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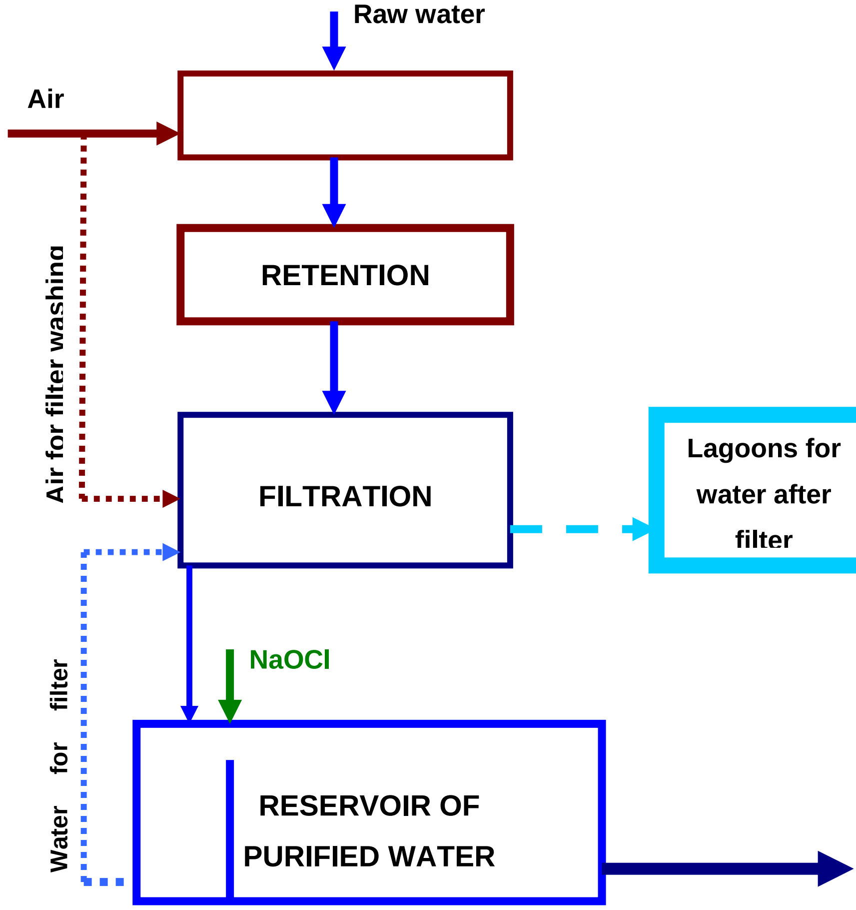

Date 8.11.2005

Project# 353

Draft Report: SUSTAINABLE SOLUTIONS TO IMPROVE THE QUALITY OF DRINKING WATER AFFECTED BY HIGH ARSENIC CONTENTS IN 3 VOJVODINIAN REGIONS

Book III - Water Treatment Plant

City of Vienna MA 31

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3 WATER TREATMENT

3.1 Water analysis results

The following tables show an overview on the analysis results. All available exact data with sampling information are given in the Book 1 Annex A Table 1.5 of data collection and in the Book 2.

3.1.1 West Bačka Region

Settlements	l/s	Turbidity	Ammonia	Iron	Manganese	Arsenic	Organic matter	Conductivity
Apatin	78,3	13,6	1,71	3,17	0,2		14,4	
Kupusina	8,7	34,9		4	0,15	0,011	24,7	1337
Prigrevica	17,5							
Svilojevo	5							
Sonta	18,8				0,14	0,013	10,9	1345
Sombor	208,1	8,22	1,38	1,29			12,4	
A.Šantić	9,3	2,03		0,92	0,07	0,1		
B.Breg	6	6,87	1,59	2,29	0,25		10,1	1283
B.Monoštor	16,8			0,14		0,02	28,3	1627
Bezdan	23,2		1,12				13,2	
Gakovo	9,4						11,5	
Doroslovo	7,9		2,1				63,7	2082
Kljaićevo	26,5	1,22	0,3	0,53				
Kolut	7,3			0,52			9,8	1830
Rastina	2,4						10,9	
Riđica	11,2			1,68			12	
Sv.Miletić	13,5			1,56	0,43	0,092		1100
Stanišćić	22			0,78				
Stapar	16						22,8	1338
Telečka	8,9			1,78				
Čonoplja	18,8	1,77	0,62	0,78		0.038		
Odžaci	39,4				0,11		11,6	1172
B.Brestovac	12,9		1,09				35,6	1322
B.Gračac	10,8						21,4	
Bogojevo	7,9						37,3	1629
Deronje	10,7		3,4				48,5	1943
Karavukovo	19,1	16,5		3,02	0,1		9,1	1427

Settlements	l/s	Turbidity	Ammonia	Iron	Manganese	Arsenic	Organic matter	Conductivity
Lalić	6,2						20,8	
Ratkovo	15,3		1,22	0,52		0,32	50	1997
Sepski Miletić	13,1		1,88				116	2691
Kula	76,2	3,12	0,73	0,92				
Crvenka	40,1	1,08	0,25	0,32				
Kruščić	8,5				0,13	0,03	11	
Lipar	6,5			0,83				
N.Crvenka	1,9			1,61	0,1			
Ruski Krstur	19,3		0,37			0,13	23	
Sivac	33,4	1,09		0,45				

Table 3-1: Results of Chemical Analysis of Raw Water in West Backa region (mg/l)

3.1.2 South East Region

Settlements	l/s	Turbidity	Ammonia	Iron	Manganese	Arsenic	Organic matter	Conductivity
Bač (g)	24,4		6,1				15,4	1116
B. Novo Selo	4,7			0,52				
Bođani	4,2							
Vajska	12,2							
Plavna	5,3						22,1	
Selenča	12,2		2,7	0,65			59,8	
Vrbas (g)	102	14,1	1,71	1,5				
B.Dobro Polje	13,9		1,7			0,021		
Zmajevo	15,4		1,67			0,039	14,4	
Kosančić	0,6							
Kucura	16,3		0,62			0,048		
Ravno Selo	12,3		4,59	1,67			149	
Savino Selo	11,9		3,58	3,73	0,09	0,046	16,61	1746
Srbobran (g)	51,7		7,2	0,44			95,8	1348
Turija	9,4		1,6	2				
Nadalj	8							
Bečej (g)	103,4	6,26	3,75	0,78				
B. Gradište	20,4		2,2				88	
B.Petrovo Selo	27,2		14,4				97	
Mileševo	4,1		1,09	2,18				
Radičević	4,8		1,86	0,4				
Novi Bečej (g)	58,6		39,1	14,6			25,3	1210

Settlements	l/s	Turbidity	Ammonia	Iron	Manganese	Arsenic	Organic matter	Conductivity
Bočar	7,3			0,33			25,3	1590
Kumane	14,7		1,7	1,86			47,7	
N. Miloševo	26,9						39,2	

Table 3-2: Results of Chemical Analysis of Raw Water in South East Region (mg/l)

3.2 Macro Regional Scenario

Whenever the treatment of drinking water is in question, it is not necessary to defend the viewpoint that centralized drinking water treatment is the best solution from a technical aspect, in other words, central water treatment plants (WTP), because it has been proven by experience the world over. In a central WTP, it is generally easier to obtain good operational, control and maintenance processes; with acceptable capital costs, as well as lower O&M costs calculated per unit volume of water, usually expressed in cubic meters of water treated by the plant.

3.2.1 Quantity and Quality of Water - Tasks for Water Treatment Technology

The estimated quantity of water required by the region (Western Backa Region, with expansion to the south and east), calculated based on maximum daily needs, and is 1500 L/s. This is accepted as the required capacity of the central WTP.

Raw water quality from the aquifer near Apatin, which is predicted as a future water source, is characterized by increased content of iron, manganese, ammonia, natural organic matter (NOM), and arsenic. At the same time, these are the characteristics of water which, during water treatment, it is necessary to decrease below the maximum allowable concentration (MAC).

3.2.2 Concept of Water Treatment Technology

The water treatment process is based on a combination of (i) proven (conventional) water treatments: degassing/aeration, filtration with dual media grain filters; (ii) relatively new treatments, but already proven in practice: ion exchange, adsorption by granulated activated carbon (GAC), i.e. GAC-filtration; and (iii) new treatments for arsenic removal: selective arsenic removal (adsorption) on specially developed media for that purpose, such as "Bayoxide E33" or a layer of IOCS (Iron Oxide Coated Sand). These combinations of treatments guarantee water treatment technology with good techno-economic parameters.

Two alternatives of water treatment technology at the central WTP are proposed. The reason for proposing the two alternatives of water treatment is to achieve some independence from the quality of water from potential sources; in other words, as soon as all investigations into potential water sources are complete, the values for two critical water quality parameters will be known for sure: (i) NOM content and (ii) arsenic content. It should be pointed out that the removal of NOM and arsenic are technically more complicated and more expensive than the removal of iron, manganese and ammonia.

3.2.2.1 Alternative 1

Alternative 1 is conceptualized for cases when the raw water has a high NOM content, and also an increased arsenic content, 25-30 μg/l. The technological water treatment process consists of the following treatments:

(1) degassing and aeration: removes eventually present gases in water (carbon dioxide, hydrogen sulphide, methane) by air stripping, with simultaneous water aeration, which is necessary for assuring dissolved oxygen for later processes of deferrization, demanganization, and biological ammonia removal; after aeration/degassing, there will be a retention tank in which the deferrization process will begin;

(2) dual media grain filtration, on anthracite and sand filter: removal of produced precipitate of iron hydroxide, which is the end of the deferrization process; demanganization catalyzed on grains of filter media; removal of ammonia by the action of specific micro flora in the filter; a significant part of arsenic content is removed by co-precipitation during deferrization;

(3) ozonization and GAC-filtration: removal of NOM from water starts with destabilization and partial degradation of NOM by ozone, and is finished with adsorption of NOM onto the granulated activated carbon; eventually present organic micro pollutants in water will be removed in this phase of water treatment as well;

(4) filtration across medium for selective removal of arsenic: residual arsenic will be removed from the water by adsorption onto a medium which selectively removes arsenic from water (NB: significant interference to arsenic removal on this medium is caused by increased NOM content in water, hence the filter for the selective removal of arsenic is made after the NOM removal phase; in order to increase the duration of acceptable biological water quality, it is necessary to remove the easily biodegradable fraction of NOM which is made by GAC, especially after colonization of GAC by specific micro flora); and

(5) water disinfection: chlorination is anticipated or eventually, the application of chlorine-dioxide. It should be pointed out that the possibility exists to exclude phase (4), i.e. the selective removal of

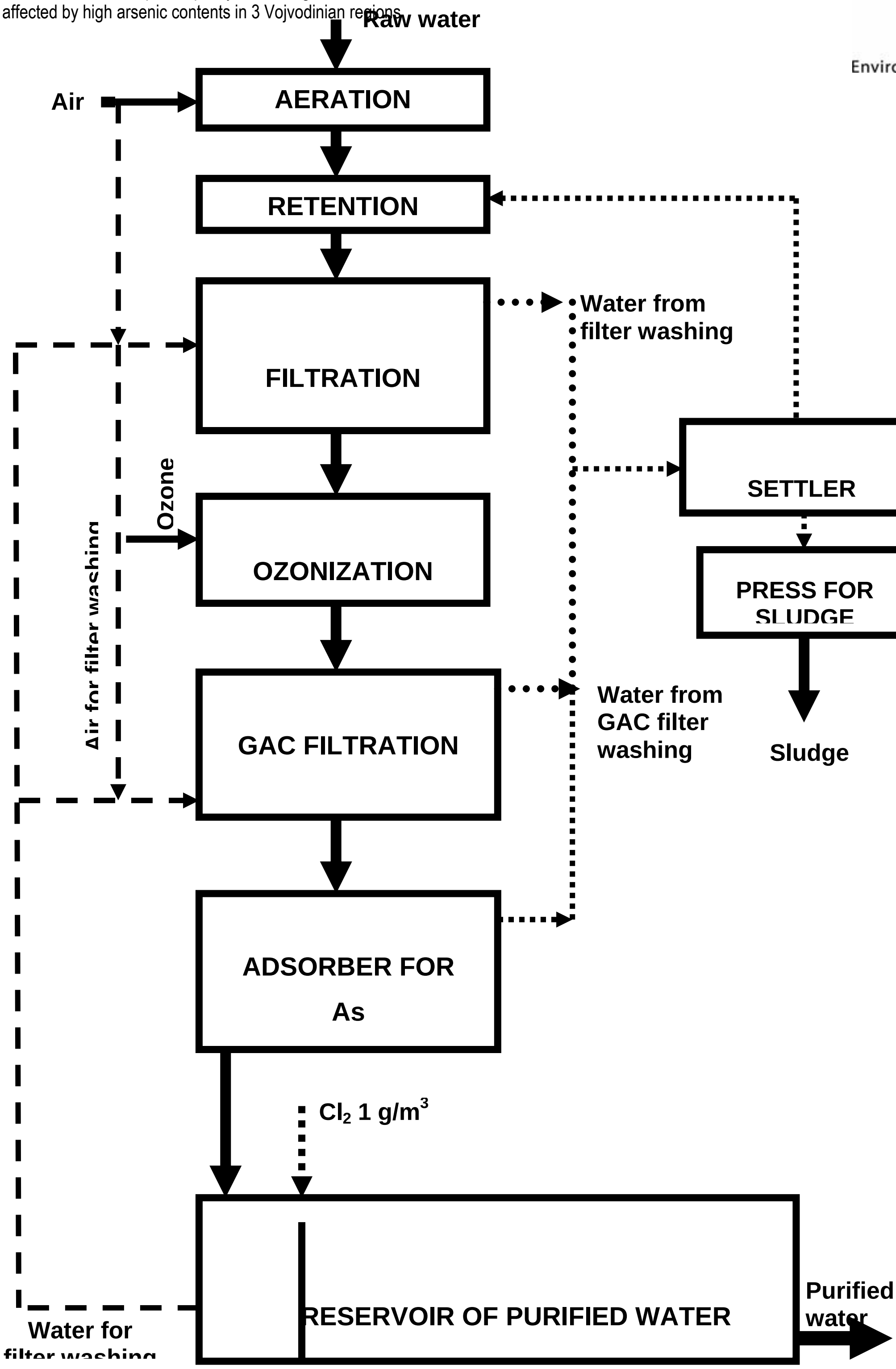


Figure 3.1: Version I for central substation at 1500 l/s

arsenic, if the average arsenic content in the water is not higher than 20 µg/l, because it is certain that the decrease in arsenic concentration below the MAC will therefore occur during water deferrization.

3.2.2.2 Alternative 2

Alternative 2 is conceptualized for cases where the dominant problem with the raw water is arsenic content, and also, if present in the water, increased NOM content. The technological water treatment process for Alternative 2 is identical to Alternative 1 in phases (1) degassing/aeration and (2) dual media grain filtration. The technological line of Alternative 2 continues with (3) selective removal of arsenic in filters with adequate medium (e.g. IOCS); because the NOM content in water is not signigificantly increased, there is no significant interference to the selective adsorption of arsenic onto the medium.

The water treatment line continues with (4) GAC-filters, for NOM removal, which assure the durability of the biological water quality; and ends with (5) water disinfection. NB: The possibility exists to exclude phase (4) i.e. GAC-filtration, in cases where (i) NOM content is not higher than the MAC, (ii) during disinfection, disinfection by-products are not formed above their MACs, and (iii) the duration of acceptable biological water quality is long enough after phase (3).

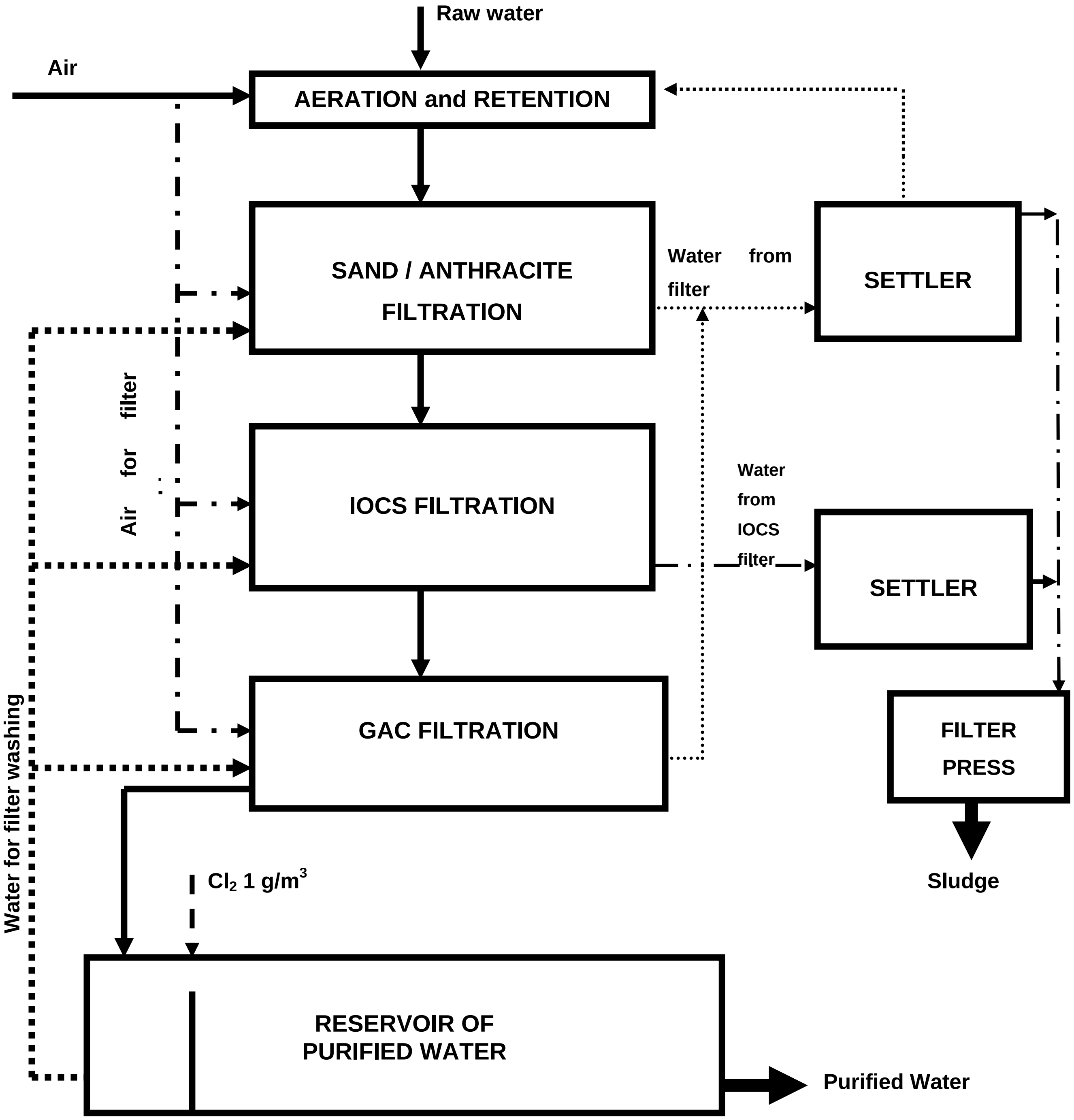


Figure 3.2: Version II for central substation at 1500 l/s

3.2.3 Estimation of Water Treatment Costs

Based on available data, in this pre-feasibility study phase, a rough estimation of the costs of the water treatment line may be made, but not the all-inclusive cost of the building and running of such a treatment plant.

The cost estimation is mainly based on: Mutschmann, J. and F. Stimmelmayer (Taschenbuch der Wasserversorgung, Franckh'sche Verlagshandlung, W. Keller & Co, Stuttgart, 1983), also consulting: Montgomery, J.M. (Water Treatment Principles and Design, John Wiley & Sons, USA, 1985), and some specific data obtained from the www.engineeringvillage2.org website.

3.2.3.1 Estimated Costs for Alternative 1

Capital Costs

Equipment and process media	8 100 000 €
(Engineering; 6% for basic engineering services for projects of above-average complexity)	486 000 €
Interest accrued during construction	750 000 €
General Contractor Overhead and Fee (9% of equipment and process media costs is accepted)	729 000 €
Water Treatment Plant Capital Cost	10 065 000 ≈ **10 100 000 €**
Unit Capital Costs (based on 20 years of WTP exploitation)	0.011 €/m3

O&M costs

The estimation of exploitation costs per unit of treated water for Alternative 1 is **0.080 €/m^3**.

NB: costs include (i) replacement of GAC and arsenic adsorbent; (ii) ozone production; (iii) energy intake (excluding ozone production); (iv) staff requirements; (v) maintenance, and (vi) amortization.

3.2.3.2 Estimated Costs for Alternative 2

Capital Costs

Equipment and process media	6 800 000 €
(Engineering; 6.2% for basic engineering	422 000 €

services for projects of above-average complexity)

Interest accrued during construction	600 000 €
General Contractor Overhead and Fee (10% of equipment and process media costs is accepted)	680 000 €
Water Treatment Plant Capital Cost	8 502 000 ≈ **8 500 000 €**
Unit Capital Costs (Based on 20 years of WTP exploitation)	0.009 €/m3

O&M costs

The estimation of exploitation costs per unit of treated water for Alternative 2 is **0.083 €/m^3**.
NB: costs include (i) replacement of GAC and arsenic adsorbent; (ii) ozone production; (iii) energy intake (excluding ozone production); (iv) staff requirements; (v) maintenance, and (vi) amortization.

3.3 Separate Scenarios

The following chapter shows the different plant schemes for different raw water types. Here is the overview on the water characteristics and their clustering into treatment groups:

Water treatment group	Problem parameters to be removed or lowered
A	ammonia, iron and manganese
B	ammonia, iron, manganese and organic matter <20 mgKMnO$_4$/l
C	ammonia, iron, manganese, organic matter <20 mgKMnO$_4$/l and arsenic <50 µg/l
D	ammonia, iron, manganese, organic matter <20 mgKMnO$_4$/l and arsenic >50 µg/l
E	ammonia, iron, manganese and arsenic >50 µg/l
F	ammonia, iron, manganese, organic matter, arsenic and inorganic matter which increases conductivity above 1000 µS/cm

Table 3-3: Water treatment groups

3.3.1 Water treatment group A

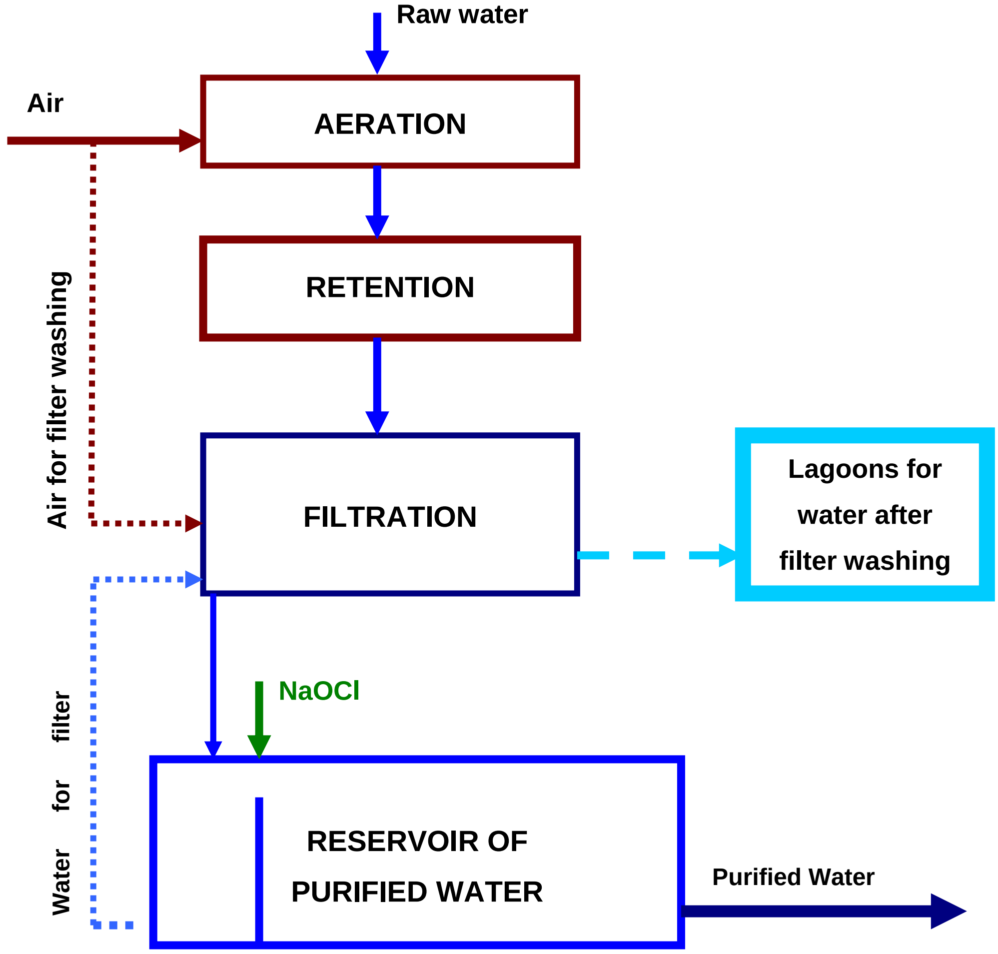


Figure 3.3: Schematic substations for ammonia, iron and manganese removal in small systems

List of settlements for which drinking water can be prepared by the proposed scheme in picture 3:

Settlement	capacity l/s
Kula	76.2
Crvenka	40.1
Sivac	33.4
Kljaićevo	26.5
Stanišić	22.0
Telečka	8.9
Lipar	6.5
Nova Crvenka	1.9
total	215,5

Table 3-4: Water companies in West Backa - treatment group A

List of settlements for which drinking water can be prepared by the proposed scheme in figure 3.3

Settlement	Capacity in l/s
Bečej	103.4
Vrbas	102.0
Vajska	12.2
Turija	9.4
Nadalj	8.0
Radičević	4.8
Bođani	4.2
Miloševo	4.1
B.Novo Selo	4.7
Total	252

Table 3-5: Water companies in South East Region – treatment group A

3.3.2 Water treatment group B

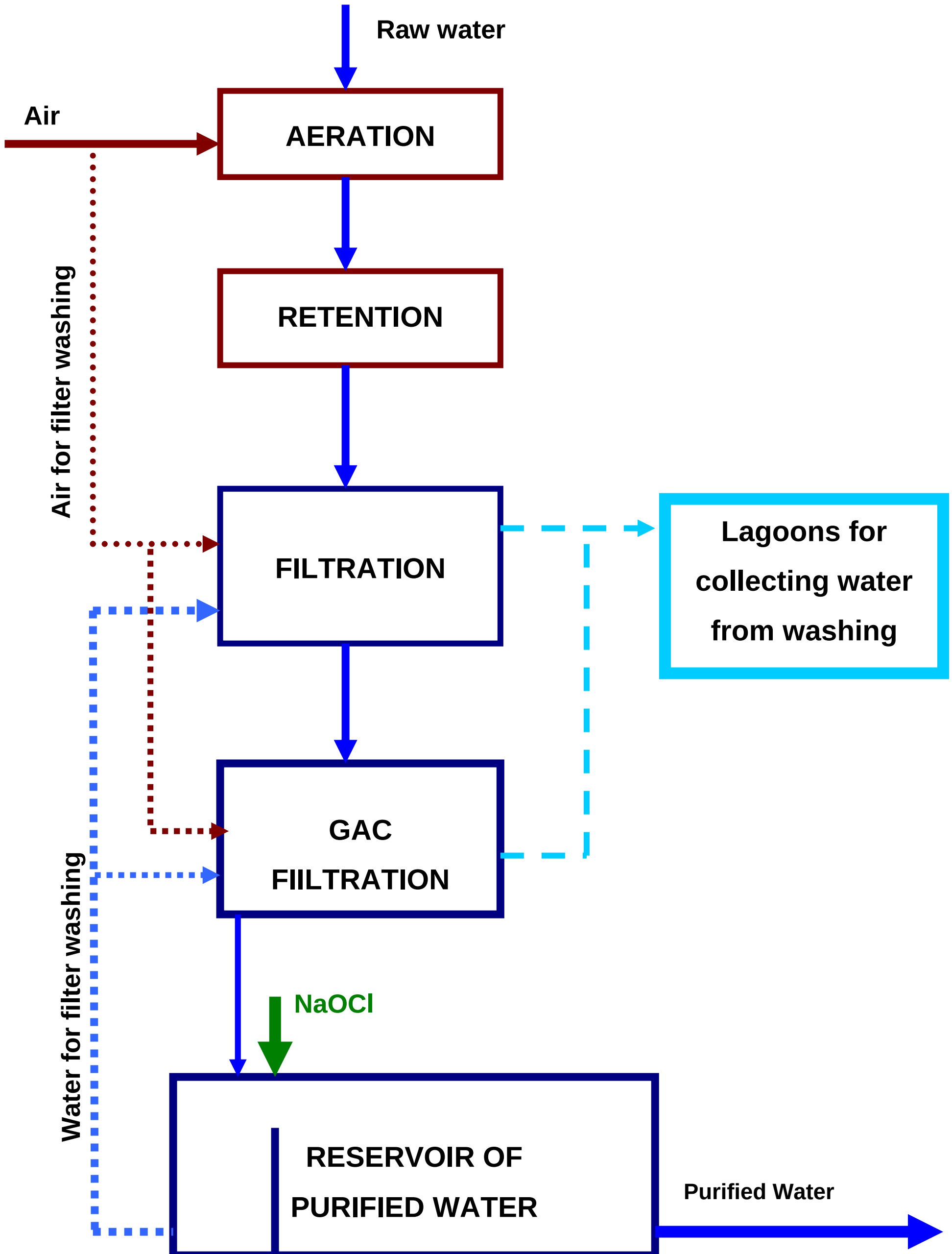


Figure 3.4: Schematic substation for ammonia, iron, manganese and organic matter <20 mgKMnO$_4$/l removal in small systems

List of settlements for which drinking water can be prepared by the proposed scheme in figure 3.4.

Settlement	Capacity l/s
Sombor	208.1
Apatin	78.3
Bezdan	23.2
Stapar	16.0
Riđica	11.2
Bački Gračac	10.8
Gakovo	9.4
Lalić	6.2
Rastina	2.4
total	349,1

Table 3-6: Water companies in West Backa - treatment group B

List of settlements for which drinking water can be prepared by the proposed scheme in figure 3.4

Settlement	Capacity l/s
Plavna	5.3
Bač	24.4
total	29,7

Table 3-7: Water companies in South East Region - treatment group B

3.3.3 Water treatment group C

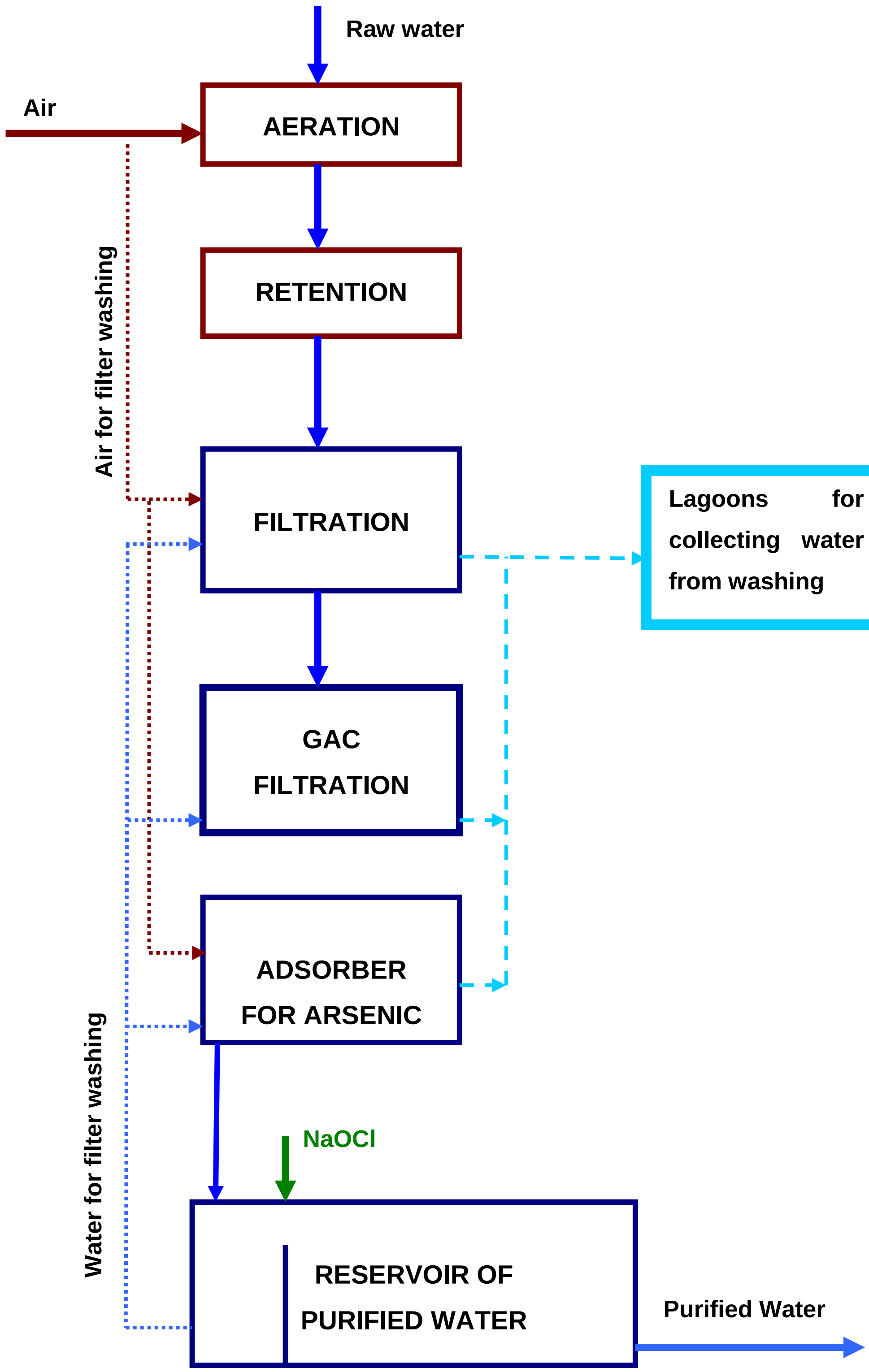


Figure 3.5: Schematic substation for ammonia, iron, manganese, organic matter <20 mgKMnO$_4$/l and arsenic <50 µg/l removal in small systems

List of settlements for which drinking water can be prepared by the proposed scheme in figure 3.5.

Settlement	capacity (l/s)
Čonoplja	18.8
Kruščić	8.5
Total	25,3

Table 3-8: Water companies in West Backa - treatment group C

List of settlements for which drinking water can be prepared by the proposed scheme in figure 3.5

Settlement	Capacity l/s
B. Dobro Polje	13.9
Zmajevo	25.4
Kucura	16.3
Total	55,6

Table 3-9: Water companies in South East Region - treatment group C

3.3.4 Water treatment group D

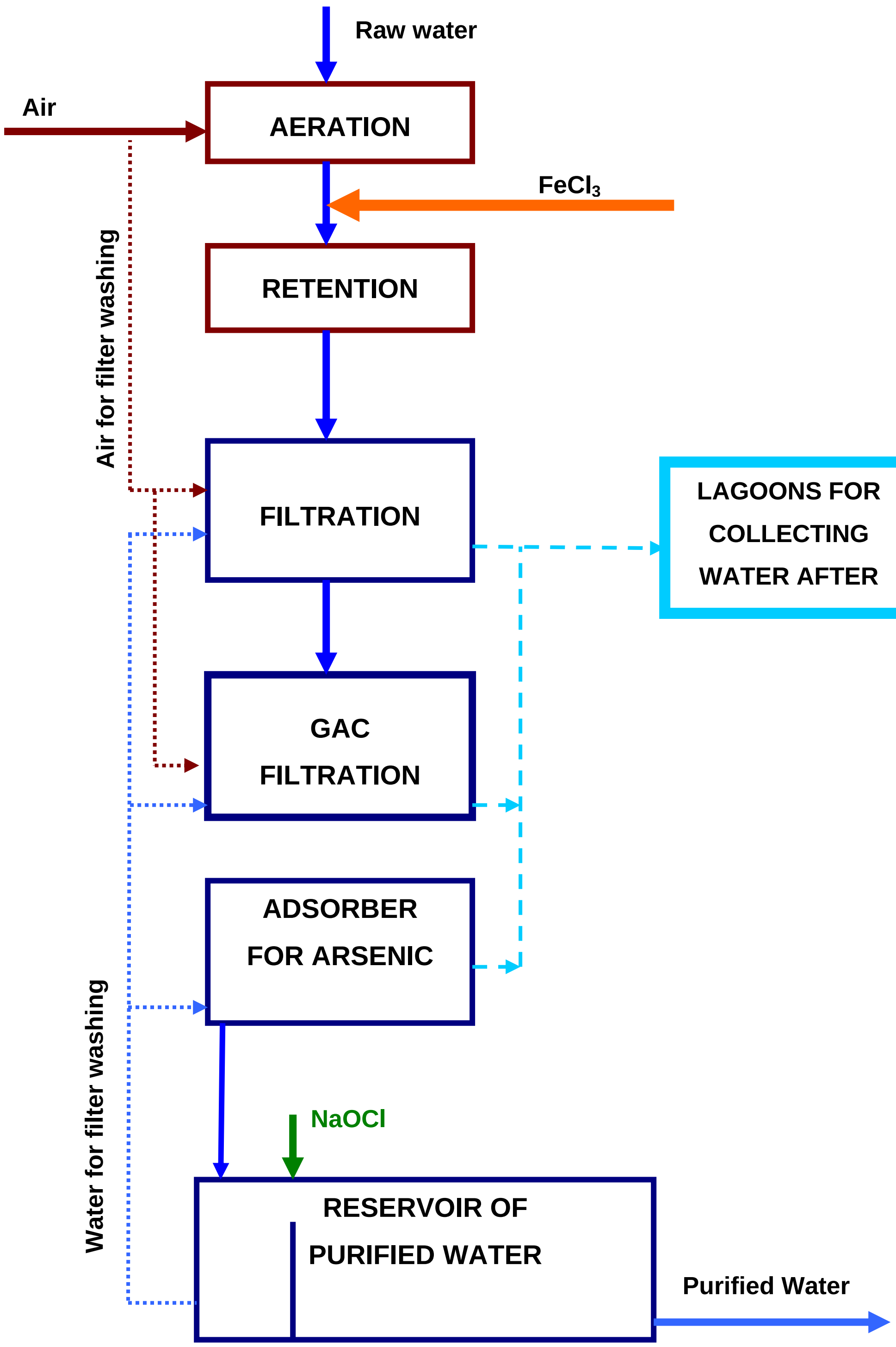


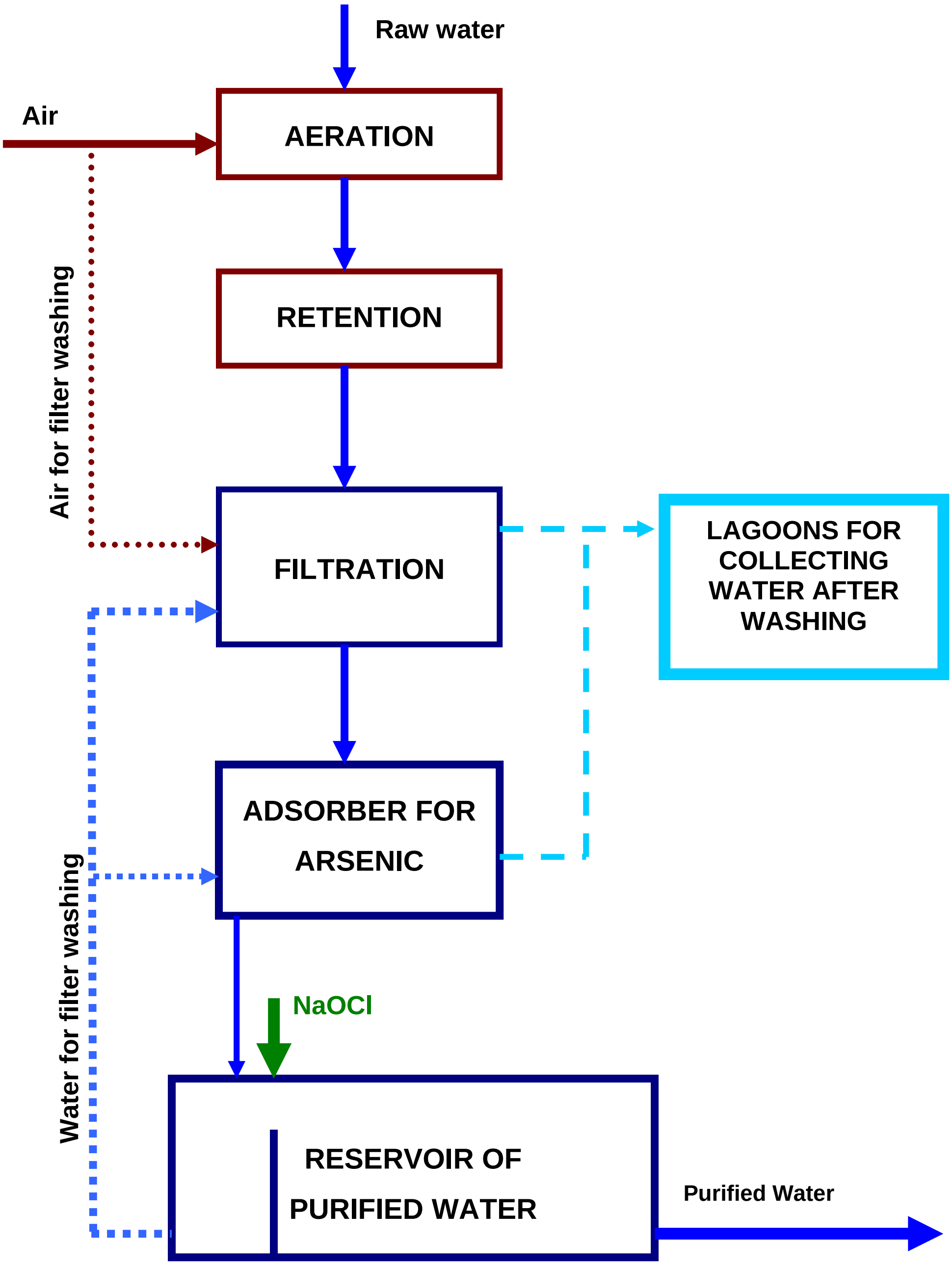
Figure 3.6: Schematic substation for ammonia, iron, manganese, organic matter <20 mgKMnO$_4$/l and arsenic >50 µg/l removal in small systems

Settlement	capacity (l/s)
Ruski krstur	19.3

Table 3-10: Water companies in West Backa - treatment group D

3.3.5 Water treatment group E

Figure 3.7:Schematic substation for ammonia, iron, manganese and arsenic>50 µg/l removal for small systems



Settlement	capacity(l/s)
Aleksa Santic	9.3
Total	9,3

Table 3-11: Water companies in West Backa - treatment group E

3.3.6 Water treatment group F

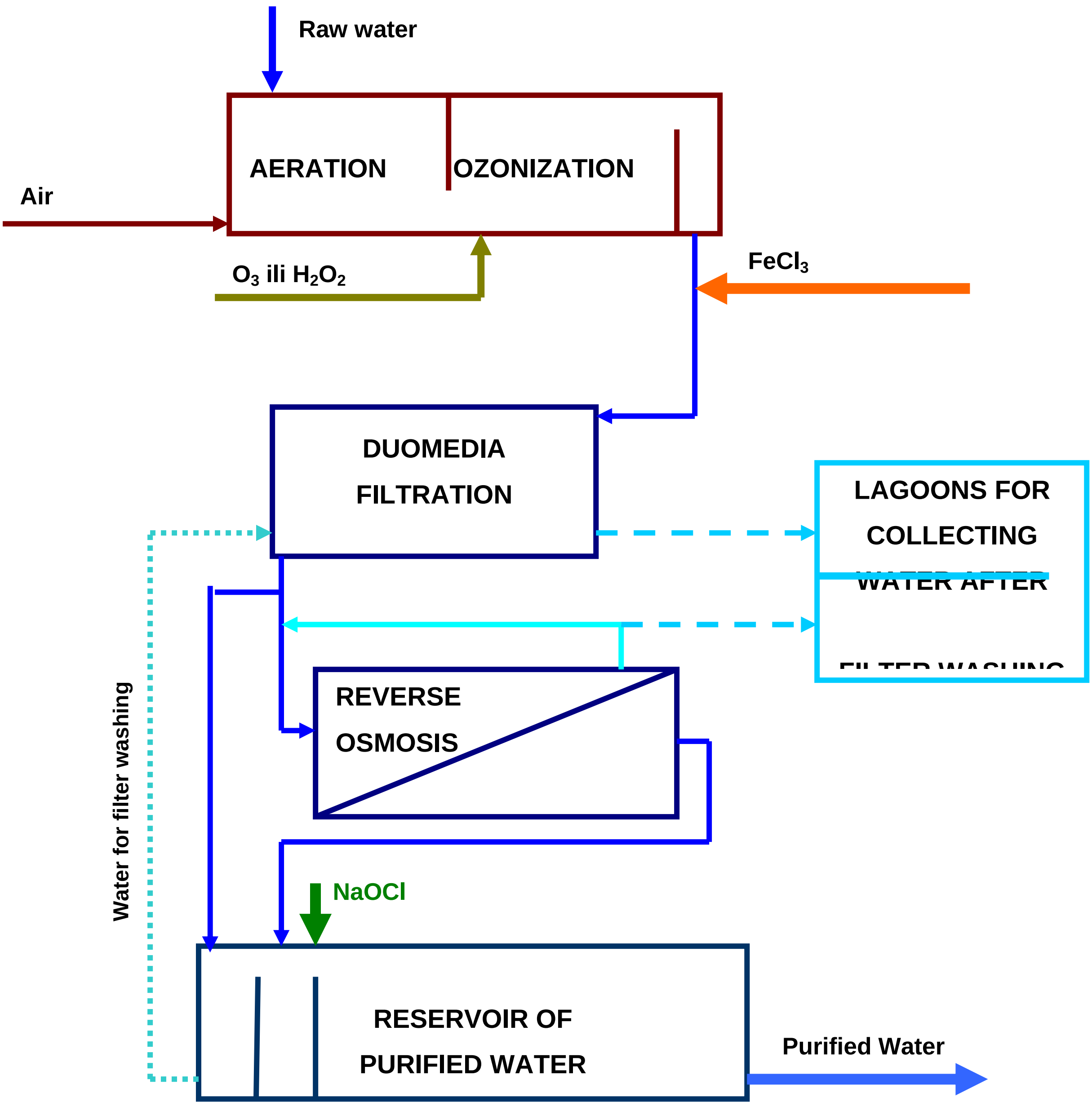


Figure 3.8: Schematic substation for removal from water of ammonia, iron, manganese, organic matter, arsenic and inorganic matter which increases conductivity above 1000 µS/cm in small systems

Settlement	capacity, l/s
Odžaci	39.4
Sonta	18.8
Karavukovo	19.1
Bački Monoštor	16.8
Ratkovo	15.3
Svetozar Miletić	13.5
Srpski Miletić	13.1
Bački Brestovac	12.9
Deronje	10.7
Kupusina	8.7
Bogojevo	7.9
Doroslovo	7.9
Kolut	7.3
Bački Breg	6.0
Total	197,4

Table 3-12: Water companies in West Backa - treatment group F

Settlement	capacity, l/s
Ravno Selo	12.3
Srbobran	51.7
Bačko Petrovo Selo	27.2
Bočar	7.3
Novo Miloševo	26.9
Settlement	capacity, l/s
Savino Selo	11.9
Bačko Gradište	20.4
Novi Bečej	58.6
Kumane	14.7
Total	231

Table 3-13: Water companies in South East Region - treatment group F