

STORAGE OF RECLAIMED WATER

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Introduction

This study case describes the initiatives taken in Vitoria-Gasteiz, Spain by several Irrigation Districts and the Álava Regional Government to build the Azúa Valley Lake for storing reclaimed water produced during the winter season as to be able to use it for agricultural and landscape irrigation during the summer season. This text is an excerpt of the paper presented at the International Symposium on Dams in the Societies of the XXI Century, Barcelona, 18 June 2006 (Mujeriego and López, 2006).

Scope and Purpose

The city of Vitoria-Gasteiz is the capital of both the Álava Foral Territory and the Regional Government of the Basque Country in Spain. With a population of 220,000 inhabitants, it includes a very diverse industrial activity that contributes about 30% of its wastewater flows. The city of Vitoria-Gasteiz shares its water supply system with the city and the regional area of Bilbao, with a population close to 1 million inhabitants, through the conjunctive use of the water reservoirs of the Zadorra River, with a total useful capacity of 180 hm³.

The urban water supply requirements of Bilbao and Vitoria-Gasteiz have been exceeding the storage capacity of the existing reservoirs in a steady increasing manner during the last decades. This situation has prompted the need for the current water users to provide additional water resources, particularly by Vitoria-Gasteiz, the user with the largest deficit. An Integrated Water Reclamation and Reuse (IWRR) Plan for Vitoria-Gasteiz was prepared by the Álava Regional Government in 1992 (Diputación Foral

de Álava et al., 1995) as a coordinated response to the water demands of urban, industrial, and agricultural users in the Vitoria region. The main objectives of the plan were 1) to improve water supply reliability, 2) to decrease flooding risks, and 3) to ensure the environmental protection of tributary streams.

The main objective of this case study is to present the role of the Azúa Valley Lake as an essential component of the IWRR Plan of Vitoria-Gasteiz, with particular emphasis on: 1) the quality of the reclaimed water that will be stored in it, 2) the environmental and economic benefits that will be derived for the region, 3) the improvement in water supply reliability that will provide to the current water supply system, 4) the reduction of flooding risks associated with current management policies for surface water supply reservoirs, and 5) the definition of those water quality management strategies to be followed for maintaining the aesthetic and environmental status of the reclaimed water stored in the lake.

Water Resources and Water Uses

Table CS3-1 summarizes the storage capacity of the Zadorra river reservoirs and the water demands of the surrounding populated areas. Table CS3-1 clearly shows two basic and important facts: 1) the flows provided by the reservoirs are devoted exclusively to urban water supply and to preservation of the rivers' environmental conditions, and 2) the annual water demands corresponding to those two uses exceed the useful capacity of the reservoirs.

This inadequate water supply reliability, historically estimated at a minimum

deficit of 20 hm³ per year, has resulted in serious coordination difficulties over the last decades for the Inter-regional Watershed Agency (Confederación Hidrográfica del Ebro, CHE), the Regional Governments of Álava and Vizcaya, the City Councils affected, and the Irrigation Districts in the area.

Table CS3-1. Available water resources and water allocations from the Zadorra River reservoirs.

Reservoir capacity	
Urrunaga	67 hm ³
Ullibarri	139 hm ³
Total	206 hm ³
Authorized maximum volume	180 hm ³
Current allocations	
Water supply to Bilbao	145 hm ³
Water supply to Vitoria	25 hm ³
In-stream flows of the Zadorra y Santa Engracia Rivers	30 hm ³
Total	200 hm ³

Planned Water Reuse and Integrated Water Resources Management

The Irrigation Districts affected, in cooperation with the CHE and the Álava Regional Government, have been implementing since 1996 an Integrated Water Reclamation and Reuse Plan, with the following main objectives:

1. To use reclaimed water for irrigation of 10,000 ha of several food crops, including orchards and raw eaten vegetables. Irrigation started in 1996, and covered initially a surface area of 4,000 ha. The additional 6,000 ha began irrigation with surface water during the summer of 2005, waiting for the corresponding volumes of reclaimed water that would be stored in the Azúa Valley Lake, by the end of 2006.
2. To replace a fraction of the in-stream ecological flows currently provided from the surface water reservoirs by the corresponding flows of reclaimed water, with the quality level required for supporting fish life, namely salmonid and cyprinid waters (European Council, 1978). Those replacement flows would be introduced just below the water

supply dams, using the pumping stations and the pipelines of the existing irrigation network.

3. To use reclaimed water for landscape irrigation of parks and public gardens in the city of Vitoria-Gasteiz. Table CS3-2 shows that landscape irrigation in Vitoria-Gasteiz represents more than 10% of the city's surface water supply. When the currently proposed new landscape areas become active in the forthcoming years, that fraction will reach an estimated 15% value.

Water Reclamation

The water reclamation facility of Vitoria-Gasteiz began operating in 1995, and has a capacity of 35,000 m³/day, equivalent to 12 hm³/year. That water volume is sufficient to irrigate 10,000 ha of agricultural land during the summer season. The edaphic characteristics of the agricultural areas of the Vitoria region render summer irrigation a suitable practice under a schedule of once every three consecutive years. This practical requirement results in an agricultural surface area actually irrigated during a summer season close to 3,300 ha, just about one third of the 10,000 ha available to the Irrigation Districts.

Table CS3-2. Surface water consumption for urban water supply and landscape irrigation in the city of Vitoria-Gasteiz.

Year	Landscape area, ha	Urban supply, hm ³	Urban irrigation, hm ³ (% total use)
2003	460	24.6	3.1 (13)
2002	437	24.6	2.5 (10)
2001	402	25.2	2.8 (11)
2000	402	24.8	2.5 (10)
1999	400	24.5	2.4 (10)
1998	380	25.3	2.0 (7.9)

The water reclamation plant of Vitoria-Gasteiz was designed according to the quality criteria for reclaimed water included in the Title 22 of the California Water Code (Asano, 1998, Asano et al. 1991). Planned water reuse for agricultural irrigation was designed according to the guidelines and technical criteria included in the Guidance Manual

prepared by the California State Water Resources Control Board (Pettygrove and Asano, 1984; Mujeriego, 1990).

The optimal operation of the water reclamation plant was limited by the ability of the irrigation system to store the reclaimed water produced during the fall-winter-spring seasons. The flow capacity of the water reclamation plant allows irrigation of a maximum of 4,000 ha (1,300 ha effective) under continuous operation during the summer season. However, storing the reclaimed water produced during the rest of the year would provide enough water to irrigate up to 10,000 ha (3,300 ha effective). To achieve that objective, the IWRR Plan of Vitoria-Gasteiz included the construction of an off-stream reservoir, where reclaimed water could be stored during the fall-winter-spring season, and subsequently used for irrigation during the summer season. Table CS3-3 summarizes the water flow provisions included in the IWRR Plan of Vitoria-Gasteiz.

Table CS3-3. Integrated Water Reclamation and Reuse Plan for Vitoria-Gasteiz.

Capacity and Uses	Objectives
Reclamation capacity (2003)	12.00 hm ³ /year
Agricultural uses (2003)	2.40 hm ³ /year
Agricultural uses (2006)	7.00 hm ³ /year
Storage capacity	7.00 hm ³ /year
Existing irrigation network	350 km pipelines

Tables CS3-4 and CS3-5 show the water quality achieved by the water reclamation plant of Vitoria-Gasteiz since 1996, when it became operational. Reclaimed water satisfies the quality criteria specified by the Title 22 of the California Water Code (Asano et al. 1991), the health guidelines recommended by the World Health Organization (1998) and the water reuse criteria proposed by the US Environmental Protection Agency (2004).

Azúa Valley Lake

The Azúa Valley Lake is the final significant construction work included in the IWRR Plan of Vitoria-Gasteiz. Is it an

off-stream storage reservoir, shaped by two earth dams that form an artificial lake with a capacity of 7 hm³. The lake has been designed and built according to the environmental requirements applicable to a high value natural landscape environment. The lake is located 75 m over the water level of the nearby surface water reservoirs of the Zadorra River, and just about 2 km from them. This topographic situation offers a unique condition to contemplate the possibility for future water contributions from the Azúa Valley Lake to the Ullibarri reservoir, after applying the water purification processes that may be considered necessary at that time.

Table CS3-4. Physico-chemical quality of reclaimed water produced at the water reclamation plant of Vitoria-Gasteiz, from 1996 to 2006.

Turbidity	< 2 NTU	Boron	< 1.50 mg/l
Electrical conductivity	< 1,000 µS/cm	Cadmium	ND
Ammonia nitrogen	1.5-19 mg N/l	Chromium	< 0.02 mg/l
BOD ₅	< 5 mg/l	Copper	< 0.05 mg/l
NO ₃	2-15 mg/l	Mercury	ND
COD	< 20 mg/l	Nickel	< 0.40 mg/l
Oxygen demand	< 7 mg/l	Lead	ND
		Selenium	ND
		Zinc	< 0.40 mg/l

ND : non detectable, lower than 0.01 mg/l

Table CS3-5. Organic and microbiological quality of reclaimed water produced at the water reclamation plant of Vitoria-Gasteiz, from 1996 to 2006.

Bromodichloromethane	< 5 µg/cm
Bromoform	1 µg/l
Chloroform	< 30 µg/l
Dibromochloromethane	< 1.0 µg/l
Chlorophenols	Non detectable
Total coliforms	Absence/ 100 ml
Helminth eggs	Absence/500 ml
<i>Giardia lamblia</i>	Absence/500 ml
<i>Cryptosporidium</i>	Absence/500 ml
<i>Legionella</i>	Absence/litre
<i>Salmonella</i>	Absence/ 100 ml

The Azúa Valley Lake is an essential component of the IWRR Plan of Vitoria-Gasteiz, for the following reasons:

1. It provides the reclaimed water volumes required for in-stream flow substitution in the Zadorra River, in case of a prolonged failure of the

biological treatment processes of the municipal wastewater treatment plant of Vitoria-Gasteiz, or the physico-chemical processes of the water reclamation facility of Vitoria-Gasteiz.

2. It ensures the water flows necessary for agricultural and landscape irrigation of the regional and the urban areas of Vitoria-Gasteiz during the summer season.
3. It provides a mechanism for nutrients removal from the reclaimed water stored in the lake. This will be achieved by alternating anoxic and aerobic conditions in the water column, and the addition of atmospheric oxygen through a deep aeration system. Compressed air will be generated by photovoltaic energy panels located in the inside slopes of the earth dams.

The reclaimed water storage reservoir was considered a basic element of the IWRR Plan of Vitoria-Gasteiz, after evaluating similar water resources management initiatives adopted in Southern California (Mujeriego, 2004, 2005). The Azúa Valley Lake promotes a more sustainable use of the hydroelectric energy generated with the surface water stored in the Zadorra river reservoirs, and results in an overall lower emission of carbon dioxide due to lower energy consumption (Sala & Serra, 2004, Mujeriego, 2005).

The water reclamation plant of Vitoria-Gasteiz has a design capacity able to satisfy the water required for agricultural and landscape irrigation, and to contribute a flow of up to 0.4 m³/s for substitution of the in-stream (ecological) flows discharged from surface water reservoirs. That flow contribution represents just 40% of the 1 m³/s in-stream flow currently established by regulatory requirements.

The indirect benefits of this flow substitution are: 1) the availability of the corresponding 0.4 m³/s of surface water, which can be diverted from the reservoirs and used for urban water supply in the Bilbao region, and 2) the

production of an additional amount of hydroelectric energy, generated by that same flow when descending the 300 m altitude difference existing between the surface water reservoirs and the hydroelectric power station in the Bilbao region. The hydroelectric energy generated by those flows will be close to 2 million kWh annually.

Reclaimed water discharged into the Azúa Valley Lake will be of excellent physico-chemical and microbiological quality (see Tables CS3-4, and CS3-5). However, it contains significant concentrations of nutrients (ammonia nitrogen, nitrates and phosphorous). Those nutrient concentrations need to be controlled, as to prevent development of anoxic conditions during ammonia nitrogen oxidation, and thus to ensure suitable biological and aesthetic conditions in the lake. An ammonia nitrogen limit of 0.5 mg N/l (equivalent to 2.3 mg/l of dissolved oxygen) has been adopted to ensure that the biological quality of the water in the reservoir and its potential to maintain aerobic conditions remain acceptable at all times in the lake. To achieve that objective, the Azúa Valley Lake design project incorporates a deep aeration system, using compressed air diffusers located 1 m above the bottom of the lake, with a capacity to maintain a dissolved oxygen concentration higher than 3 mg/l.

The considerable amount of compressed air that will be required to satisfy the oxygen demand of lake water makes necessary to consider an inexpensive energy source, with a low carbon dioxide emission rate. A large surface area of photovoltaic plates will be installed on the inside slopes of the earth dams, preventing any undesirable aesthetic impact from the outside. The top line of the earth dams has a length of 900 m, which allows for a total surface area of photovoltaic plates of 1,800 m², with a power capacity of up to 150 kW. The direct current produced by the plates will be stored and subsequently converted to alternate current, which will be used for running the air compressors.

Economic Indicators

The total investment required for an annual production of 12.5 hm³ of reclaimed water was 3.25 M€, which represents a specific investment of 0.26 €/m³ of annual capacity, in 1995. The unit cost of reclaimed water at the plant site, including investment costs and operation and maintenance costs, was 0.065 €/m³ in 2006.

The total investment required to convey, store and distribute 12.5 hm³ of reclaimed water for irrigation of 10,000 ha of agricultural land was 28 M€, which represents a specific investment of 2.25 €/m³ of reclaimed water available. In particular, the investment required to build the off-stream Azúa Valley Lake, with 7 hm³ storage capacity, was 11,8 M€, which represents a specific investment of 1.70 €/m³ of storage capacity.

Based on that information, the following economic indicators can be estimated for the Vitoria-Gasteiz water reclamation and reuse project for agricultural irrigation:

1. Reclamation:
Reclaimed water index: 0.065 euros/m³ produced (2006).

Reclamation investment index: 0.26 €/m³ annual capacity.
2. Reuse
Reuse investment index: 2.25 €/m³ annually available.

Storage investment index: 1.70 €/m³ storage capacity.
3. Reclamation and reuse
Reclamation and reuse investment index: 2.51 €/m³ annually available.

Summary

The Azúa Valley Lake is the most emblematic element of the ambitious Integrated Water Reclamation and Reuse Plan of Vitoria-Gasteiz that began in 1992. Construction of the Azúa Valley Lake was completed in June 2004, and

full operation is expected by late 2006, once the required safety and operation protocols are completed and approved. The lake has been designed to store the winter-spring excess of reclaimed water produced at the Vitoria-Gasteiz water reclamation plant, so it can be used for agricultural and landscape irrigation during the summer, and also for in-stream ecological flow substitution. The Azúa Valley Lake is a unique infrastructure in Spain, but similar to others built in Southern California and Israel to store reclaimed water for multiple uses.

Operation of the Azúa Valley Lake will serve the following main objectives:

1. To provide the reclaimed water flows necessary for substitution of the in-stream (ecological) flows of the Zadorra River, especially during the summer season.
2. To provide the reclaimed water flows necessary for agricultural and landscape irrigation in both the Vitoria region and the city of Vitoria-Gasteiz during the summer months.
3. To promote nutrient removal from stored reclaimed water, mainly in the form of ammonia nitrogen and nitrates.
4. To provide a future option for complete recycling of a fraction of the reclaimed water produced by the city of Vitoria-Gasteiz.

Furthermore, operation of the Azúa Valley Lake will satisfy the following secondary objectives:

1. To gradually restore the water allocations of the Bilbao region, which have been increasingly used for drinking water supply in the Vitoria Region.
2. To allow for a more sensible management protocols for the water levels in the surface water reservoirs, as to ensure a higher protection level with respect to flooding episodes in the Vitoria region.
3. To produce an additional 2 million kWh annually of hydroelectric energy.

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Edited by

Rafael Mujeriego, PhD
Prof. of Environmental Engineering
Universidad Polit cnica de Catalu a

ETS de Ingenieros de Caminos
Jordi Girona, 1-3, Building D1
08034 Barcelona, Spain

rafael.mujeriego@upc.edu