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PLANNING OF INTEGRATED SYSTEMS FOR SUPPLY OF NATURAL WATER AND UNCONVENTIONAL RESOURCE IN AGRICULTURE: THE FEASIBILITY OF MUNICIPAL SECONDARY EFFLUENTS REUSE IN IRRIGATION DISTRICTS OF APULIA REGION

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ABSTRACT: Municipal wastewater reuse represents a topic of real interest due to the potential for environmental impact reduction and the availability of "unconventional" water resource. This paper examines some of the main aspects involved in the planning of the reuse of treated secondary effluents in irrigation supply systems which use a primarily "conventional" natural source (surface water and groundwater). To evaluate the feasibility of such an action, the main aspects to be investigated are both technical-operative and economical. In order to make evidence the critical issue and the real potential reuse finalized to supply irrigation district which are localized in semi-arid climate in Mediterranean areas, based on a large review of research described in scientific literature concerning treatment process, three case studies in Apulia region have been described and analyzed.
Keywords: municipal wastewater, secondary effluent, reuse, irrigation, planning, treatment, storage

1. INTRODUCTION

Municipal wastewater reclamation represents a real option in water resource management in agriculture, mainly in the country of Mediterranean area, even though it does not make a final contribution to the resolution of the satisfaction of increasing irrigation water demand. In large parte of Southern Italy it has not been widely used due to the availability of good quality water from conventional natural water sources collected in artificial reservoirs and extracted by groundwater. Irrigation by reuse of treated municipal secondary effluent can be applied by different treatment process and several systems properly distributing water on the agricultural land surface, surface sub-soil and cultivated plants [1, 5, 21]. The most part have been based on the „direct use" of daily effluent flow subject to a tertiary treatment, combined with balance tanks or operating seasonal storage in artificial reservoirs or stabilization ponds (Figure 1). In this scenario, the integration of municipal wastewater in the water irrigation supply systems, which use natural water as primary source, assumes an important role. From this perspective, the discharge in surface water bodies and on the surface layer of the soil, in the permitted cases by the law, the seasonal storage in reservoirs with natural water, and the groundwater recharge, constitute an indirect utilization of treated wastewater. In this case, the consequent degradation of the original water quality must be carefully verified.

The main objective is to maintain standards of safe of public health and to protect operators from infection and illness and to preserve the natural state of water, soil and crops. Considering that the water quality level for reuse is presently determined by normative, in Italy is regulated by D.M.

185/2003 [7], the planning and operation of the municipal wastewater reclamation plants should prevent the control of health and environmental risks [3, 6].

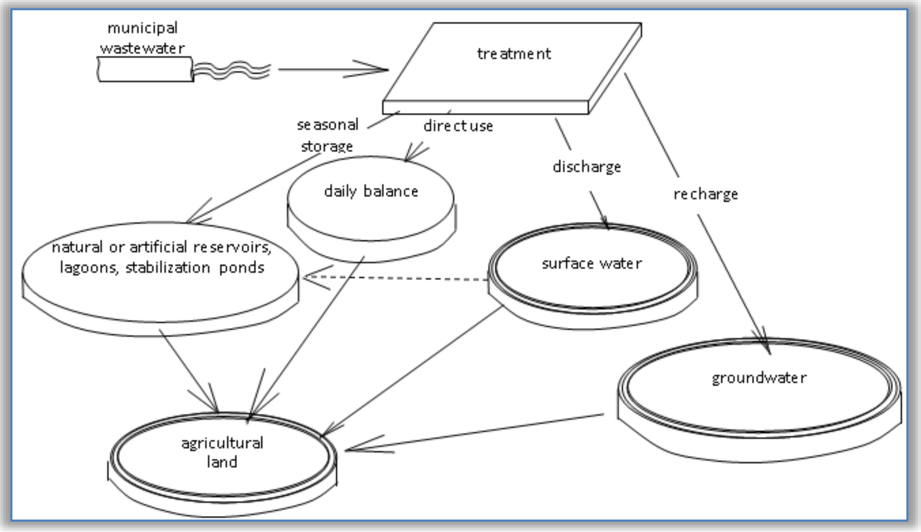


Figure 1. Patterns for municipal wastewater recovered for agricultural land.

The sanitary risks to health and to the community, can occur when watering is prolonged, is conducted with wastewater with not suitable quality and food crops are irrigated without implementing specific preventive actions. The main health risks are caused by infections caused by pathogens (viruses, bacteria, protozoa and nematodes), and by the accumulation of toxic and harmful substances in products (micro-organic and inorganic pollutants) that enter into the food chain. In order to reduce these risks, even irrigation techniques have to be applied adequately to different crops [10, 14]. The contamination of natural surface waters and groundwater, can be the consequence of spilling or the accumulation of chemical pollutants in soil (nitrates and heavy metals), the eutrophication, creating habitats favorable to the development of diseases.

In order to evaluate the feasibility of an irrigation system based on the reuse of municipal effluents, the cost of infrastructure for wastewater treatment, the daily balance, the eventually seasonal storage and the distribution must be estimated, specifically with the aim to evaluate available alternative sources. The treatment cost is a primary factor to be evaluated but we should consider also the aspects connected to make available the water resource in the agricultural area. Regarding this aspect, it is significant to verify the fraction of total irrigation water demand which can be covered by reused wastewater.

2. MATERIAL AND METHOD

2.1. Innovation in wastewater treatment for reuse in agriculture

The choice of treatment processes to be taken depends on the type of pollutants present in the wastewater under the technic and economic point of view. Currently the treatment layout is still widely operated in water treatment systems based on activated sludge in which conventional pollutants are removed (such as total suspended solids, BOD, COD, macro-nutrients, colloidal solids, bacteria, cysts, protozoa, viruses). In order to allow the irrigation reuse, the configurations of secondary effluent treatment involve the use of stages in series of tertiary treatments such as chemical precipitation, flocculation, sand filtration adsorption on active carbon microfiltration, reverse osmosis [8, 18]. The applications of advanced techniques introduce technical solutions that employ processes of membrane filtration [2, 11, 16] and advanced oxidation and disinfection [13, 15, 17].

Regarding to the definition of the optimal treatment, we must consider that, besides the pathogens and harmful compounds to the environment, treatment processes commonly applied tend to remove the organic substance and the macro-nutrients elements (nitrogen, phosphorus), useful to the practice of ferti-irrigation. In this respect, the irrigation using municipal wastewater can replace or partially reduce the practice of use the industrial fertilizers. The current legislation provides that in the case of recovery the wastewater for irrigation, the nutrients such as nitrogen and phosphorus, can find only a partial abatement instead of a strong removal to the levels requested for the direct discharge to surface water bodies, in order to prevent the eutrophication. This aspect allows a simplification of secondary treatments with the review process of nitro-denitro and chemical precipitation.

For the removal of non-conventional pollutants (VOC, metals, surfactants, total dissolved solids, refractory organic substances) further processes such as adsorption on activated carbon, ion exchange, desorption of gas, distillation, are used. The problems more recently highlighted are connected to the recognition in the wastewaters of emerging pollutants (drugs and antibiotics, sex hormones, steroids, drugs, detergents, endocrine disruptors). In this regard, only just over 60% of drugs residues present in urban effluents are removed in the activated sludge process, generating a growing level of alarm. Contaminants such as xenobiotic compounds (or ECDs) can cause diseases of the endocrine system. Several processes can be applied in order to treat these pollutants, although the yields of removal should be determined with specific investigations.

2.2. Integrated systems for agricultural reuse of municipal secondary effluent

In the Mediterranean EU Countries, the WWTPs have usually a medium-low capacity, up to 40,000-50,000 eq. inhab. The reuse of water resources in agriculture using the treated effluents is often limited by a scale effect which does not make it economically sustainable, in particular when the WWTPs are located far from each other.

The integration of the volumes of urban wastewater in irrigation systems can behave locally, considering a stage of refinement at the service of the individual treatment plants. On a wider regional scale, when in a local site the treated wastewater is not convenient, the return of the wastewater to the environment, through an appropriate work discharge to surface water bodies can be expected, and a suitable controlled catchment downstream system through a monitoring of water quality can be implemented.

In other way, when the WWTPs are not far each other and the altimetric elevations are suitable, the common reuse using a single site where convey all treated effluent may be convenient. The realization of such a system requires high costs of investment and operation for the hydraulic infrastructures related to the adduction of wastewater, in addition to the problems connected to the treatment for achieve the required levels of effluent quality. When, in order to provide greater volumes of useful resource to be allocated to the agricultural reuse, we operate a seasonal accumulation of wastewater in the irrigation period, we can have the problems related to the maintenance of a proper water quality in the infrastructures for storage, transport and distribution of water.

These systems become particularly feasible when the seasonal increase in potential due to the accumulation of the wastewater in the periods without irrigation can be obtained by arranging a storage capacity in the agricultural areas. In that case, during irrigation periods the practical solution provides that refined wastewater are directly used, while in the non-irrigation periods, the secondary effluents, also not refined, are stored in the reservoir. In this case we have to consider and compare the opportunity to treat the effluent in centralized WWTPs instead of to treat these waste in single municipal plants.

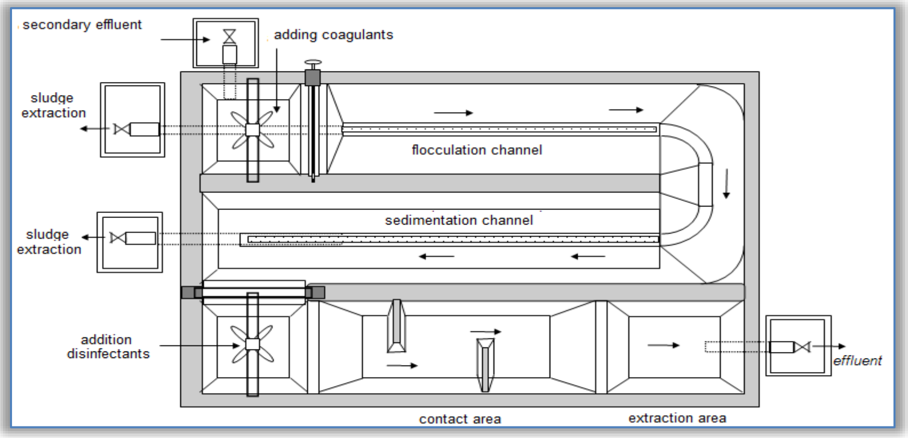
At local scale, in the case of small WWTPs with low capacity, not more than 20000 eq. inhab., for the irrigation of selected crops the use of installations which operate secondary effluent treatment and which can allow to combine the functions of offsetting daily flow of wastewater can be foreseen [4, 9, 12, 19, 20]. These plants consist of channels in series, in which are conducted chemical and physical processes of clear-flocculation and disinfection by chlorination, with the addition of hypochlorite or chlorine gas, or UV radiation (Figure 2a).

These channels are made up of a series of appropriately water proofed excavated or banked channels provided with proper electro-mechanical facilities. The channels have a volume useful to balance the daily wastewater flow.

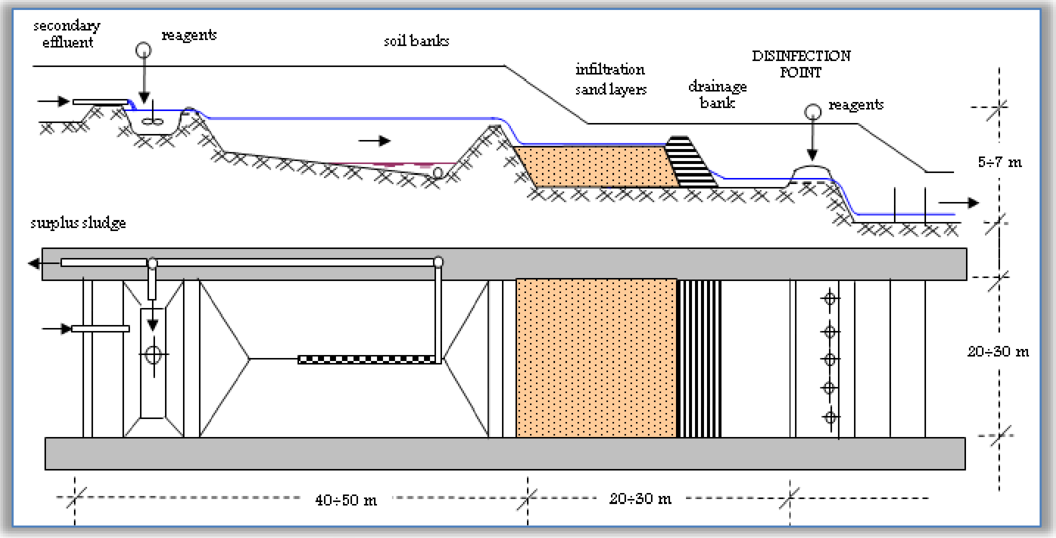
The secondary effluent arrives in a small tank where is a reagent mixing before coagulation; effluents pass in the first channel in which are carried out the flocculation and sedimentation; in the second channel the waters are clarified and the settled sludge are collected using perforated pipes laid on the bottom connected to a pneumatic pump; in the third channel there is the disinfection phase; in the case of chlorination the initial zone of the third channel operates as a tub of contact and in the terminal part the extraction of the effluent by means of a lifting plant is carried out. Effluent is supplied to the irrigation network.

The feasibility of these systems requires careful consideration. A convenient application of these effluents can be obtained in irrigation systems that operate the sub-irrigation and can find a proper application for irrigation of golf grounds. These plants constitute a control stage of the efficiency of treatment made by WWTPs and can be conveniently used as recovery plants [7]. Such a plant could be used also as post-treatment of secondary effluent at the discharge site where a proper land surface and soil morphology is available. The channels can be positioned in a cascade mode. Also, a sand infiltration basin of suitably dimension could be evaluated after a clariflocculation stage (Figure 2b).

The inclusion of phytoremediation units that perform processes of phytoremediation with superficial or subsurface flow, can be considered in order to give suitable characteristics to the discharge and to maintain an adequately good quality status of the water body to be used for irrigation.



(a)



(b)

Figure 2. Combined plant with channels in series for post-treatment of municipal secondary effluent: (a) plant for irrigation reuse; (b) plant for surface water discharge [5].

3. RESULTS: REUSE OF TREATED MUNICIPAL WASTEWATER IN IRRIGATION DISTRICT IN APULIA REGION

3.1. Reuse of treated municipal effluents in large irrigation district of Tavoliere delle Puglie

Tavoliere delle Puglie is a vast plain located in the province of Foggia, in the north of Apulia region (Southern Italy) with a population of around 500,000 inhabitants. It is one of the main agricultural zone of the country covering a surface of more than 400,000 hectares. Irrigated crops represents the principal sector of the local economy in terms of both agricultural production and employment. The satisfaction of the increasing water demand, will pose an important challenge for local planning authorities. *Tavoliere delle Puglie* constitutes a typical Mediterranean area and the water resource management should take in account scarcity of natural surface water and rainfall in spring and summer.

Main water source of potable and irrigation uses is represented by accumulation of natural water in the numerous articificial reservoirs: Occhito along the Fortore river, Capacciotti" and Osento in the watershed of the Ofanto River and along the Celone river. Locally, groundwater is diffusely used by farmers and for limitated industrial uses.

Many vegetal species and crops have been cultivated: arboriculture is applied with olive, grape and peache, and some herbaceae are very diffuse. The industrial transformation and commercial distribution of agricultural products involves intensive cultivation of spring-summer crops such as tomatoes, sugar cane, pepper and water melons, and vegetables such as cauliflowers, brussels sprouts, celery, fennel and lettuce produced in autumn-winter. Perennial crops include asparagus and artichokes.

At the present, in the area which is managed by the main operator, the Consorzio di Bonifica della Capitanata, an area of 140.000 hectares have been served by irrigation works, realized in two districts: the larger district, "Fortore", in the north with a 102,000 hectares irrigated surface; the water resource is mainly consituted by the Occhito reservoir; in the south, the district "*Sinistra Ofanto*", with 38,000 hectares irrigated surface, utilising water from the watershed of Ofanto River. A third district is under construction to operate, the district *Carapelle*. The distribution network develops for approximately 8,000 km and is a system under pressure constructed with adduction pipe in reinforced concrete and PVC pipes for water distribution.

The irrigation is operated usually from March to November. In the "Fortore" district, 75 % of demand is concentrated in June, July and August, in 75 days; while in the "Sinistra Ofanto" district, water demand is distributed substantially over the entire irrigation period. Yearly water demand is evalauted about 280 Mm^3. Water demand varies in relation to the different cultivation in use. An average amount demand can be estimated about 2,000 m^3 per irrigable hectare. The present annual water deficit with regard to the primary resource is estimated at 110 Mm^3.

3.2. Planning of an integrated supply system for combined use of natural waters and municipal wastewater

About 70 % population living in the Tavoliere delle Puglie is concenrated in 10 urban centres having more than 10,000 inhabitants. The municipal plants operating in the larger urban centres with a capacity higher than 30,000 a.e. (Foggia, San Severo, Cerignola, Manfredonia, Lucera and Margherita di Savoia) constitutes about 80 % of the annual volume available in the area of Tavoliere delle Puglie. As showed by Table 1, the evaluation of amount of municipal wastewater makes evident that they can represent a fraction of about 23% of total irrigation water demand.

Table 1. Municipal wastewater and water demand in the urban areas and irrigation districts of Tavoliere delle Puglie

Irrigation district	Watershed or receiver water body	Municipal plans and irrigation area	Population	Specific water demand	Wastewater volume	Irrigable surface	Irrigation water demand	Wastewater from water demand rate
			10^3*inhab.	m^3/inhab*day	Mm^3/year	10^3xha	Mm^3/year	%
"FORTORE"	Artificial channel "della Contessa"	Foggia	157.7	0.30	17.3	22.8	45.6	37.9
	Triolo	San Severo	54.9	0.25	5.0	27.0	54.0	9.2
		Torremaggiore	17.1	0.20	1.2	12.3	24.5	4.9
	Celone	Lucera	33.3	0.20	2.4	7.4	14.8	16.2
		Troia	8.4	0.20	0.6	3.0	6.0	10.0
	Gargano area	Manfredonia	53.1	0.25	4.8	2.6	5.3	90.5
		San Giovanni Rotondo	21.5	0.20	1.6	2.1	4.2	38.1
		San Marco in Lamis	16.3	0.20	1.2	1.6	3.3	36.4
		Apricena	14.1	0.20	1.0	6.5	13.0	7.7
"SINISTRA OFANTO", "CARAPELLE	Carapelle, Ofanto river	Cerignola	54.3	0.25	13.6	20.4	40.8	33.3
		Margherita di Savoia	21.6	0.20	1.6	1.4	2.8	57.1
		San Ferdinando	12.7	0.20	2.5	3.5	7.0	35.7
		Orta Nova	12.9	0.20	2.6	8.2	16.4	15.8
		Total	477.9	~~~	55.4	118.8	237.7	23.3

The municipal wastewater treatment plants operate a secondary treatment by activated sludge provided of a pre-denitrification stage (*Ludzach-Ettinger* process). Tertiary treatment for reuse of secondary effluents is provided by clariflocculation, filtration and disinfection by chlorine.

An optimal reuse of treated municipal should operate the accumulation of wastewater during non-irrigation period. One or more artificial reservoirs could provide the volume to store treated effluents from the main rurban centers, Foggia, and a pumping station should allow to transport waters to irrigation networks.

With this aim, stabilization ponds could be realized properly. The effluents from the plants working at several small urban centres find disposal discharged in the Candelaro river. The residual polluting load should be reduced preliminarly by disharge in stabilisation ponds which can provide a proper volume for accumulation of these waters.

3.3. Integrated purification systems for irrigation reuse of treated municipal effluents accumulated in a reservoir

A system using water treated by different wastewater treatment plants operating in the proximity of the province of Bari (Figure 3) was implemented with the aim at the irrigation. In the area Alta Murgia, close to the Sagliocca reservoir, with a storage capacity of about 1.8 million m^3: Altamura, 70,000 equivalent inhabitants, Gravina 45,000 eq.inhab. and Santeramo in Colle 25,000 eq. inhab.

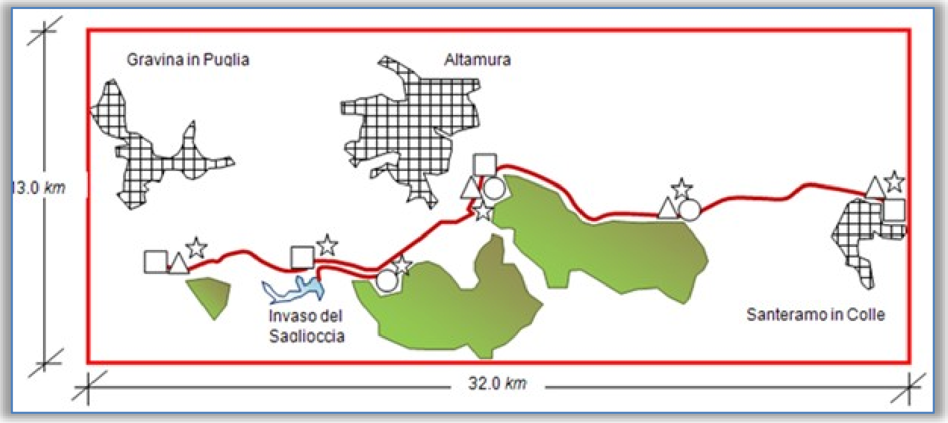


Figure 3. - Wastewater reuse in urban areas of Alta Murgia (Apulia region).
Legend: urban area; purification plants; artificial reservoir; lifting plants; supply pipelines; irrigation works; monitoring; irrigated area.

The system has a capacity of about 130,000 eq. inhab. for a given daily flow rate of about 20,000 m^3. The secondary effluents are treated in each of the individual WWTP with activated sludge scheme pre-denitrification and refining phase with flocculation, filtration and chlorination. Effluents refined are conveyed through supply pipelines and distributed to crops during the irrigation period and raised in the artificial reservoir in the non-irrigation period. The inclusion in the scheme of the Saglioccia reservoir and the subsequent use of the water accumulated allows to increase the irrigable area up to 2200 hectares. In this case, the waste are raised in the artificial mainly in the period not irrigated; the reservoir provides the volume of monthly compensation during the irrigation period. The main problems are associated with maintaining the quality of water retained in the spring and summer periods and the efficiency of the system of transportation and distribution of wastewater.

3.4. Reuse by post-treatment of secondary urban effluent in a combined process plant in channels

A system of reuse the secondary urban effluent was realized downstream of the purification plant of Fasano town (provincia di Bari) in *Contrada Forcatella*. The climate in this area is semi-arid: in the period from April to September the monthly average of temperature vary in the range 22-26°C, and total rainfall height is approximately 200 mm. A high tourist flux is observed in the urbanized area during the summer.

The extraction of groundwater, by wells realized by local farmer, satisfies the water demand for agriculture- use.

The project aims to reduce the use of groundwater subject to a diffuse phenomena of sea intrusion, intervening on an agricultuiral area with a surface of about 800 ha. Cultivated crops are arboricultural: olive, almond, pistachio and fig. The irrigation period starts in April and ends in September.

In order to estimate the water leakage a rate equal to 20 % was applied and the irrigation demand was calculated 1.9 Mm^3/year. The water demand was distributed during the irrigation season according to the following monthly rates: April 0.07, May 0.157, June 0.225, July 0.255, August 0.253, and September 0.04.

The water sources available to satisfy the irrigation water demand is constituted by the treated municipal wastewater produced by the residential population, which increases during the summer due to the tourist population, and groundwater supplied from wells. The capacity of municipal sewage plant is about 40000 a.e. The volume of wastewater secondary effluents available in the year was estimated about 2 Mm³/year, estimating a daily water flow per capita of 0.2 m³/day*inhabitant and a loss factor of 0.7). The flux of the tourist population during the summer increases the residential population to ~~of~~ 60, 70 e 75 % respectively in the month of June, July and August.

The groundwater is extracted by four 4 wells and supplied to irrigation network esclusively during periods of high water demand, according to a highest flow of 40 l/sec.

In order to satisfy the irrigation water demand in the period of highest water demand during the summer, the monthly water balance of the project makes evident the need to use both integrate municipal wastewater and groundwater (Figure 4).

The secondary municipal effluents are treated in a plant operating a combined physico-chemical process in a serie of channels (see parargaph 3 and figure 2a).

In order to analyse and verify the quality and the state of groundwater, a monitoring system was realized: sampling and analysis of the groundwater and measurements with multi-parameters probes are periodically carried out in 10 wells.

More recently was positively evaluated and tested the reuse of treated municipal effluents for irrigation of a golf course.

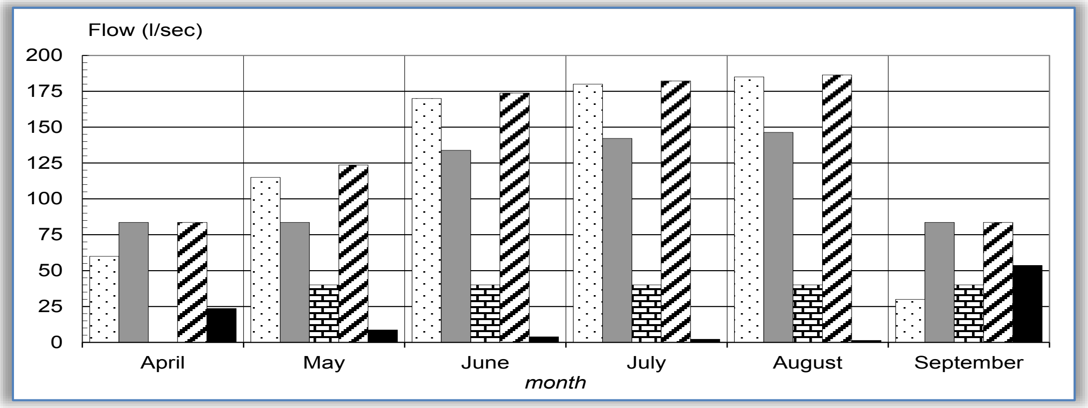


Figure 4.Monthly water balance of the integrated system of reuse of treated municipal wastewater at "Contrada Forcatelle".

Legend: water irrigation demand; wastewater produced by residential population; wastewater produced by tourist population; groundwater; residual wastewater.

4. CONCLUSIONS

In order to support the water demand in agricultural, the integration of secondary municipal effluent in supply systems which use natural water as primary source represents a real option in irrigation districts. The feasibility of this option requires yet a proper analysis to be planned. Although the treatment phase plays a fundamental role to make the water quality suitable for the use, as well as to prevent both health and environmental risk, the economic costs and energy consumption which are required to realize the infrastructure which provide seasonal storage, balance and distribution, and environmental monitoring, cannot be negligible.

The works of three irrigation districts in the Apulia region wich is expected to reuse ~~of~~ municipal effluents as integration of natural source (surface water and groundwater) have been described and examined.

The examined cases make evident that the yearly volume of treated municipal wastewater covers a fraction not higher than 25 % of total irrigation water demand and that seasonal storage can double the volume of unconventional water resource.

Even the secondary effluents can find a suitable treatment by the use of processes such as membrane filtration, in MBR schemes, or as tertiary stage, and disinfection by chlorination or UV, further research efforts are required to determine the optimal solution to plan and operate reuse systems sustainable by agricultural economy and making available the use of large volume of treated municipal effluents.

With this aim, the application of plants operating natural processes or using combined physical-chemical processes combined in integrated channels may constitute a potential solution, in particular, suitable to realize the balance of daily flow and the correct insertion in natural environment.

Seasonal storage of wastewater in reservoirs, which allows the increase of available non conventional water resource and the irrigated surface, requires however, in particular, the study of the problems related to maintain the good state of water quality of in reservoir and the works of supply and distribution.

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