Problems and perspectives concerning reclaimed water reuse in urban areas

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PROBLEMS AND PERSPECTIVES CONCERNING RECLAIMED WATER REUSE IN URBAN AND AGRICULTURAL AREAS

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ABSTRACT
Reclaimed water reuse is at present encouraged throughout the world with regulations and international agency guidelines. This reuse allows the saving of water resources, a reduction in the use of high value resources for nonpotable purposes and a lower impact of discharged water on rivers. The technological perspectives for water reuse involves the evaluation of the quality standards that are required for different uses, the treatment, transport and distribution costs, and the benefits that can be obtained from the reduction of supply costs for the users. Four significant experiences in refining treatments, performed on reclaimed municipal and industrial wastewaters in the Piedmont area (Northwest Italy), are proposed in this work: a plant in a big town area (SMAT, Castiglione Torinese, Turin), a plant in an industrial area (SMAT, Collegno, Turin), and two plants in a mixed agricultural–industrial context (AMIAS, Novi Ligure and Cassano Spinola, Alessandria). The four plants have developed different refining technologies, and therefore obtained different effluent qualities, with different treatment costs. The potential users of the refined water from the four plants were carefully evaluated, with particular reference to industrial activities and also considering agricultural reuse, and an economic analysis was performed. The reuse of reclaimed water for nonpotable purposes is a valid solution in case of resource shortages and it is an alternative to the aqueduct supply that has undeniable environmental benefits.
Keywords: industrial wastewater, municipal wastewater, recycling, refining, reuse, tertiary treatment.

1 INTRODUCTION

Reclaimed water reuse (i.e. the use of industrial and municipal wastewater after reclamation for nonpotable purposes) is under investigation throughout the world because of the regulations and the development of new treatment technologies, which allow high quality effluents to be obtained [1–5]. In the US, reclaimed water reuse has been the subject of investigations for several years; the first regulations concerning water reclamation and reuse standards were adopted by the State of California in 1918. At present, there is a lack of federal regulations concerning wastewater reuse in the US, and although several states have their own regulations, these do not cover all potential uses, especially as far as potable reuse is concerned, and different standards exist throughout the country [6]. The US EPA *Guidelines for Water Reuse* [7], which include not only the quality standards for each considered possible reuse but also the recommended treatment processes, the monitoring frequencies and the setback distances, are intended to provide guidance for the different states in the US and countries throughout the world that have not developed their own regulations. Other important guidelines on agricultural water reuse were drawn up by the World Health Organization [8]. Wastewater reuse is also common, particularly for irrigation purposes, in Mediterranean countries: Cyprus, France, Israel, Italy and Tunisia have established national guidelines or regulations that are characterized by different requirements, and many research projects are in operation in Greece, Spain, Turkey, Morocco, Malta and Egypt [9–12]. **[AQ1]**

Based on literature data [1–5], and previous field studies [13–16], a functional approach towards reclaimed water reuse is proposed in this paper, which requires the following investigations to be carried out:

- evaluation of the manufacturing, agricultural and civil activities that are located in the area of interest, and assessment of their water requirements and of their supply methods and costs;

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- identification of the required standards for reclaimed water reuse for industrial, agricultural and civil nondrinkable use;
- analysis of any additional water treatments;
- assessment of the total territorial distribution of the potential users, including the connected distribution costs;
- evaluation of the total calculated costs and comparison with the present supply costs;
- assessment of the environmental benefits connected to a better use of high value resources and to a lower impact on water resources.

The aforementioned procedure was tested in the Piedmont area (Northwest Italy), with reference to [AQ2] four important experiences financed by the EEC:

- a plant in the Turin urban area (SMAT, Castiglione Torinese, Turin);
- a plant in an industrial area (SMAT, Collegno, Turin);
- two plants in a mixed agricultural–industrial context (AMIAS, Novi Ligure and Cassano Spinola, Alessandria).

The four plants use different refining technologies, applied to water coming out from wastewater treatment plants, and thus obtain different quality effluents and treatment costs; the potential users of the refined water from the four plants were carefully evaluated, with particular reference to industrial activities, and, finally, an economic analysis was performed.

2 REQUIREMENTS FOR RECLAIMED WATER REUSE

The main nonpotable reuses for reclaimed municipal and industrial wastewater include industrial, residential, commercial and agricultural uses.

The industrial reuse alternatives include cooling waters, steam production, process waters (particularly in the pulp and paper production and textile manufacturing industries), dust abatement systems, and sanitary and fire service waters. After an examination of the literature data [7, 17], and on the basis of the field analysis [13, 14], it can be stated that the main industrial water consumption concerns cooling and process waters.

Cooling waters can contain dissolved salts, insoluble substances and microorganisms that can affect the efficiency of the global system to a great extent [7, 18, 19]. Open recirculating plants based on cooling towers are affected to a great extent by these substances: as a consequence of the evaporation of the cooling water, the pollutants, introduced due to the makeup flow and the air–water contact in [AQ3] the cooling towers, accumulate in the system.

High concentrations of impurities can lead to the reduction of the heat transfer coefficient because of scaling, corrosion, fouling and algal growth. The main cause of scaling, which involves the creation of mineral and amorphous aggregates, usually near the heat exchangers, is the supersaturation of the cooling waters due to temperature, pH and flow changes. When the soluble ion concentrations become higher than the solid–liquid equilibrium values, the aggregates form. High concentrations of calcium, magnesium, iron, carbonate, sulfate, phosphate and silica, basic pH values, and high alkalinity values are all essentially responsible for scaling.

Corrosion, which may be a diffused or localized phenomenon of metal surface degradation, is linked to high concentrations of chlorine and carbon dioxide dissolved in the cooling waters, acidic pH values, and high concentrations of ferric, rameic, bromide and sulfide ions and total suspended solids. Products formed due to corrosion can create aggregates.

Fouling and algal growth, mainly caused by high oxygen, carbon dioxide, nitrogen, phosphorous and total dissolved solids concentrations, involve amorphous aggregates produced by photosynthetic and iron and sulfur oxidant bacteria.

The most important parameters for the characterization of cooling waters are therefore electrical conductivity (EC), total suspended solids (TSS), total dissolved solids (TDS), pH, alkalinity, total hardness (TH), chemical oxygen demand (COD), biochemical oxygen demand (BOD), and some metal (Ca, Mg, Fe, Mn, Al), chloride and sulfate concentrations.

The process water quality requirements depend on the kind of production and the technical solutions adopted. Cooling water quality requirements [7], together with process water quality requirements, for the textile industry [17] and for pulp and paper production [20] are shown in Table 1. Cooling water quality requirements are particularly restrictive and may need additional treatments such as ion exchange and reverse osmosis. The quality of water for paper production varies according to the type of product (fine or medium-fine paper), and the requirements, like the ones concerning the textile industry, are even more restrictive than cooling water quality requirements.

Agricultural reuse of reclaimed waters can satisfy a huge fraction of the total water demand (40% of the US total water demand, [7]) and is surely the oldest type of wastewater reuse. The parameters governing water quality are salinity, sodium, trace elements, residual chlorine, nutrients and microorganisms. Each crop has its own sensitivity to these water constituents, especially concerning salinity (often measured by means of EC or TDS) and sodium (the reference parameter is the sodium adsorption ratio, SAR: it is linked to the sodium, magnesium, calcium and carbonate concentrations); soil permeability also has to be considered. Thus, based on their salinity and SAR values, reused waters used for irrigation could be utilized for certain types of crops and soils. High concentrations of trace heavy metals, some of which are essential for plants but which are all toxic at high concentrations, and of free residual chlorine (derived from disinfection treatments), pH and organic pollutants are all parameters that must be kept under control. Nitrogen, phosphorous and potassium are all essential nutrients for plant growth, and their presence, within certain limits to prevent eutrophization in sensitive areas, enhances the value of water for agricultural purposes.

Table 1: Industrial water quality requirements (adapted from [7, 17, 20]).

	EPA		TAPPI		
Parameter	Cooling water	Steam production	Fine paper	Medium-fine paper	Textile industry
pH	6.9–9.0	8.2–9.0	6–10	6–10	–
TDS (mg/l)	500	200	200	500	100
TSS (mg/l)	100	0.5	5	25	5
Turbidity (mg/l SiO_2)	50		10	50	–
Color (Pt)	–	–	5	30	5
TH (mg/l $CaCO_3$)	–	0.07	100	200	25
Alkalinity (mg/l HCO_3^-)	350	40	75	150	–
Cl^- (mg/l)	500	–	75	75	–
SO_4^{2-} (mg/l)	200	–	–	–	–
Ca (mg/l)	50	0.01	10	20	–
Mg (mg/l)	0.5	0.01	10	12	–
Fe (mg/l)	0.5	0.05	0.1	0.3	0.1
Mn (mg/l)	0.5	0.01	0.05	0.1	0.01
Al (mg/l)	0.1	0.01	–	–	–
COD (mg/l O_2)	75	1.0	–	–	–
BOD_5 (mg/l O_2)	25	–	–	–	–

Water reuse guidelines and regulations for agricultural and civil nonpotable purposes are basically directed at public health protection, through the control of microbiological parameters; therefore, a high degree of treatment and disinfection is required. The requirements for the irrigation of crops that are eaten raw and public areas are always more restrictive than the ones concerning the irrigation of processed food/nonfood crops and restricted access areas. The main issue of the guidelines and regulations for agricultural reuse of reclaimed water concerns microbiological parameters. The EPA [7] and WHO [8] guidelines are compared with the California State [21] and Italian regulations [22] in Table 2. These guidelines may be applied to municipal and industrial wastewater that have undergone a reclamation treatment.

Table 2: Irrigation water quality requirements (adapted from EPA [1, 7, 22]).

Guidelines/ regulations	Type of reuse	Treatment required	Water quality
California	Spray and surface irrigation of food crops and high exposure landscapes	Secondary treatment, filtration, disinfection	Total coli (MPN/100 ml) < 2.2 Turbidity (NTU) < 2
	Irrigation of pastures for milking animals, landscape impoundment	Secondary treatment, disinfection	Total coli (MPN/100 ml) < 23
WHO	Irrigation of crops likely to be eaten uncooked, sports fields, public parks	A series of stabilization ponds or equivalent treatment	Fecal coli (MPN/100 ml) < 1000 Helminths (eggs/l) < 1
	Irrigation of cereal crops, industrial crops, fodder crops, pastures and trees	Stabilization ponds with 8–10 days retention or equivalent removal	Helminths (eggs/l) < 1
	Landscape irrigation where there is public access, such as hotels	Secondary treatment, disinfection	Fecal coli (MPN/100 ml) < 200 Helminths (eggs/l) < 1
EPA	Irrigation of any food crops eaten raw, urban uses, recreational impoundments	Secondary treatment, filtration, disinfection	pH = 6–9, $BOD_5 \leq 10$ mg/l, turbidity ≤ 2 NTU, no detectable fecal coli/100 ml, free $Cl_2 \geq 1$ mg/l
	Irrigation of restricted access areas and processed food crops	Secondary treatment, disinfection	pH = 6–9, $BOD_5 \leq 30$ mg/l, TSS ≤ 30 mg/l, fecal coli $\leq 200/100$ ml, free $Cl_2 \geq 1$ mg/l
Italian law	Irrigation of any crops	Secondary treatment, disinfection	*Escherichia coli* $\leq 10/100$ ml (in 80% of the samples) $<100/100$ ml (maximum value) Salmonella: absent

California promotes very high quality standards, relying on the total coliform count and the requirement of a secondary wastewater treatment followed by filtration (only for crops eaten raw and public areas) and disinfection (for all purposes); the California requirements inspired the regulations in Israel, South Africa, Japan and Australia. WHO quality standards, based on fecal coliform and intestinal nematode counts, and the requirement of a treatment performed by means of stabilization ponds, are less restrictive and inspired the guidelines in France and Andalusia, which have been integrated with additional criteria such as treatment requirements and use limitations [9].

EPA guidelines, like WHO, consider the fecal coliforms and also many other parameters, and the treatment requirements are analogous to the California regulations. Italian law takes into account the *Escherichia coli* parameter as a microbiological standard and also many other parameters. Civil nonpotable reuse can include the following: irrigation of public and private areas, fountain supply, fire protection, toilet flushing and commercial uses (i.e. window and car washing). This kind of reuse can be connected to residential, commercial and industrial activities through the use of dual distribution systems, which foresee a complementary network that is separate from the potable water distribution system. The requirements for civil nonpotable reuse are analogous to the ones concerning the irrigation of crops eaten raw. A free chlorine residual concentration is recommended to prevent odors, slimes and algal growth in the distribution systems (1 mg/l as per EPA guidelines [7]).

3 RECLAIMED WASTEWATER REFINING PLANTS

Four different and significant situations for refining treatments for reclaimed water reuse (mainly for industrial purposes) in the Piedmont territory (Northwest Italy) have been analyzed: these are all post-treatment plants following a reclamation treatment performed in the same site on industrial and civil wastewater. A distribution network is foreseen from each refining plant to the potential users, and in most cases it has already been set up.

A first SMAT plant, located in Castiglione Torinese (Turin, Northwest Italy) treats the municipal and industrial wastewater from the town of Turin and its surroundings (2,100,000 equivalent inhabitants), and it is the main municipal wastewater treatment plant in Italy. The refining treatment performed in this plant includes disinfection by means of sodium hypochlorite with a flow rate equal to about 1700 m^3/h (about 1/12 of the total outflow rate of the wastewater treatment plant, and this percentage could be increased in the future). The cost of this treatment is about 0.04 €/m^3, which includes the pumping costs for a 4 km distribution network. The refining treatment is done after a tertiary treatment that is performed by means of clariflocculation and sand bed filtration; an additional denitrification treatment is now being set up. The SMAT wastewater treatment plant outflow (about 6 m^3/s) is discharged into the Po River (average natural flow of about 100 m^3/s) at a site where the total flow rate is about 2–20 m^3/s, due to upstream collections; the wastewater reuse and the consequent reduction of the discharged outflow is therefore a good opportunity to obtain a lower impact on the Po River.

A second SMAT plant in Collegno (Turin, Northwest Italy) treats municipal and industrial wastewater (400,000 equivalent inhabitants). The total outflow is about 1700 m^3/h, and it is discharged into the Dora Riparia River. The refining treatment, performed on an average flow of about 500 m^3/h, produces an average outflow rate equal to 250 m^3/h, with a cost of about 0.25 €/m^3, and consists of the following phases: pressurized filtration using sand filters, active carbon filtration, zenon or **[AQ4]** tubular membrane filtration and sodium hypochlorite disinfection. The active carbon filtration phase, according to the inflow quality, can be performed before (for high organic content inflows) or after (for low organic content inflows) the ultrafiltration phase.

The AMIAS Consortium manages two refining plants for the treatment of municipal and industrial wastewater (200,000 equivalent inhabitants in total); one is located in Novi Ligure (Alessandria, Northwest Italy) and the other in Cassano Spinola (Alessandria, Northwest Italy). The total outflow of the wastewater treatment plants is about 1500 m^3/h, and each refining plant is built for inflows of about 400 m^3/h. The refining treatments are made up of the following phases: clariflocculation by means of iron chloride, anionic polyelectrolyte and sodium hydroxide, rotating disk filtration, and UV disinfection. In the Cassano Spinola plant, the potential scaling of the effluent is controlled by [AQ5] means of organic fosfonates; in the Novi Ligure plant, an ion-exchange treatment (one hard cationic resin column and one weak anionic resin column) is performed on 50% of the outflows. The refined and the demineralized outflows are then mixed to make up the final Novi Ligure plant outflow. The treatment costs (including the distribution costs) are consequently different: about 0.11 €/m^3 for the Cassano Spinola plant treatment and about 0.13 €/m^3 for the Novi Ligure plant treatment. A feedback pipe from the users to the wastewater treatment plants is foreseen.

The values of the water quality for the four refining plant outflows are shown in Table 3, together with the Italian law (185/2003) prescriptions for the agricultural reuse of refined waters. The values

Table 3: Quality of refined water from the four refining plants.

Parameter	SMAT (Castiglione Torinese)*	SMAT (Collegno)*	AMIAS Cassano Spinola**	AMIAS Novi Ligure (refining + demineralization)**	AMIAS Novi Ligure (refining)***	185/2003 Limits
Rate (m^3/h)	1700	250	375	375	375	–
pH	7.1	7.8	7.0	7.0	7.5	6–9.5
TSS (mg/l)	20	0.5	5.0	5.0	5.0	10
BOD_5 (mg/l)	20	5	10	10	10	20
COD (mg/l)	42	21	25	25	40	100
EC (μS/cm)	725	991	–	400	787	3000
SAR	1.64	–	–	–	–	10
TH (mg/l $CaCO_3$)	128	–	250	200	246	–
SiO_2 (mg/l)	–	16.9	–	–	–	–
SO_4^{2-} (mg/l)	54	–	150	–	71	500
Cl^- (mg/l)	65	–	250	–	84	250
$N–NH_4$ (mg/l)	5	7.52	4	5	5	2
Fe (mg/l)	0.05	0.16	–	–	–	2
Ca (mg/l)	48	–	–	–	–	–
Mg (mg/l)	12	–	–	–	–	–
Na (mg/l)	25	–	–	–	–	–
P (mg/l)	2.00	1.80	0.25	0.25	0.58	2
Total coli (MPN/100 ml)	–	–	<20	<20	2	–
Escherichia coli (UFC/100 ml)	–	–	–	–	–	10 (80% campion) 100 (val. max.)

*Values measured by the authors.
**Values measured in pilot scale tests.
***Values measured by the IdroCons Company (average values for the period 30/10/2001–31/01/2002).

for both SMAT plants were measured by the authors, while the AMIAS-Cassano Spinola and the AMIAS-Novi Ligure (refining treatment followed by demineralization) values were obtained from pilot scale tests; the AMIAS-Novi Ligure values were measured by the IdroCons Company (Rivalta Scrivia, Alessandria, Northwest Italy) on an outflow that was not subjected to the demineralization treatment. The SMAT plant (Castiglione Torinese) effluent is characterized by rather high TSS and COD values. The SMAT (Collegno) outflow has particularly low values, in comparison to the other examined cases, for TSS, BOD_5 and COD parameters, due to the final ultrafiltration phase. Both the AMIAS effluents are characterized by low TSS, BOD_5 and COD values, due to the clariflocculation and filtration phases, but they also have a high TH values and, if the Novi Ligure plant is considered, the chloride and sulfate values are lower than the design expected values.

The outflow of the SMAT plant (Castiglione Torinese) was also sampled and analyzed by the authors in order to evaluate the variation with time of the chemical and physical characteristics. Three 2 l samples were collected during the day (at 8, 12 and 4 o' clock) and they were used to build average daily samples. The sampling operation was performed during a week in the months of May, June and July 2000. The results of the chemical analyses of the average samples are shown in Table 4. Based on the gathered data a variation of the outflow quality with time was observed. In fact, the total alkalinity, TH and the conductivity increase from May 2000 to July 2000. This effect is probably due to the scarcity of rains and the temperature increase during the summer season. On the other hand, the COD value decreases in the considered time, which may be due to the higher efficiency of the aerobic treatment phase of the wastewater treatment plant. The concentrations of

Table 4: Chemical parameters of refined waters from the SMAT plant (Castiglione Torinese).

Day	pH	Alkalinity (mg/l)	COD (mg/l)	TH (mg/l)	TDS (mg/l)	Cl^- (mg/l)	SO_4^{2-} (mg/l)	K (mg/l)	Na (mg/l)	Ca (mg/l)	Mg (mg/l)
7/5/2000	7.2	134	–	200	695	68	77	10.0	30	50	15.2
8/5/2000	7.1	128	52	200	645	67	63	10.3	25	45	11.9
9/5/2000	7.1	146	67.5	220	775	91	82	11	38	90	14.5
10/5/2000	7.2	104	52.5	150	578	64	57	6.9	18	35	9.8
11/5/2000	7.1	128	45	150	705	73	79	8.3	26	60	14.6
12/5/2000	7.2	132	55	160	615	63	62	3.2	23	40	12.2
Average	7.1	129	54.0	180	687	71	69	8.3	27	52	13
11/6/2000	6.8	152	32.5	140	570	36	42	9.0	8	25	7.4
12/6/2000	6.8	116	37.5	160	670	48	58	7.0	9	33	8.5
13/6/2000	7.2	128	37.5	200	780	51	60	8.0	12	36	9.0
14/6/2000	7.1	146	65	200	865	82	70	10.0	13	43	10.5
15/6/2000	7.1	146	60	180	870	88	73	7.0	40	39	10.6
16/6/2000	7.4	195	22.5	220	930	69	73	6.0	25	46	10.7
Average	7.1	147	42.5	183	781	62	63	7.8	18	37	9.4
17/7/2000	6.7	183	24.6	240	965	60	73	12.6	25	61	18.2
18/7/2000	7.4	170	19.5	220	999	58	84	7.8	45	68	14.5
19/7/2000	7.0	170	24	240	941	62	122	12.4	33	35	10.4
20/7/2000	7.3	170	35.1	220	1040	67	74	6.4	18	50	14.4
21/7/2000	7.4	158	46.1	240	1035	61	75	7.1	22	71	10.8
Average	7.2	170	29.9	232	996	62	86	9.3	29	57	13.7

chlorides, sulfates, potassium, calcium and magnesium are almost constant in the considered period of time.

4 MATERIALS AND METHODS

All the reagents and standard solutions used were ACS grade (i.e. they fulfill American Chemical Society purity standards), purchased from Fluka, Aldrich, Riedel-deHaën and Merck.

The pH and EC values were measured using an Orion 420A pH meter and a WTW LF 538 conductimeter. The iron, calcium, magnesium and sodium concentrations were measured using a Perkin-Elmer 1100 B flame atomic absorption spectrometer. **[AQ6]**

The determination of the following parameters, according to the *Standard Methods for the Examination of Water and Wastewater* [23], was performed: TSS (dried at 103–105°C), BOD_5 (5-day BOD test, using a Velp 6 bottle incubator), COD (closed reflux, titrimetric method, using a Velp Eco6 digestion apparatus), TH (EDTA titrimetric method, using a Titriplex A Merck standard solution), sulfates (turbidimetric method, using a UV-Vis Unicam Helios α spectrophotometer), chlorides (ferricyanide method, using a UV-Vis Unicam Helios α spectrophotometer), ammonium nitrogen (phenate method, using a UV-Vis Unicam Helios α spectrophotometer) and total phosphorous (stannous chloride method, using a UV-Vis Unicam Helios α spectrophotometer).

5 RESULTS

The authors singled out several potential users for the refined water from the four considered plants; they are listed in Table 5 [15, 16]. Paper, rubber, tires and mechanical industries can be found in the first SMAT plant area (Castiglione Torinese): the paper industry mainly needs process waters while the other industries mainly need cooling water. Small and medium firms that mostly need cooling water and a prison, with a potential use for civil nonpotable purposes, were found in the area around the second SMAT refining plant (Collegno); one food industry that requires dust deodorization water and a mechanical industry that uses cooling water are the potential users of the refined water from the Cassano Spinola plant, while two industries (one mechanical and one food industry) that require cooling waters are the potential users in the area around the Novi Ligure plant. The agricultural reuse of reclaimed waters is foreseen in the two AMIAS plants and in the Castiglione Torinese SMAT plant even though the flow rate is actually not specified.

The potential users in the areas of the four considered refining plants are mainly interested in reclaimed water reuse as cooling, process and dust deodorization waters. Based on the industrial water quality requirements reported in Table 1, the following suggestions have been made:

- Reuse of the SMAT/Castiglione Torinese refined water is possible as cooling waters for once-through systems, because of the high TDS and magnesium concentrations values. Reuse as process water in the paper industry would require a further reduction of the TSS, TDS and calcium concentrations. The COD should also be kept under control: this parameter, even though not foreseen in the TAPPI requirements, is usually rather high in paper industry outflows (see Tables 1 and 4). Reuse for civil nonpotable purposes requires the control of the microbiological parameters, which can be guaranteed by the addition of sodium hypochlorite.
- The reuse of the SMAT/Collegno refined water is possible for both cooling water in once-through systems and for civil nonpotable purposes, as the ultrafiltration treatment that is performed ensures the almost total absence of bacterial and viral contents (see Tables 1 and 4).
- The reuse of the AMIAS refined water is possible for both cooling water and dust deodorization waters (see Tables 1 and 3). The ion-exchange treatment, foreseen in the design phase of the Novi Ligure plant to reduce chloride and sulfate concentration values, was not necessary as the quality requirements of the potential users are achieved without the demineralization phase. Thus, the

Table 5: Potential users of the refined water from the four plants (adapted from [15, 16]).

Refining plant	Potential user	Main use	Actual supplier	Total rate (m^3/h)
SMAT (Castiglione Torinese)	Bosso (fine paper)	Process water	The Stura River	1260
	De Molli (medium-fine paper)	Process water	Wells	85
	Reno De Medici (medium-fine paper)	Process water	Stura River (50%) and wells (50%)	595
	BTR (rubber)	Cooling water	Wells	125
	CEAT Cavi (mechanical)	Cooling water and civil nonpotable uses	Wells and tap water	390
	Pirelli S.p.A. (tires)	Cooling water	Wells	225
	Antibiotics (pharmaceutical)	Cooling and process water and other uses	Wells	500
	Michelin S.p.A. (tires)	Cooling water	Wells	250
	CF Gomma (rubber)	Cooling water	Wells	690
		Agricultural reuse	Wells and Stura River	
SMAT (Collegno)	Different industries	Cooling water and civil nonpotable uses	Wells and tap water	290
	Jail	Civil nonpotable uses	Tap water	110
AMIAS Cassano Spinola	Europa Metalli (metal alloys)	Cooling water	Wells	30
	La Roquette Italia (starch and derivates)	Dust deodorization water	Wells and the Scrivia River	250
		Agricultural reuse	Wells and Stura River	
AMIAS Novi Ligure	ILVA (metals)	Cooling waters	Wells	220
	PCA (food products)	Cooling waters	Wells	120
		Agricultural reuse	Wells and Stura River	

refining treatment and distribution costs for the reclaimed waters are equal to about 0.09 €/m^3, with a saving of about 30% in comparison to the foreseen cost of about 0.13 €/m^3.

In the future, the SMAT/Castiglione Torinese and AMIAS reclaimed waters could be used for agricultural purposes. If the EPA guidelines and the Italian law are considered, based on actually available data, the SMAT/Castiglione Torinese water may have some problems with respect to the TSS and ammonia nitrogen parameters and the AMIAS waters may have some concerns with respect to the ammonia nitrogen parameter as well.

The four examined refining plants produce water that is very different in quality, with different treatment costs. The largest quantity of water of the hypothesized users of the refined water from the four plants is actually supplied by wells or rivers, with very low costs, of about 0.02 €/m^3. Therefore, the adoption of the reuse of reclaimed wastewater, which has a higher supply cost and a lower quality, [AQ7] is actually very difficult for the two SMAT plants considered. However, this is not the case for the AMIAS refining plants, because here the scarcity of available water, wells and rivers compels the potential users to adopt the reclaimed water.

Therefore, the reuse of reclaimed water is a valid solution when there is no available water elsewhere and when it is an alternative to the aqueduct supply (which has a cost of about 0.5–0.8 €/m^3), even though the additional costs of a dual distribution network should be considered.

6 CONCLUSIONS

In Italy the costs involved for groundwater and surface water supply are very low, and so in case of a large availability of water for agricultural, industrial and civil purposes water reuse is not a valid solution from an economic point of view. Otherwise, other considerations must be taken into account regarding the environmental advantages and disadvantages of the water reuse technical solution.

Some environmental benefits may be the saving of primary water resources and a lower environmental impact of wastewater treatment plant outflows; on the other hand, some possible disadvantages are that further treatment operations may be required, resulting in sludge production, energy consumption and so on, and the possible increase of the piezometric surface due to lower primary water consumption. For these reasons, the public authority must evaluate the externalities (environmental advantages/disadvantages) involved in water reuse according to the different characteristics of the territory and establish a policy based on the results. Some possible policies may be the enhancement of water reuse by means of economic incentives and/or restricting the exploitation of primary water sources.

Therefore, the public authority may play a fundamental role in water reuse enhancement or depletion, according to the water availability in different countries and territories.

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