WATER SUPPLIES BUILD THE CITIES: THE CANAL DE ISABEL II AS ORIGIN OF THE METROPOLIS OF MADRID

Ana Rubio-Gavilán
PhD student, Assistant Professor
ana.rubiog@upm.es

Patricia Hernández-Lamas
PhD student, Assistant Professor
patricia.hlamas@upm.es

Jorge Bernabeu-Larena
Associate Professor
jorge.bernabeu@upm.es

School of Civil Engineering, Technical University of Madrid (UPM)
Profesor Aranguren, s/n. Ciudad Universitaria, 28040 Madrid.

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Abstract

Water supply systems in big cities are fundamental parts of their metabolism. They respond to a *scenario of increasing demands, and they actually act as a catalyst for their growth*. This last reason is essential to explain the development of some big cities. A model example of this is the city of Madrid and its water supply, built up and managed by the public enterprise *Canal de Isabel II*. Since its origins in the 19th century, the *Canal* laid down the foundations that allowed Madrid to develop and shape itself as a metropolis.

Public works, dams, channels and reservoirs, constitute the technical solution to water supply as well as they *extend the influence of the urban area to wider territory*, connecting urban and rural. The paper studies the origins of the *Canal* and its principal works which enabled the metropolitan growth of Madrid until today, and analyzes the influence of this works in the development of the city, in the processes of exchange and water management.

Public works are not just useful infrastructures in contemporary polis, they have strong influence in social cohesion and urban processes.

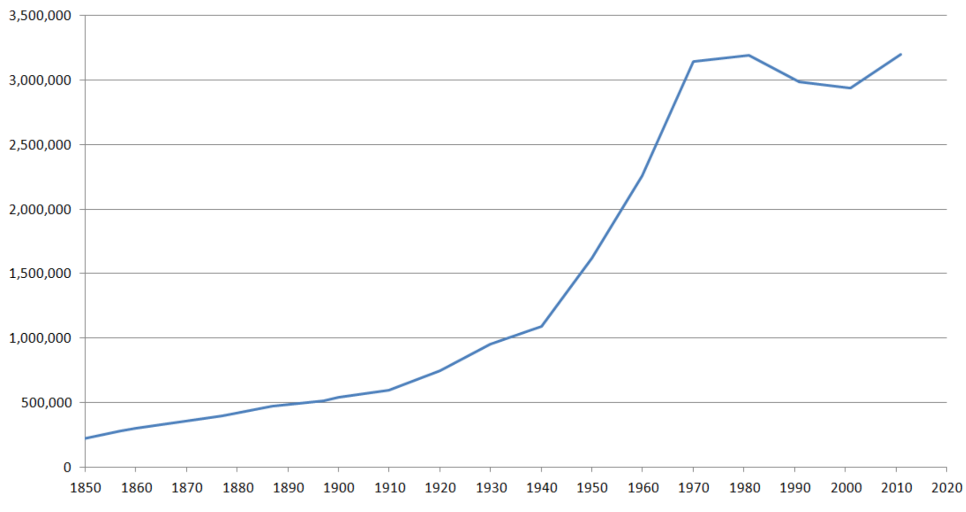
Introduction

Cities in the 21st Century grow spatially, forming large areas and absorbing new territories. Water supply systems in big cities are fundamental parts of their metabolism. For their water supply, they take water from the ground or from rivers many kilometers away from the city. They establish nets that distribute water from the catchment areas to the city to allow the different urban uses. Public works extend the influence of the urban area to a wider territory, connecting urban and rural.

During the 19th Century, most of big European and Northamerican cities had to rethink their water supply systems because they were not adequate in terms of quality and quantity. Cities grew because of rural migration and industrialization and the consequences were the growth of water demand and the decline of quality. Madrid was no exception. New sources were to be sought justified by the demographic growth, the citizen's hygienic habits change and the risk of pollution of the traditional medieval water supply system, known as "viajes del agua" (Arroyo Illera, 2004). From the 18th Century new projects to solve the water supply problem by bringing water from the mountains of Madrid arise. But none of these projects succeeded. The proposal of the engineer Manuel Cortijo to bring water from the Lozoya River in 1846 may be considered the direct precedent of the first modern water supply system in Madrid. The Interior Minister approved this project to bring water from the mountains using the traditional system of "viajes del agua"[1] but including the innovation of lifting water with hydraulic pumps, and created the "S.A. corporation for the expansion of water supply in Madrid"[2] (Gavira, 2001, p. 209). Finally, water is caught from this river basin through the Canal de Isabel II but using gravity to transport water. In the 1960s, due to the city's demographic growth (Figure 1), the catchment area expands to Jarama, Guadalix, Manzanares and Alberche river basins, extending the influence of Madrid to the whole region.

The paper highlights the key role of water supply in the construction of the city. The case of Madrid is significant to show in parallel urban growth and public works development, and the water management systems that build them up.

Figure 1. Madrid's population: year - inhabitants



Source: Elaborated by the authors based on INE data.

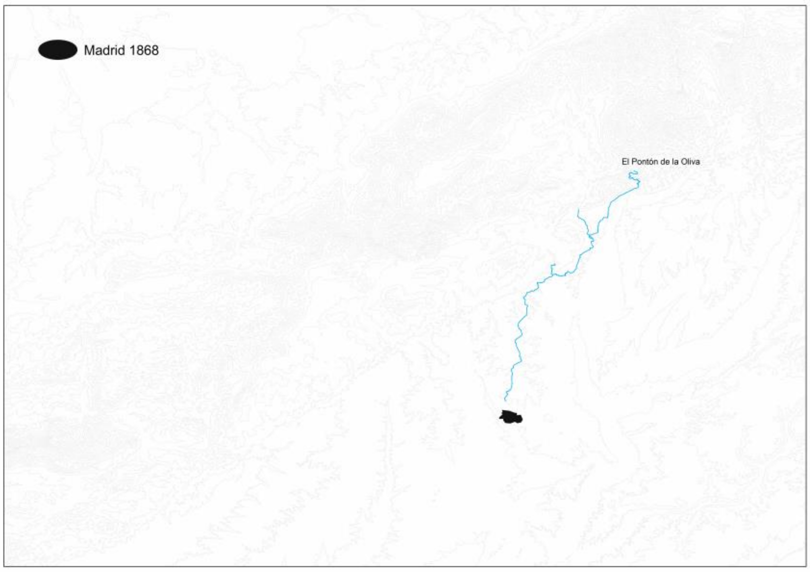
[1] Qanat: gently sloping underground channel with a vertical access shafts, used to transport water.
[2] "*Sociedad Anónima para el aumento de aguas a Madrid*"

Water Supply Public Works

Water Supply acts as a catalyst for the growth of urban settlements. To explain the case of Madrid three representative moments of the construction of water supply public works are depicted and analyzed. With these three pictures, the evolution process of the city and the extension of the influence of the urban area to wider territory are drawn. Channels and reservoirs appear in urban areas as significant elements of the urban pattern that become part of the city. Each temporal scenario is illustrated by a cartography that presents water supply nets and the land use of urban area in a territorial way, as well as a sequence of photographs of public works built up in that period.

1868: the first channel

Figure 2. Water supply net and urban area, Madrid, 1868.



Source: Elaborated by the authors

The first channel brought water from the Lozoya river basin, traveling more than seventy kilometers from the Navarejos diversion Dam to the diversion in Madrid through tunnels, siphons and bridges. The first dam constructed was the Pontón de la Oliva but it had numerous problems of infiltrations because of the limestone bed. This problem forced to catch water from the Guadalix River while the Navarejos diversion Dam was being built up upstream of the first dam. In 1868, water arrived to the city through the old channel and filled the first underground reservoir of Campo de Guardias (Figure 3), that had already begun to have infiltration problems (Martínez Vázquez de Parga, 2001, p. 171). From this first reservoir two pipes took water to the distribution network starting point, from where water was transported through the two principal waterlines, Fuencarral and San Bernardo (González de Agustina e Iribarren, 1954, p. 31). The first distribution net, designed by engineer José Morer (Morer, 1885, pp. 11–12), was still in construction at this time.

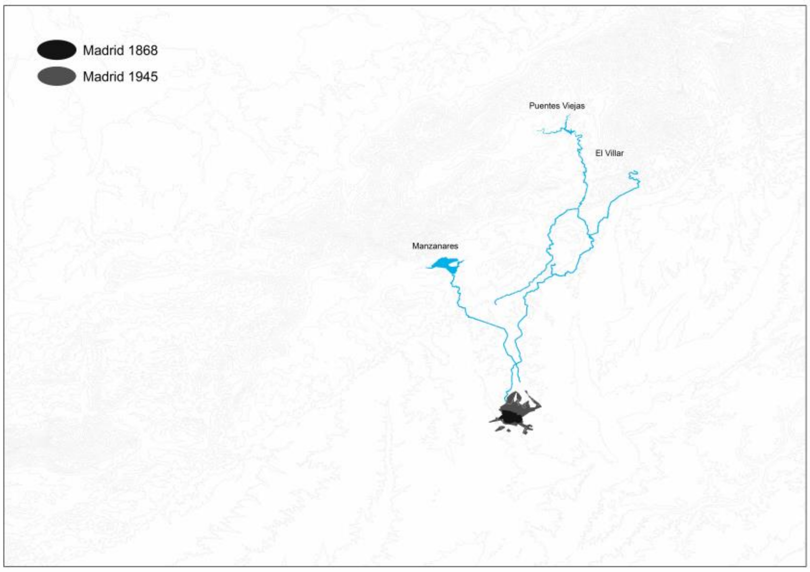
Since the ecclesiastical confiscations of Mendizábal, the city had been growing inside its walls by means of constructing new residential buildings in open spaces left by convents, and new floors on existing houses up to four (Gavarrón Casado, 1978, p. 30). The population had grown from 206.714 inhabitants in 1845 to 289.043 in 1860, exceeding 300.000 in 1868 (González de Agustina e Iribarren, 1954, p. 52). But the city couldn't depend only on the first channel (Figure 3), the population continued to use fountains, waterwheels, wells and hand pumps (Gómez, 1868). The Canal was criticized by the City Council and citizens, for the difficulties of supplying water to some neighborhoods and bringing up water to taller houses, as well as for the issue of water quantity and quality. The major problem was water turbidity caused by deforestation with different origins in territories nearby the Lozoya River basin (Gutiérrez Andrés & López-Camacho y Camacho, 2004, p. 41).

Figure 3. Canal Bajo: Amaniel Bridge (1858), El Espartal Bridge (1858), First reservoir of Campo de Guardias (1858).

Source: Photographs by Charles Clifford, 1858

1945: regulation and multiple-supply

Figure 4. Water supply net and urban area, Madrid, 1945



Source: Elaborated by the authors

The city was supplied by the old channel, the new Lozoya channel called the Canal Alto, and the Canal Manzanares. To solve issues of water quantity and quality, three regulation dams and two diverting dams were built up by the institution. The first one, the El Villar Dam, was constructed upstream Navarejos, and was designed to catch water from snowmelt of the Lozoya mountains. But when it started operating, problems of turbidity of city water during river overflows were even worse. The third storage reservoir in Madrid pretended to solve this matter but for different reasons it wouldn't be finished until 1915. The turbidity of water continued and Navarejos Dam was soon sediment-filled and therefore a new diverting dam, La Parra, was constructed. Meanwhile another hydropower company, Hidráulica de Santillana, was given a royal grant to supply water to the north neighborhoods of Madrid that began when Grajal Dam was finished in 1908 (Villanueva Larraya, 1995, p. 41). This context of competition, the hydropower arrival to the region, the need to lift water in the core of the city, and the poor conditions of the Canal Bajo, pushed forward the construction of the Canal de El Villar that connected the reservoir and the Canal Bajo (Aguinaga Arrechea, 1911, p. 64). The first hydropower central of the Canal was located in this channel between two intermediate reservoirs and the energy generated pretended to be used to lift up water to the First Water Tower in the city (Figure 5). This First Water Tower improved the distribution in the city that had underpressure problems caused by the lack of planning and coordination between the City Council and the Canal and the fact that numerous individuals connected themselves spontaneously to the network.

Years later the Puentes Viejas Dam was built to ensure the storage capacity of the system and in parallel El Tenebroso system was materialized to attend to turbidity problems. El Tenebroso consisted on two lateral channels that intercepted the runoff that went to El Villar Dam to discharge it downstream of the dam. Through another channel, the "Canal de aguas claras", water flowed from Puentes Viejas to El Villar to feed this last one with clean water from the first one. When cloudy water from Puentes Viejas couldn't be retained for decanting, it was discharged to the river downstream of El Vijjar through a channel that started at El Tenebroso diverting Dam (García Augustín, 1945, p. 25). At the same time, the Canal Bajo reached its maximum capacity and the construction of the Canal Alto began. The new channel carried water from Torrelaguna down to the fourth reservoir, Plaza Castilla Reservoir (Figure 4). This reservoir, together with the Second Water Tower beside it, allowed the supply of the north expansion of the city, the highest area.

At that moment, the quality issue in the head is solved and the capacity of waterworks is increased. The capacity expansion is almost to be achieved as well in the distribution system. In 1945 this network is working with the first leg of the Canal del Este, that followed the water divide of the Jarama and Manzanares rivers arriving to both the 5th and 6th reservoirs of Hortaleza and Puente de Vallecas under construction. The principal network, a grid with multiple-feed, had almost all galleries already done. As well, to give the final integrity to the network and be able to feed the urban network with the Canal Alto, the fourth reservoir was joined with the second and third reservoirs and the principal elevated network, by another gallery (García Augustín, 1945, p. 25).

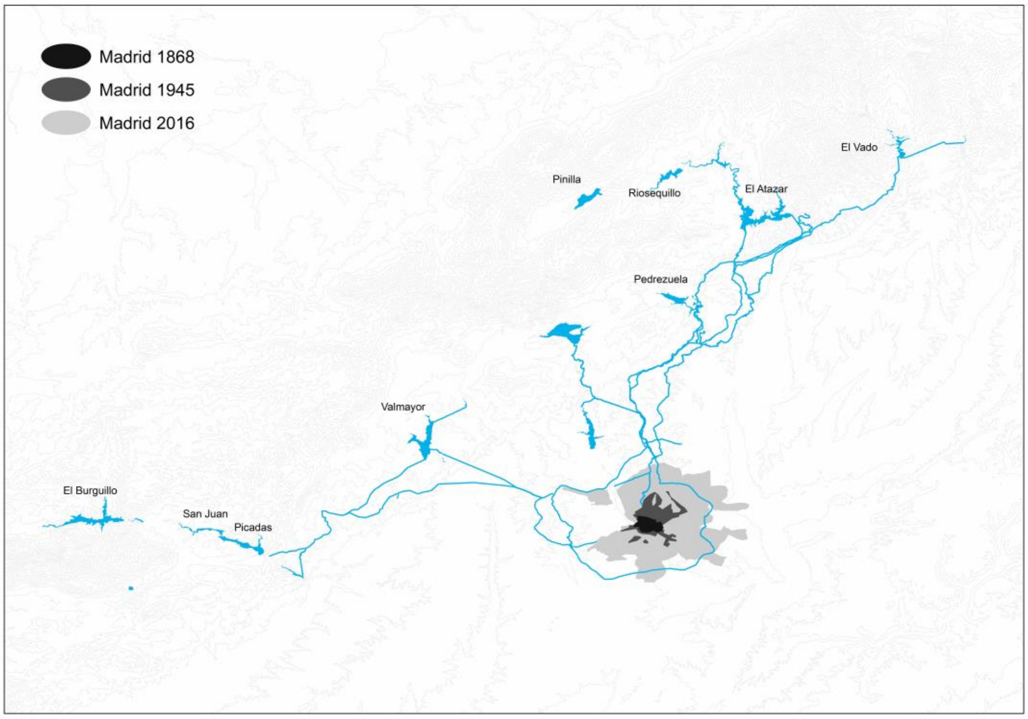
The important problem in 1945 comes to be the storage capacity of the catchment area, insufficient for the growing population (García Augustín, 1945, p. 25). Rural exodus, the change of hygienic habits, and a severe draught in 1944, leaded the Canal to a critic situation. From 1900 to 1945, Madrid's population triples, and arrives to one and a half million inhabitants. The city is extended lengthwise its radial roads. The developments of Ciudad Universitaria, Nuevos Ministerios, and the residential colonies of Ciudad Jardín are finished (Comisión de Planeamiento y Coordinación del Área Metropolitana de Madrid, 1979, p. 1). Water supply had complications in furnishing the south area of the city from the second and third reservoir due to Villaverde and Legazpi industrial expansions. The Canal had also to give supply to the independent municipalities of Getafe and Leganés, because of an imposition of a Ministerial Decree of 1946 (García Augustín, 1970, p. 197). The same happened with Campamento and Cuatrovientos further aggravating the situation. Carabanchel Alto and Puente de Vallecas also depended on the Lozoya and were willing to have finished the works on the Canal del Este (Terán, 2006, p. 282). Furthermore, tall buildings constructed in the north extension of the city didn't have water supply in the highest floors.

Figure 5. First Water Tower (1912), third reservoir (1915), *Plaza Castilla* Water Tower (1935)

Source: Fundación Miguel Aguiló, P. Candela 2005 , the authors

2016: water supply for the metropolis

Figure 6. Water supply net and urban area, Madrid, 2016



Source: Elaborated by the authors

Madrid's water supply works are completed to provide water to the circa 3.2 millions inhabitants of the city (INE, 2011) and other municipalities of the region. The water conveyance goes further away from the Lozoya River basin, with the Canal del Jarama and the complex driving system of the Alberche River (Figure 6). The system is the result of different actions carried out during the sixties and seventies, after a difficult period of the Canal. The Canal had problems of turbidity, deficiencies in the discharge during overflows, and lack of pressure and of water lines capacity. But the principal issue was that there was not enough storage capacity to ensure the supply of a city in continuous growth (Martínez Vázquez de Parga, 2001, p. 268).

A number of severe draughts (1945, 1948 and 1949, and again in 1965) and typhoid fevers occur after 1945. In 1947 Canal de Isabel II elaborated a plan to improve supply in twenty five years. The plan projected the construction of Riosequillo Dam, Matallana and Los Ramos dams, two new channels from Jarama and Sorbes, as well as an increase and improvement of the distribution network. After the draught of 1949, as an interim measure, another catchment at El Roncadero is done, to elevate water from the Jarama River to the Canal Bajo. Then the construction of both channels begins: the Canal del Jarama starting from the El Vado Dam, and the Canal del Sorbe, that takes water from the Pozo de los Ramos Dam to the beginning of Canal del Jarama.

The sixties are crucial in the demographical growth of the city, and therefore problems to provide basic needs accentuate, especially in the case of water supply. From 1950 to 1960 the population increased from less than one million and a half to two million three hundred thousand. Moreover, in 1963, the Commission of Planning and Coordination of the Metropolitan Area of Madrid, incorporated fifteen new municipalities and extended the area of water supply of the Canal. New catchments in other river basins were investigated and a new Works Plan in 1961 was developed. The forecast for the growth and the demand made in 1947 was definitely insufficient (García Augustín, 1970, p. 197).

The greatest relief to the tensions of the system's demand occurred when the Atazar Dam entered into service in 1972. It balanced the supply warrant and achieved the complete regulation of Lozoya river basin (Aguiló, 2002, p. 88). The new Canal del Atazar that arrived to Plaza Castilla's Dam was projected at the same time, augmenting the waterline capacity. The Canal also incorporated to its system the Santillana Dam in Manzanares River that was property of Hidráulica Santillana until 1963 when the Canal purchased 93 % of its shares. A channel of circa four kilometers was done from the Marmota to the Canal Alto, to transfer water from this river basin. Both Canal del Este, with the seventh and eight reservoirs, and the Canal del Oeste, were finished to furnish the urban fringe, specially the south.

While the construction of Atazar Dam and channel (Figure 7) was taking part, different short-term solutions were carried out in the different river basins of the region. Pedrezuela Dam in Guadalix and Pinilla Dam in Lozoya River with their respective channels were finished in the late sixties. The impulsion system was done in 500 days and took water from the Alberche River, at the Picadas Dam, and transported it to the Canal facilities at the El Plantío Dam. At Jarama River, the impulsion of El Roncadero was substituted with a catchment of ground water by means of two Ranney wells. Years later, in 1975, also the Guadarrama River was regulated with the diversion dam, azud de las Nieves, and water was transferred through a tunnel to Valmayor Dam.

Until 1992, when another severe drought happens, no other catchment works were done. At this moment the Canal rethinks its supply and the use of water: In first term it puts in operation its ten well fields to get water from the underground. Some of these well fields discharged directly to the general network of the Canal and others supplied water to the different municipal reservoirs (López-Camacho Camacho, 1995, p. 34). After this year total water demand in the region declined sharply for reasons that are not clearly identified: environmental education campaigns, increased efficiency in industries or the permanent effect of drought among society (March & Saurí, 2010, p. 11)

The principal problems in the distribution network were to ensure pressure and to enable the expansion of the system, and they were solved with a perimeter ring outside the city with radial waterlines that followed the principal roads finished in the 80s. The stability of the system has enabled the supply of the new low-density peripheral neighborhoods developed during the last twenty years. Madrid has increased its developed residential area with the PAUs – Urbanistic Intervention Programs – that were planned and constructed between 1995 and 2010 and extends the influence of the Canal to an area of 20 square kilometers and circa 70 thousand households (López de Lucio, 2013, p. 106).

Figure 7. Riosequillo Dam (1958), Valmayor Dam (1975), El Atazar Dam (1972)

Source: Fundación Miguel Aguiló

Water Management for Water Supply: CYII

Water management policies are indissolubly associated to the construction of water supply public works. They are at the base of their promotion, construction, regulation and exploitation. The management model determines the growth of the city and the sociocultural signification of water. This section identifies the turning points in water management that have influenced the urban development.

At the beginning the Canal de Isabel II (CYII) was organized as a public company addressed by an Administrative Board constituted by the state, the City Council and a small group of stakeholders. But soon in 1868 it became a public entity dependant on the Ministry of Public Works and Transport. It is not until hydropower arrived in the region and the private company Hidráulica Santillana was constituted, that this management scheme changed. Hidraulica Santillana put in service the Colmenar hydropower central in 1902, and achieved a royal concession to supply water the northern neighborhoods of the city, supported by the City Council, in 1906 (Sánchez de Toca, 1925, p. 20). These two events created a situation of threat because of competitiveness that forced the administrative reorganization of the company in 1907. The CYII became an autonomous body under an industrial society model, still dependant on the Ministry of Public Works (Gavira, 2001, p. 214). It was from that moment on that the CYII posed the modernization of its infrastructures and its organization (Canal de Isabel II, 1907, p. 483). In 1976 it became a public ownership enterprise with its own legal personality, own patrimony and autonomous administration and dependant on the Ministry of Public Works and Transport, until 1984, when it started to depend on the regional government, Comunidad Autónoma de Madrid.

But the crucial turning point started in 2002 when its objectives and the composition of its management board were modified by Decree. From this moment on, the CYII has the authority to provide services out of the Comunidad Autónoma de Madrid territory and is allowed to carry out any kind of commercial or industrial activity directly linked with its functions, including taking a minority or majority shareholding in companies with the permission of the regional government (Ortega de Miguel & Sanz Mulas, 2007, p. 144). This way the CYII, and the city, become part of the virtual networks system that organizes the new international-scale economic processes. This new conception of CYII as a multinational company widens its territorial influence making it difficult to draw.

An Act of the regional government in 2008 goes one step further in this idea of liberalization and extension of the influence of the CYII. This Act permitted the creation of a public limited company whose object is the provision of services related to water, and allows the privatization of 49 % of its shares. In June 2012 the new society “Canal de Isabel II Gestión, S.A.” was constituted, separated from the original CYII that remains as regulation entity. Canal de Isabel II Gestión, S.A assumed the operations of water supply, sanitation and hydraulic works for the following 50 years. Even though nowadays more than the 80 % of the shares are held by CYII and the rest by the municipalities (Marcos, 2015), there is still tension between the citizenship and the regional government. Hydraulic technique has replaced water culture in Madrid, as it happened in the 19th siècle when the Canal de Isabel II was constituted (Gavira, 2001, p. 208). Under political, technical and hygienic arguments water has been transformed into a commodity.
However, in global city water does not arrive only through the water supply network. The consumption of water hidden behind products, freights and goods – virtual water – extends the water footprint to a global geographical scenario where local water management agents are insufficient. Madrid is gradually consuming more virtual water type and less regional resources. The annual per capita use of water from the region has decreased from 261 m^3 to 191 m^3, and virtual water consumption has increased from 1.169 m^3 in 1984 to 1.667 m^3 in 2005. (Naredo Pérez, Carpintero Redondo, Frías San Román, Saa Requejo, & Gascó Montes, 2009). Water supply in contemporary cities is water supply of global economy.

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