scenario
- DOCUMENTATION is a text summary for every data Table in the model, detailing important assumptions, sources of data, known errors etc. for future reference.

Figure 3-3 – Example of the Modules in RIBAMAN-5



3.2.2 SCENARIOS

RIBAMAN-5 is based on SCENARIOS. A scenario generally comprises any combination of:

- Water Framework Directive (WFD) compliant River Basin Management Plan (RBMP) period, from 2010-2015 (Baseline) to 2040-2045
- A climate change option (influences temperature, ET_0 and precipitation)
- A precipitation option, ranging from P95 (95% exceedance) to P5 (5% exceedance)
- A population growth option (based on forecasts, influencing water demand and BOD)
- A hydropower growth option (based on forecasts, influencing water demand)
- An industrial growth option ((based on forecasts, influencing water demand)
- An irrigation expansion option (based on forecasts, influencing water demand)

Each of these options can take three alternative states (typically high, medium and low) in terms of forecast quantities. With a single precipitation event, there are at least 2187 possible scenarios!

The scenario setup applies equally to all catchments in the river basin i.e. climate change, precipitation percentile, population forecast etc.

If the scenario is the BASELINE, specific data is taken from the BASELINE database. For any other scenario (2016-2045), data are generally taken from the FORECAST database

Once data are entered into the database, RIBAMAN-5 has extremely useful functionality in terms of assessing the water use and environmental impacts of any single scenario with a minimum of input from the user.

Figure 3-4 – Main Scenario Setup Options

PLANNING SCENARIOS	RBMP CYCLE	CLIMATE CHANGE	PRECIPITATION	POPULATION	HYDROPOWER		INDUSTRY	IRRIGATION
S1 Baseline +	2010-2015	RCP2.6 Low	PMX	Medium Growth	Baseline +		Baseline +	Baseline +
Planned		Temperature	Annual Precipitation	Pop Equivalent (PE)	MegaWatt Hours		Pop Equivalent (PE)	Hectares
	CATCHMENT A0	9.5	647	5,951			24,408	4,739
	CATCHMENT A1	9.5	706	767	144,221		66,691	
	CATCHMENT A2	9.5	734	33,845	549			
	CATCHMENT A3	9.5	789	1,060	18,214			366
	CATCHMENT A4	9.5	706	210,982			494,919	9,598
SAVE SCENARIO	Σ SUB-BASIN	9.5	711	252,606	162,984	0%	586,019	14,703

3.2.3 MODES

RIBAMAN-5 can be operated in various ‘modes’, depending on need or application.

- DATABASE MODE – because RIBAMAN-5 is structured in ‘database format’, it is very easy to look up specific values. Data are transparent and easily checked. One of the most useful function sis to use the scenario checker for forecast data.
- BASELINE MODE – this is used to make water use, water allocation or environmental impact assessments with baseline data in the baseline period.

  The main purpose is to identify how water is being used in the catchment(s), and where improved efficiencies can be made as part of an effective River Basin Management Plan.

  Fundamentally, in BASELINE mode it is necessary to have all sectors operating with water demands ‘as now’ in order to establish whether or not all water uses are in ‘equilibrium’.
- FORECAST MODE – this is used to test future possible combinations of climate change and/or sectoral water demands to assess future levels of sustainability in terms of quantity, quality and flow regime.
- OPERATIONAL MODE – this can be used with ‘live’ or recent hydrometeorological data and sectoral outputs to test impacts on operations from e.g. flood or drought conditions, changes in upstream activity etc. in order to manage operational effectiveness.

4 BASIC OPERATIONS WITH RIBAMAN-5

4.1 UNDERSTANDING AND WORKING WITH BASELINE DATA

We will use the Crna Reka Model for all practical exercises.

4.1.1 VARIOUS FAMILIARISATION EXERCISES WITH MUNICIPAL DATA

Navigate to BASELINE Table B9. Answer various questions:

- Which catchments are the smallest and largest consumers of water?
- Which catchment is most efficient in terms of per capita supply?
- Which catchment is most efficient in terms of overall water use?

4.1.2 VARIOUS FAMILIARISATION EXERCISES WITH IRRIGATION DATA

Navigate to BASELINE Table B17, B18, B19. Answer various questions:

- Which catchments are abstracting surface irrigation water?
- What is the total surface quantity abstracted in AMJ and JAS
- How much water is supplied per hectare in JAS in Catchment A4?
- How much of this water is actually used by the crops?
- Which catchments have water supplied from reservoirs? What are the reservoirs?
- Which catchments have water supplied from groundwater?

4.2 UNDERSTANDING AND WORKING WITH FORECAST DATA

4.2.1 *VARIOUS FAMILIARISATION EXERCISES WITH IRRIGATION DATA*

Navigate to Table FORECAST F14 - F19. Answer various questions:

- Even without any data changes, the crop water consumption (SAC, RAC, GAC) increases every RBMP. Why?
- Change an irrigation area in any RBMP. What happens? Why?
- Change the 'water supplied' value (SAU, RAU, GAU). What happens? Why?
- Change the crop coefficient *kc*. What happens? Why?
- What unit rate of application (m³/ha) could we specify for irrigation supplied by Reservoir R1 (Tikvesh) in order to achieve a consumption efficiency of >85% in 2040-45?

Figure 4-1 – Example of Irrigation Forecast Database

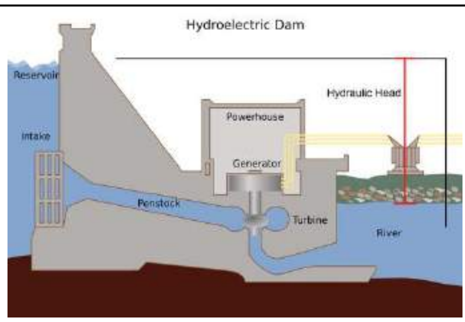
	2010-2015	BASELINE				2016-2021				
IRRIGATION R (Hectares)	R0	R1	R2	R3	R4	R0	R1	R2	R3	R4
Baseline +	0	4,000	0	8,000	0	0	4,000	0	8,000	0
Planned	0	4,000	0	8,000	0	0	4,000	0	8,000	0
F16	0	4,000	0	8,000	0	0	4,000	0	8,000	0
RAU-Water Supplied	0	3560	0	2912	0	0	3560	0	2912	0
RAC-Water Consumed	0%	67%	0%	78%	0%	0%	67%	0%	78%	0%
RAR-Water Returned	0%	8%	0%	5%	0%	0%	8%	0%	5%	0%
•	0	A0	0	A4	0	4000	0	0	0	8000

	2022-2027					2028-2033				
IRRIGATION R (Hectares)	R0	R1	R2	R3	R4	R0	R1	R2	R3	R4
Baseline +	0	4,000	0	8,000	0	0	4,000	0	8,000	0
Planned	0	4,000	0	8,000	0	0	4,000	0	8,000	0
F16	0	4,000	0	8,000	0	0	4,000	0	8,000	0
RAU-Water Supplied	0	3560	0	2912	0	0	3560	0	2912	0
RAC-Water Consumed	0%	68%	0%	79%	0%	0%	68%	0%	79%	0%
RAR-Water Returned	0%	8%	0%	5%	0%	0%	8%	0%	5%	0%
•	4000	0	0	0	8000	4000	0	0	0	8000

4.2.2 *VARIOUS FAMILIARISATION EXERCISES WITH HYDROPOWER DATA*

Navigate to Table FORECAST F9 - F10. Answer various questions:

- In Table F10, change MWh production data for Reservoir R1 (Tikvesh) for any RBMP period. Navigate back to SCENARIOS, and confirm this value in the scenario setup.
- You should see a negative % value against Reservoir R3 (Strezhevo). Why? Correct the FORECAST data accordingly.
- Which are the unit rates of m³/MWh for each HPP at the two Dams? Which is the more efficient?

4.3 Understanding and Working with CLIMATE CHANGE data

4.3.1 Various Familiarisation Exercises with CLIMATE CHANGE Data

Navigate to Table FORECAST F1 – F3.

- For the high emissions scenario, calculate what will be the net reduction in ANNUAL water resource availability (precipitation - evapotranspiration) both as an absolute value AND as a % of baseline value

Navigate to Table SCENARIOS S1.

- Under the high emissions scenario, use the SCENARIO selector tool to show what will be the ANNUAL inflow volume reduction to Tikvesh Reservoir between 2015 and 2045.
- You can obtain this inflow volume from two locations:
  a) from SCENARIOS Catchment A1, parameter CVO (Catchment Volume Out)
  b) from RESERVOIRS Reservoir R1, parameter A1 or RIV Why is there a difference?

- Use the E-Score indicator to assess the overall impact of climate change on the river basin. Why ARE the values changing?

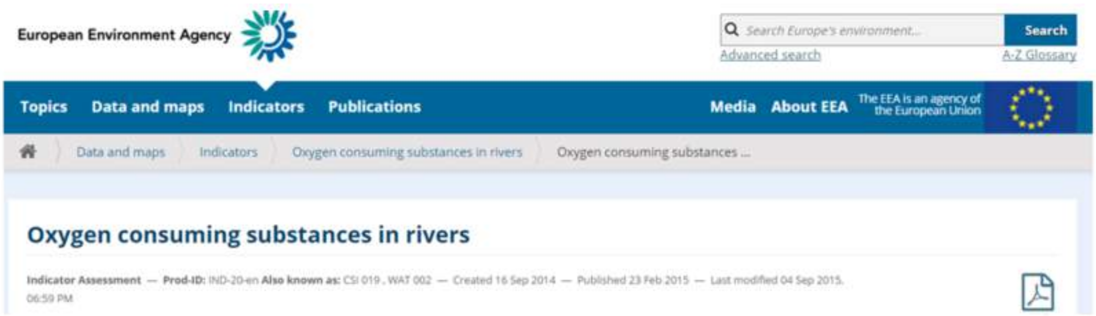
5 UNDERSTANDING AND CALCULATING INDICATORS

5.1 PRACTICAL EXERCISE – CALCULATING A BOD INDICATOR

The level of oxygen in the waterbody is one of the most critical parameters for aquatic ecosystem health, and therefore BOD_5 is considered one of the most useful general measures of pollutant impact on water quality.

At the exact point of discharge, before complex deoxygenation and reaeration processes initiate, the resultant BOD_5 level in the waterbody is a simple mass-balance calculation based on the pollutant load of the wastewater + initial load in the river (g or kg) divided by the total volume carrying the load (m^3) (load / volume = concentration mg/l), Figure 5-1.

Figure 5-1 – Definition of the BOD Indicator



$$\frac{(\text{River volume} \times \text{River BOD}) + (\text{Effluent volume} \times \text{Effluent BOD})}{\text{Total Volume}} = \text{BOD mg/l}$$

KEY ASSUMPTION IN RIBAMAN-5: the entire urban population of the catchment discharges at a single downstream point (the catchment outlet).

- To simplify the calculation we will assume that the river BEFORE the effluent discharge has 0.00 BOD.
- We will also ignore the BOD from industry
- Therefore we need only the TOTAL POPULATION in the catchment, the BOD load per capita, and the TOTAL VOLUME of the catchment OUTFLOW
- We will use the real example of Crna Reka Catchment A4, in the SUMMER period.
- Assume standard BOD load of 60g/capita/day
- Assemble your data from the model!

Load (g) / Volume (m³) = Concentration (g/m³ = mg/l)	
Total Population of A4 –	210,982
BOD load per capita per day – 60g	
Total BOD load in outflow in 92 days (g)	1164.6×10^6 g
Volume of outflow in 92 days (m³) (CVO)	24.96×10^6 m³
Total load / Total volume = Concentration mg/l	46.2 g/m³

5.2 PRACTICAL EXERCISE – CALCULATING THE WEI AND EFI INDICATORS

Abstractions for different uses exert the most significant pressure on the quantity of freshwater resources. Abstraction rates must be sustainable in order to ensure the protection and management of water resources and related ecosystems[4].

The WEI$^+$ indicator is now an EU and international standard. It identifies whether rates of abstractions are sustainable over the long term. The higher the WEI$^+$ index, the greater the pressure on water resources, the greater the vulnerability of the river basin to drought events, and the more likely that downstream water quality is reduced.

Figure 5-2 – Definition of WEI$^+$ Indicator

[4] Water Scarcity & Droughts in the EU – Portal http://ec.europa.eu/environment/water/quantity/about.htm

The most significant single feature of the index is that it is a measure of **water consumption**, and understanding of this definition is essential. Water that is **abstracted** in any operation but which is also fully **returned** to the same source is not consumption of water; it is merely **water use** by the activity in question.

An example is Dam hydropower, where typically > 98% of the abstraction is used by turbines and then returned downstream. In such cases the consumption (or exploitation) is near-zero. Consumption therefore = Exploitation.

Conversely, water that is abstracted, used and NOT returned to the source is described as consumption of water i.e. permanent loss of water from that specific resource. Examples are water consumption by industrial processes and evapotranspiration by irrigated crops.

We will now use the Crna Reka model to calculate the WEI^+ indicator for Catchment A4, SUMMER period (JAS).

Figure 5-3 – Extracted Data for WEI Calculation from Crna Reka Catchment A4

		Catchment Losses					Surface Abstractions and Returns								Storage Volumes			Runoff	
IMP	SRO	ETA	EVP	SRC	GRC	EXP	SMI	SMR	SHI	SHR	SII	SIR	SAI	SAR	SS	RS	GS	CVO	CQO
2.2		-109.0	-195.0	-199.8		-12.7	-5.6	0.9			-6.8	6.8			177.9			76.72	9.65
2.2		-102.2	-96.3	-199.4		-22.9	-5.6	0.9			-6.6	6.6			279.0			164.72	21.18
2.2	2.1	-488.2	-187.2	-264.1		-11.3	-5.6	0.9			-6.7	6.7	-1.2	0.1	62.9			136.06	17.30
2.3	1.5	-165.5	-214.4	-134.6		-1.4	-5.7	0.9			-6.8	6.8	-1.6		41.3			24.98	3.14
9.0	3.6	-864.9	-693.0	-797.8		-48.23	-22.53	3.77			-26.81	26.81	-2.80	0.13				402.5	12.82

Abstractions + Exports	(SMI) -5.7, (SII) -6.8, (SAI) -1.6, (EXP) -1.4	-15.4
Returns + Imports	(SMR) 0.9, (SIR) 6.8, (SAR) 0.20, (IMP) 2.3	10.0
Modified Outflow Variable SIM	24.96 MCM (3.14 m^3/s)	24.96
NATURAL Outflow Variable ΣNRO	WEI must use the original, natural outflow of the catchment, NOT the modified outflow. Stored in Table BASELINE C14	12.320
WEI^+ Formula	(15.4 – 10.0) / 12.32 = 0.32	42%
EFI Formula	Modified Flow / Natural Flow = 24.96 / 12.32	2.03

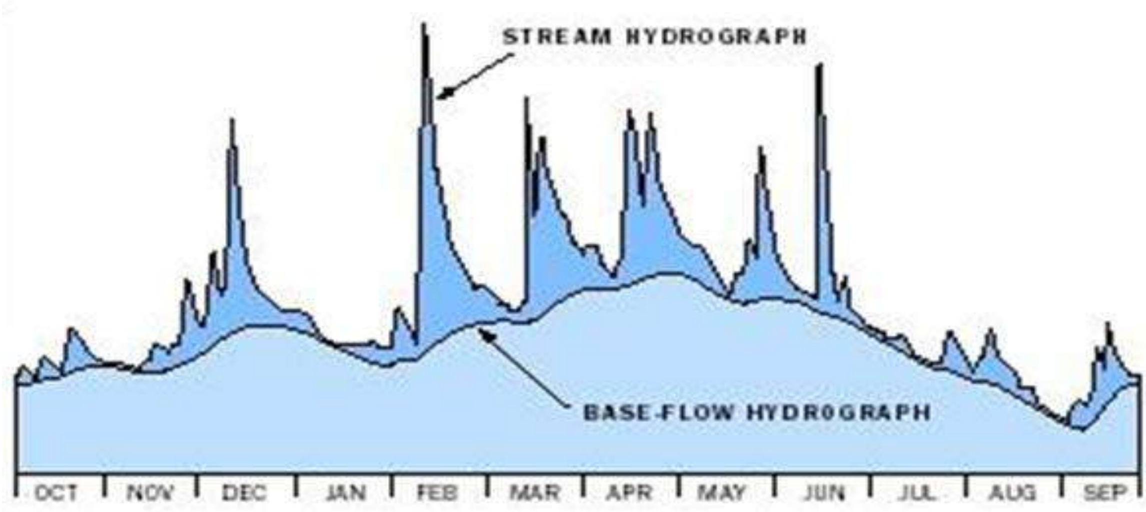
According to international definitions:

- WEI > 20% – represents a 'stressed' catchment
- WEI > 40% - represents unsustainable levels of abstraction. Why?

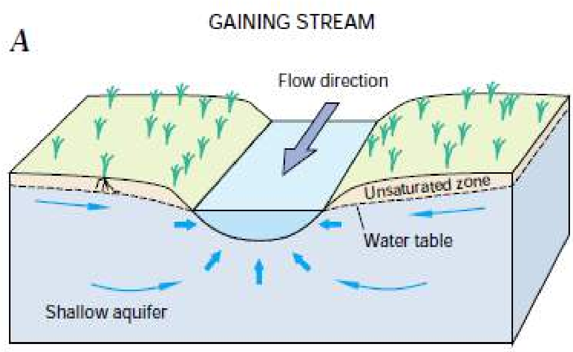
6 ROLE AND IMPORTANCE OF GROUNDWATER

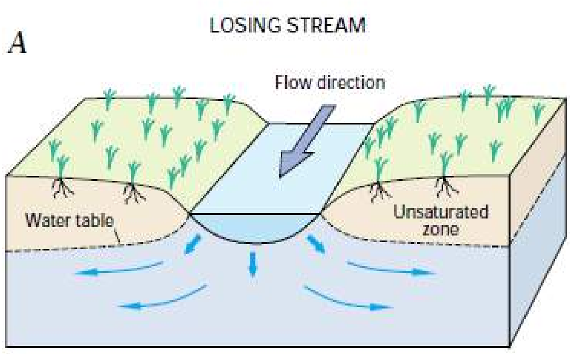
6.1 IMPORTANCE OF GROUNDWATER

- As we have seen, groundwater is a fundamental part of overall catchment 'runoff', sometimes as much as 50%+.
- Groundwater, because of its long-term stability and properties different from surface water, has a significant influence on aquatic ecology.
- Groundwater also provides a reliable, stable source of water for <u>downstream</u> catchments, which increases drought resilience.



- If we do not safeguard the groundwater resource also, there is a significant risk of decreasing streamflow. In extreme cases of groundwater depletion, the river may even lose water to the lower water table.





6.2 VIDEO – UNITED KINGDOM GEOLOGICAL SURVEY

"How Rivers Work"

https://www.youtube.com/watch?v=ci-ABWPG7LQ&index=1&list=FL55C-ZxFvGBB60Wc5rnEWyg

7 INTRODUCTION TO RESERVOIR MODELLING IN RIBAMAN-5

7.1 Reservoir Characteristics and Data Entry

7.1.1 Data Entry

- Dams and Reservoirs have a major impact on river basin water resources, through storage and changes in flow regime.
- Therefore in RIBAMAN-5 they are explicitly modelled with a lot of sophistication.

RESERVOIR DATA R1

			Characteristics							HydroPower			Long-term Inflow			
RCD	CCD	NAME	PFUP	PFDN	RSA	RMX	RFS	RMS	RST	RHP	RHT	RHQ	QM1	QM2	QM3	QM4
R0																
R1	A0	Tikvesh			12.725	439.00	439.00	150.00	84%	113.00	4	144.00	*17.32*	*41.07*	*32.77*	*5.91*
R2																
R3	A4	Strezhevo			4.320	112.00	112.00	3.13	65%	2.80	3	8.10	*1.44*	*2.73*	*3.75*	*0.38*
R4																
TAV																

Evaporation and Seepage					Imports				Exports				Ecological Release				Operational Release				
RKC1	RKC2	RKC3	RKC4	RSP	RIM1	RIM2	RIM3	RIM4	REX1	REX2	REX3	REX4	EF1	EF2	EF3	EF4	OF1	OF2	OF3	OF4	RBOD
1.25	1.25	0.65	0.65						-0.849		-2.023	-15.5									1.0
1.00	1.00	1.00	1.00		12.709	22.860	11.295	1.371													1.0

7.2 SETTING UP HYDROPOWER PROFILES

Navigate to BASELINE Table B13

- We will use the example of the HPP Tikvesh in Crna Reka River basin, which is Reservoir R1 situated in Catchment A1.
- From ELEM data:

Table 7-1 – Baseline Data Inflow and Energy Production 1981 - 2015

Installed Power	113 MW					
Installed Flow	144 m³/s (4 x 36)	OND	JFM	AMJ	JAS	ANN
Long-term 'equilibrium status'						
Measured Inflow (m³/s A1)	1981-2016 (Mean)	17.32	41.07	32.77	5.91	24.42
Energy Production MWh	1981-2016	32,514	52,272	39,455	15,194	139,435
Recent 'operational status' – RBMP 2009-2015						
Measured Inflow (m³/s A1)	2009-2015	23.87	54.54	37.78	4.59	30.19
Energy Production MWh	2009-2015	46,466	75,814	55,598	17,667	195,546

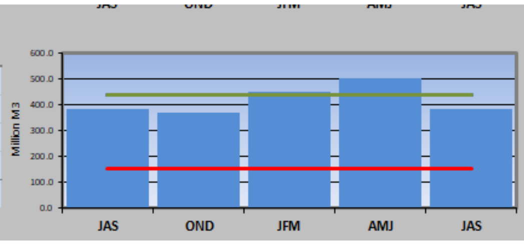
7.3 UNDERSTANDING THE OUTPUT PARAMETERS

Figure 7-1 – Example of Tikvesh Performance 1981 - 2015

	Inputs			Losses + Releases				Demands					Inflow Outflow				Storage			Spillway		
	PMX	A1	RIM	EVP	RSP	EFQ	OFQ	RMI	RHI	RII	RAI	REX	RIV	RQI	ROV	RQO	RVL	REL	ΔRS	RSV	RSQ	QMX
OND	2.889	137.64		-1.48					-149.2			-0.85	140.53	17.68	151.49	18.77	370.97		-10.96			17.50
JFM	2.163	319.35		-1.37					-239.8				321.51	41.35	253.48	32.42	439.00		68.03	12.31	1.58	41.17
AMJ	2.265	257.62		-2.39					-181.0		-12.65	-2.02	259.89	33.05	259.89	30.88	439.00			61.82	7.86	32.76
JAS	1.667	46.95		-2.95				-0.01	-69.7		-15.84	-15.51	48.61	6.12	104.01	8.77	383.60		-55.40			5.75
TAV	8.98	761.56		-8.19				-0.01	-639.7		-28.48	-18.39	770.54	24.55	768.87	22.71	408.14		1.67	74.14	2.35	24.29

Figure 7-2 – Example of Tikvesh Storage and Indicators

Storage			Spillway		
RVL	REL	ΔRS	RSV	RSQ	QMX
370.97		-10.96			17.50
439.00		68.03	12.31	1.58	41.17
439.00			61.82	7.86	32.76
383.60		-55.40			5.75
408.14		1.67	74.14	2.35	24.29



INDICATORS						Reservoir R1
MXI	REI	WEI+	EFI	HEP	HER	RBOD
85%	0.52	106%	0.98	32,514	13%	0.7
100%	0.83	74%	0.71	52,272	21%	0.4
100%	0.68	75%	0.96	39,455	16%	0.3
87%	0.35	214%	1.27	15,194	6%	0.2
93%	2.38	89%	0.98	139.44	14%	0.4

- What are your observations about the INDICATORS?
- How would you verify the WEI value? The formula is identical to that for catchments. Try a calculation.

7.4 Concepts of equilibrium storage, inflow, outflow

NAVIGATE to RESERVOIRS Table RESERVOIR R1

- It is of critical importance that reservoirs are correctly managed with respect to long-term equilibrium
- You cannot utilise (in the long-term) more than the long-term annual inflow.
- The long-term inflow is probably reducing due to climate change.
- Check how you know that the reservoir is in equilibrium!
- Understand the importance of the annual start volume/level (RST)!

7.4.1 Practical Exercise – Evaluating Changes in Equilibrium – Case Study of Tikvesh Reservoir

- Use the data from Table 7-1 and adjust the energy production values to the last RBMP period 2009-2015.
- What happens to the reservoir equilibrium?
- What adjustments would we need to make to the model?
- What does this exercise tell us about the EFI indicator?
-
-

7.5 Practical Exercise – Adding a new Reservoir – Case study of Cebren Reservoir

7.5.1 *Project Background*

HPP Cebren is at the narrowest part of the river bed of Crna Reka nearby the village Manastirec with appropriate topographic, geological and geotechnical characteristics that allows for construction of a high dam – 192,50 m and forming a storage volume of 915 Mm³ . Part of this volume up to level of 515,00 maSL as minimal level will represent utilization volume of 555 million M³ water or 60 % of the entire storage, which provides possibility for multi-year regulation of the natural flows of Crna Reka.

HPP Cebren is located nearby the dam - on the river bank with a switchyard close to the power house. Three reversible units are installed in the power house with 110.85 MW rated power per unit in turbine regime and 115.78 MW rated power per unit in pumping regime

According to the analyses performed in the Feasibility Study, HPP Cebren will annually generate 840,300 MWh.

Table 7-2 – Basic Operational Data for Reservoir Cebren

1. HYDROLOGICAL FEATURES	
HYDROLOGICAL PERIOD	1946 ÷ 2005 year
TOTAL ANNUAL FLOW - NATURAL	803,00 x 10^6 m^3
AVERAGE ANNUAL FLOW	25,46 m^3/s
2. HYDROTECHNICAL FEATURES	
2.1 WATER STORAGE *(Dam Lake)*	
TOTAL VOLUME	915.00 x 10^6 m^3
USEFUL VOLUME	555.00 x 10^6 m^3
NORMAL LEVEL	565.00 maSL
MAX. LEVEL	565.00 maSL
MIN. LEVEL	515.00 maSL

3. BASIC ENERGY PARAMETERS	
NUMBER OF UNITS	3
INSTALLED CAPACITY	
TURBINE MODE	3 x 110.95 MW
PUMP MODE	3 x 115,78 MW
TYPE OF UNITS	REVERSIBLE
ANNUAL GENERATION	840,30 GWh
ANNUAL CONSUMPTION	785,60 GWh
VOLTAGE LEVEL	110 kV
4. ELECTROMECHANICAL PARAMETERS	
4.1 PUMP-TURBINE	
TYPE	FRANCIS-VERTICAL
RATED POWER-TURBINE MODE	110,95 MW
RATED POWER-PUMP MODE	115,78 MW
NUMBER OF REVOLUTIONS	333,33 r/min.
RATED FLOW - TURBINE MODE	77,00 m^3/s
RATED FLOW – PUMP MODE	69,33 m^3/s

7.5.2 ADD RESERVOIR CEBREN TO THE RIBAMAN-5 CRNA REKA MODEL

- The reservoir needs to be in the correct place! Fortunately Catchment A2 terminates at the Dam location!
- THE most important check of all is the decision on the inflow hydrology!

Table 7-3 – Historical Data for Inflow to Tikvesh Reservoir

Period		OND	JFM	AMJ	JAS	ANN
1969-2015		18.08	42.16	34.59	5.24	25.02
1981-2016		17.32	41.07	32.77	5.90	24.27
1966-1975		14.11	51.39	41.03	6.06	28.15
1976-1985		26.45	46.34	41.42	5.67	29.97
1986-1995		9.90	26.92	25.50	5.35	16.92
1996-2005		18.18	40.93	33.11	5.42	24.41
2006-2015		20.59	47.98	33.82	3.94	26.58
Option 1	1986-2015					22.64
Option 2						
Option 3						
Option 4						

8 HANDLING INTER BASIN WATER TRANSFERS IN RIBAMAN-5

8.1 CONCEPT OF IMPORTS AND EXPORTS IN WATER ACCOUNTING

SEASONAL IMPORT-EXPORT [Mm³/3 months]		October-November-December								January-February-March							
B8	ID	IM1A	IM1B	IM1C	IM1D	EX1A	EX1B	EX1C	EX1D	IM2A	IM2B	IM2C	IM2D	EX2A	EX2B	EX2C	EX2D
	A0				0.047				-0.011				0.047				-0.011
	A1				0.013								0.013				
	A2																
	A3					-0.003								-0.003			
	A4	0.003			2.245		-12.709			0.003			2.240		-22.860		
	T-AV	0.003			2.305	-0.003	-12.709		-0.011	0.003			2.299	-0.003	-22.860		-0.011

ge	Imports				Exports				E
RSP	RIM1	RIM2	RIM3	RIM4	REX1	REX2	REX3	REX4	EF1
					-0.849		-2.023	-15.5	
	12.709	22.860	11.295	1.371					

9 CRNA REKA GROUP RIVER BASIN PLANNING EXERCISE

9.1 OBJECTIVES, CRITERIA AND RULES FOR THE PLANNING EXERCISE

9.1.1 MAIN OBJECTIVES

- We will set up a Draft Programme of Measures for the RBMP period **2040-2045** based on climate change projections and planned irrigation expansion.
- The principal objective will be to reduce or equal the environmental indicators BELOW the initial 2040-2045 value, in accordance with WFD principles (waterbody status must be maintained).
- Secondary objective will be to maintain hydropower generation at existing levels.

9.1.2 CRITERIA

- Obviously climate change is 'built-in', so our measures must overcome any background impacts of climate change.
- We will consider the MoAFWE stated proposals from the Spatial Plan of Macedonia to irrigate to a total of 267,158 ha throughout Macedonia by 2020 (currently 27,540 ha.).

We will change the irrigation areas only in Catchment A0, Catchment A3 and Catchment A4.

Table 9-1 – Planned Irrigation Areas from Spatial Plan 2004

Sub-basin	Catchment	Existing IR infrastructure (ha)	New IR areas by 2020 (ha)	Total IR areas by 2020 (ha)	Adjusted IR area - total by 2045 (ha)
Crna	A0	12,253.65	9,255.00	21,508.65	21,508.65
Crna	A1	0.00	0.00	0.00	0.00
Crna	A2	106.35	0.00	106.35	106.35
Crna	A3	8.77	832.73	841.50	1,222.66
Crna	A4	24,725.23	36,444.27	61,169.50	89,011.84

Table 9-2 – Changes to Irrigation Areas 2015 - 2045

	SW 2015	RW 2015	GW 2015	Σ 2015	SW 2045	RW 2045	GW 2015	Σ 2045
A0/G0	237	-	502	739		-	10,000	
R1	-	4,000	-	4,000	-	8,000	-	
R3	-	8,000	-	8,000	-	-	-	
A3	366	-	0	366	841	-	0	
A4/G4	480	-	1,118	1,118		-	20,000	
TOT	1,083	12,000	1,620	14,703				

- **STOP!** Before doing any modelling, CHECK how much additional irrigation water would be used by 61,000 ha. in **July-August-September** based on existing application rates.
- Is this quantity feasible?? Use the model to establish the Water Available for Use.
  Use the FORECAST module (Table F14) to find the optimum irrigation rate and maximum possible irrigation area. This is a trial and error solution!!
- You will need to check the A4 RWU parameter in SCENARIOS and/or GRAPHICS

Proposed Irrigation Area (A4)	Unit irrigation rate (JAS) m^3/ha	Volume Required (MCM)	Volume Available (MCM)
61,000	2,915	92.03	10.40
5,400	2,915 (82% efficient)		

- All reservoirs must be in equilibrium condition!
  REMEMBER!! For a reservoir to be in equilibrium OUTFLOW (ROV) must = INFLOW (RIV).

9.2 PRACTICAL EXERCISE - BASELINE REVIEW – ESTABLISH MAIN PRESSURES, PRIORITY NEEDS ACCORDING TO INDICATORS

9.2.1 ORIGINAL BASELINE QUANTITIES AND INDICATORS FOR 2010-2015

	M-SW B9	M-RW B10	M-GW B11	A-SW B17	A-RW B18	A-GW B19	HPP B13	IMPT B8	EXPT B8	WEI	BOD	EFI
A0	0.075	-	0.172	0.938	-		-			1.6%	0.4	1.74
R1	-	0.009	-	-	15.83	-				213%	0.35	2.06
A1	0.032	-	0.001		-		-			0.7%	0.1	1.34
A2	0.817	-	0.400		-		-			2.1%	1.9	0.83
R3	-	1.490	-	-		-	14.27			967%	0.7	4.92
A3	0.032	-	0.006	1.176	-		-			28%	1.9	0.83
A4	5.657	-	0.990		-		-			42%	46.2	2.03
RB	-	-	-	-	-	-	-	-	-	7.0%	4.1	1.10

9.2.2 FORECAST BASELINE QUANTITIES AND INDICATORS FOR 2040-2045

For the INDICATORS, use the worst case SUMMER period (July-August-September)

	M-SW	M-RW	M-GW	A-SW	A-RW	A-GW	HPP	IMPT	EXPT	WEI	BOD	EFI
A0		-			-					1.7%	0.1	2.20
R1	-		-	-						442%	0.3	2.17
A1		-			-					0.7%	0.1	0.79
A2		-			-					2.3%	0.6	0.73
R3	-		-	-						1334%	0.7	5.39
A3		-			-					66%	2.0	0.56
A4		-			-					446%	38.5	0.45
RB	-	-	-	-	-	-	-	-	-	16%	2.4	0.97

10 CRNA REKA GROUP RIVER BASIN PLANNING EXERCISE

10.1 PRACTICAL EXERCISE - REVIEW AND TEST ALL PLANNING OPTIONS – MUNICIPAL, HYDROPOWER, IRRIGATION, IMPORTS, EXPORTS

10.2 Practical Exercise - Finalise preferred option, Enter relevant data

	OND	JFM	AMJ	JAS
A0				
R1				
A1				
A2				
R3				
A3				
A4				

10.3 PRACTICAL EXERCISE - RUN RIBAMAN-5 MODEL TO OUTPUT FINAL INDICATORS

10.3.1 QUANTITIES AND INDICATORS FROM BASELINE PLAN 2045

	M-SW	M-RW	M-GW	A-SW	A-RW	A-GW	HPP	IMPT	EXPT	WEI	BOD	EFI
A0		-			-							
R1	-		-	-								
A1		-			-							
A2		-			-							
R3	-		-	-								
A3		-			-							
A4		-			-							
RB	-	-	-	-	-	-	-	-	-			

10.3.2 QUANTITIES AND INDICATORS FROM REVISED 2045 PLAN

	M-SW	M-RW	M-GW	A-SW	A-RW	A-GW	HPP	IMPT	EXPT	WEI	BOD	EFI
A0		-			-							
R1	-		-	-								
A1		-			-							
A2		-			-							
R3	-		-	-								
A3		-			-							
A4		-			-							
RB	-	-	-	-	-	-	-	-	-			

11 CRNA REKA GROUP PRESENTATIONS OF FINAL PLAN

11.1 GROUP 1 SUMMARY OF ISSUES AND FINAL PLAN

11.2 GROUP 2 SUMMARY OF ISSUES AND FINAL PLAN

11.3 Group 3 Summary of Issues and Final Plan

11.4 Group 4 Summary of Issues and Final Plan

11.5 GROUP 5 SUMMARY OF ISSUES AND FINAL PLAN

11.6 GROUP 6 SUMMARY OF ISSUES AND FINAL PLAN

A1 National Indicator Maps

Figure 11-1 – Map of National WEI Pressures

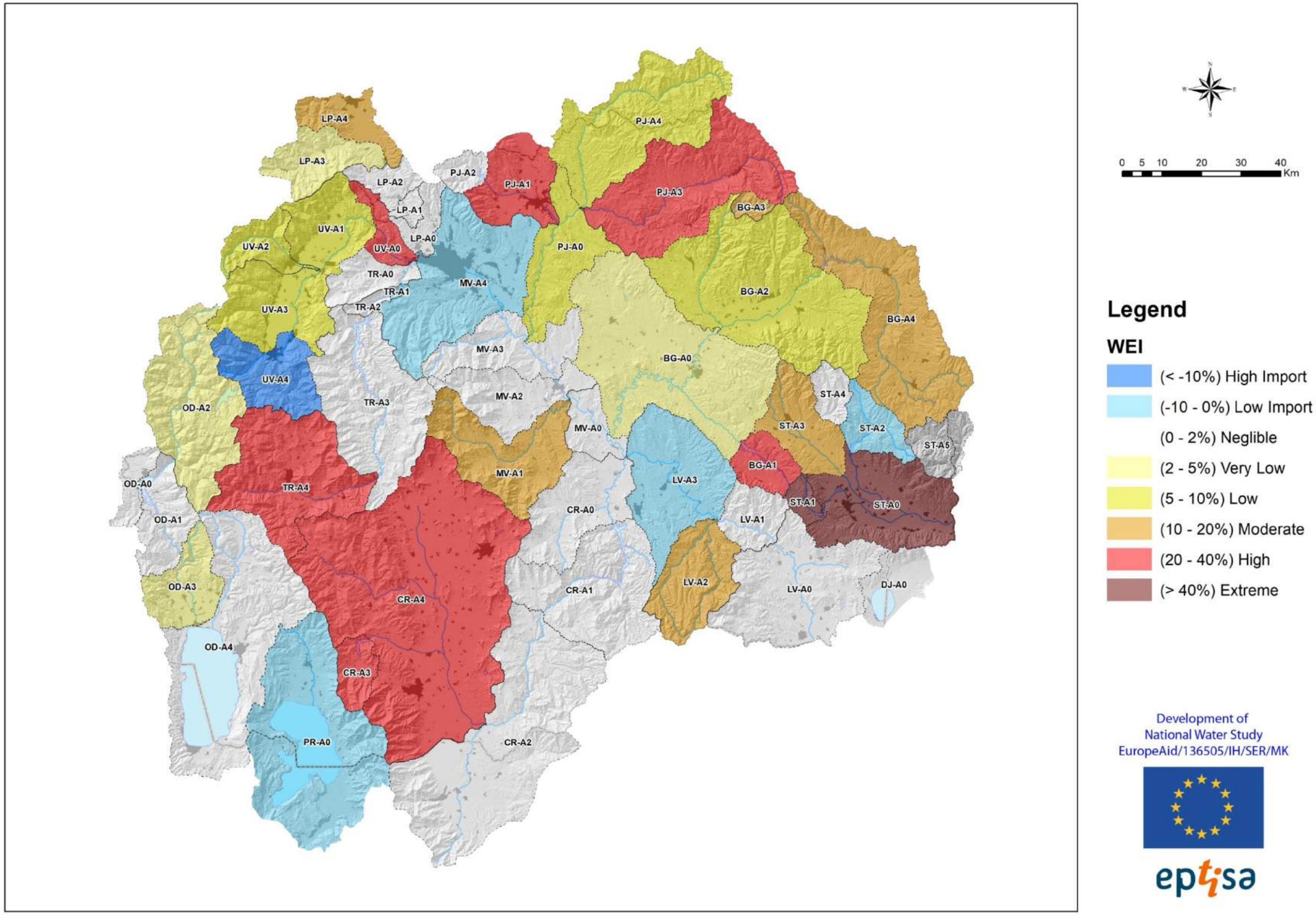


Figure 11-2 – Map of National BOD Pressures

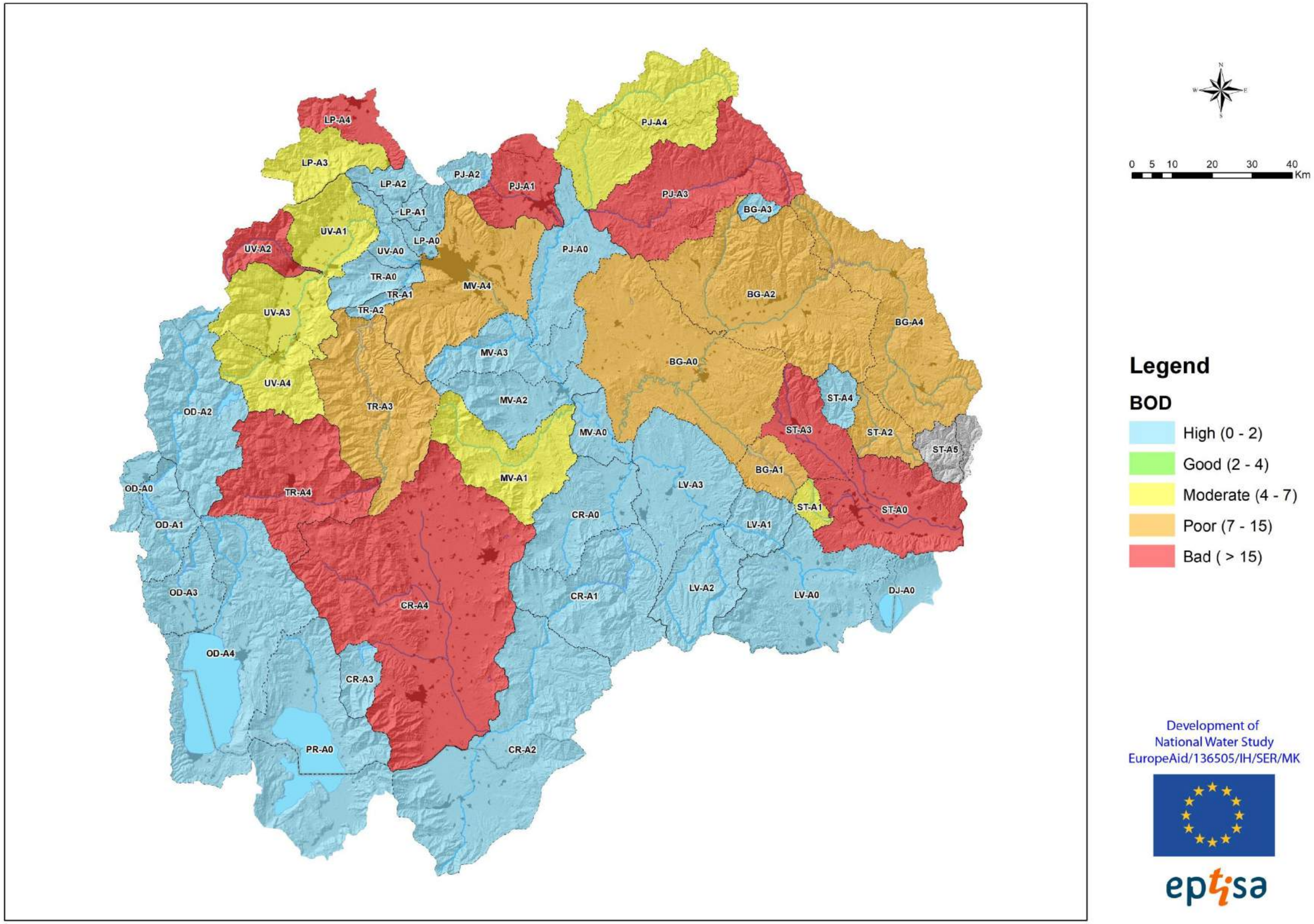


Figure 11-3 – Map of National EFI Pressures