Water Policy 17 (2015) 332–348

Groundwater management: a search for better policy combinations

Takahiro Endo

College of Sustainable System Sciences, Osaka Prefecture University, A4 Building, 1-1 Gakuen-cho, Naka-ku, Sakai city, Osaka 599-8531, Japan. E-mail: tte23042@osakafu-u.ac.jp

Abstract

Excessive groundwater pumping is now a global concern. There is no panacea for this problem, which needs to be addressed through continual policy improvements based on case studies. Good examples of the diversity of groundwater management are demonstrated by the Tokyo (Japan) and Orange County Water District (OCWD, California, USA) experiences. In Tokyo, excessive groundwater pumping was addressed through technological restrictions, including restrictions on the diameter and depth of wells, and construction of industrial waterworks. On the other hand, in Orange County, OCWD introduced a pump tax to purchase external water for artificial groundwater recharge. These two strategies are in striking contrast, from two perspectives. First, while OCWD's main policy tools were tax and artificial recharge, Tokyo depended on technological restrictions and construction of waterworks. Second, OCWD uses a combination of surface water and groundwater, but water supply in Tokyo has shifted almost completely from groundwater to surface water. What are the strong and weak points of each strategy? What causes such diversity? In this paper, a comparative case study was conducted to clarify (1) the institutional contexts causing the diversity of groundwater management and (2) the advantages and disadvantages of each policy combination.

Keywords: Artificial recharge; Excessive groundwater pumping; Groundwater management; Land subsidence; Property rights; Pump tax; Seawater intrusion; Technological regulation; Waterworks

1. Introduction

Excessive groundwater pumping is currently a growing global concern (Wada *et al.*, 2010). In Asia, for example, groundwater problems have been observed in Tokyo and Osaka, Japan, and recently in Bangkok, Thailand, and Jakarta, Indonesia. This suggests that the problem occurs in conjunction with economic development, and can be predicted to emerge in future areas of economic development. This is partly caused by rapid population increase and by development of pumping technology (Green *et al.*, 2011). Excessive groundwater pumping causes land subsidence and seawater intrusion, which trigger other problems, such as physical damage to infrastructure, exacerbation of flood damage, and

doi: 10.2166/wp.2014.255

© IWA Publishing 2015

المنارة للاستشارات

www.manaraa.

threats to drinking water. Discontinuation of wasteful groundwater pumping is important for disaster prevention (Jago-on *et al.,* 2009).

From a wider standpoint, excessive groundwater pumping is regarded as an example of inefficient use of natural resources (Ostrom, 1990). Methods of natural resource management can be generally classified into three categories: direct regulation, market approach (tax and tradable permit), and community-based approach (Agrawal & Lemos, 2007). Needless to say, each method cannot always be a perfect solution by itself. They are often implemented in combination with other supply-oriented policies, such as artificial recharge and construction of waterworks for water supply conversion. The classification above is very useful to understand the variety of policy combinations among regions.

For example, construction of waterworks and direct regulation were the main solution for excessive groundwater pumping in Tokyo and Osaka (Kataoka, 2006; Sato *et al*., 2006). It is difficult to implement direct regulation on groundwater pumping where the number of regulation agency staff is limited compared to the number of groundwater wells. A case study in Gujarat, India, shows that, even in that situation, groundwater pumping can be regulated by indirect regulation such as restriction on energy supply (Shah *et al.,* 2008). Artificial recharge backed up by a groundwater tax was the main policy tool in Orange County Water District, California, USA (hereafter referred to as OCWD) (Orange County Water District, 2009). A groundwater tax was also introduced in Bangkok, Thailand, but artificial recharge has not been done (Babel *et al.*, 2006; Lorphensri *et al.,* 2011). Pumping in the Edwards Aquifer, Texas, USA, was controlled mainly by tradable permits and artificial recharge (Colby, 2000; Charbeneau & Kreitler, 2011). Lastly, groundwater management in the Raymond Basin, California, USA, is a classic example of a community-based approach that introduces various methods including artificial recharge, tradable permits, and construction of waterworks (Wright, 1952; Lipson, 1978; Ostrom *et al.*, 2003).

Although these works succeeded in detailing each policy experience, there was little comparative analysis. Therefore, the following questions remain: what caused the diversity of policy combinations? what are the advantages and disadvantages of each combination?

The purpose of this paper is to answer the above questions through comparative analysis of groundwater management by OCWD and Tokyo Metropolitan Government, Japan (hereafter referred to as Tokyo). Although they both faced excessive groundwater pumping at almost the same time, their countermeasures were quite different. Clarifying the social background that led to various policy combinations furnishes useful information to policy-makers who are (and will be) considering appropriate policy tools in local areas. Moreover, the two cases facilitate analysis of the long- and short-term effects of each response, because it has been more than 50 years since OCWD and Tokyo initiated countermeasures against excessive groundwater pumping.

A theoretical explanation of excessive groundwater pumping is given in the next section. Principal countermeasures in Tokyo (construction of waterworks and technical regulation) and in OCWD (pump tax and artificial recharge) are presented in the third and fourth sections with a brief history of groundwater development. In the fifth section, the two cases are compared to deduce lessons for groundwater management.

2. Theoretical explanation of excessive groundwater pumping

Unclear property rights are a major cause of excessive groundwater pumping (i.e. inefficient use of groundwater) (Howe, 2002). This means that an unspecified number of people can use the same

للاستشارات المنارة
www.manaraa.

groundwater because the system of exclusion does not work. In other words, groundwater is treated as a 'free-buffet restaurant' in which property rights are not well established.

In such a situation, while a groundwater user considers private costs of pumping such as fees for well construction and electricity for pumping, the social costs of lowering groundwater levels tend to be forgotten. A lower groundwater level raises the pumping costs of all users because they have to deepen existing wells or pay more for electricity to pump up deeper groundwater. Moreover, it may lead to land subsidence and seawater intrusion, which are direct threats to social infrastructures. Such social costs are often called 'external diseconomy'. These costs are directly imposed on the neighboring users because groundwater is a shared resource without clear property rights. A groundwater user does not take the external diseconomy into consideration. Therefore, more groundwater is likely to be pumped up than is socially desirable. External diseconomy caused by a groundwater user may be very small. However, when the number of groundwater users increases, the accumulation of such small effects produces a sharp decline in groundwater levels (Glennon, 2002).

Ill-defined property rights hinder recovery of groundwater levels. Moreover, it prevents conservation. Even if a person decreases groundwater pumping through conservation, there is no guarantee that this person can pump up the conserved amount in the near future because groundwater is a shared resource. It is probable that other people will pump up this water instead. In this situation everyone has an incentive to use groundwater as much as possible (Ostrom, 1990).

Artificial recharge is another way to restore groundwater levels. However, even if an individual somehow contributes artificial recharge, the benefit will accrue not only to the contributor, but also to other people who share the groundwater. This may not pay from the contributor's personal standpoint. Rather, there is an incentive to be a 'free rider' who expects someone else's contribution, thereby enjoying the benefit of groundwater level recovery without making one's own contribution (Olson, 1965).

If unclear property rights cause inefficient use of groundwater, property rights' modification – privatization or nationalization – can be a solution (Hardin, 1968). Such solutions may work in theory, but are very difficult to implement. The number of existing and potential groundwater users in a basin is often large. It is prohibitively expensive to exclude these users from using groundwater to promote privatization or nationalization. For this reason, it is very difficult to establish clear property rights to groundwater. How can we set up institutions for pumping regulation and groundwater conservation when there are numerous existing groundwater users, and technology for exclusion is limited? This general question arises in the cases of groundwater management in Tokyo and OCWD.

Figures 1 and 2 show volumes of groundwater pumping, alternative water supplies (surface and recycled water), and historical change of groundwater level. As discussed in detail later, groundwater level in Tokyo and OCWD sharply declined because of massive groundwater pumping driven by rapid urbanization. As a result, land subsidence was observed in Tokyo and seawater intrusion in OCWD during the 1920s. Both areas began to take countermeasures in the 1950s to restore groundwater level. The main policy tools introduced in Tokyo were construction of waterworks to supply surface water and technological regulation, while those in OCWD were to impose a pump tax and artificial recharge based on the tax revenue. The results of the two policies were in sharp contrast. Water supply was almost fully changed from groundwater to surface water in Tokyo, whereas groundwater remained an important water source in OCWD. In summary, although the social backgrounds, time of problem recognition, and initiation period of countermeasures were very similar in both areas, the practical solutions and results varied substantially. What caused this difference? What are the advantages and disadvantages of each policy combination? To

للاستشارات المنارة
www.manaraa.

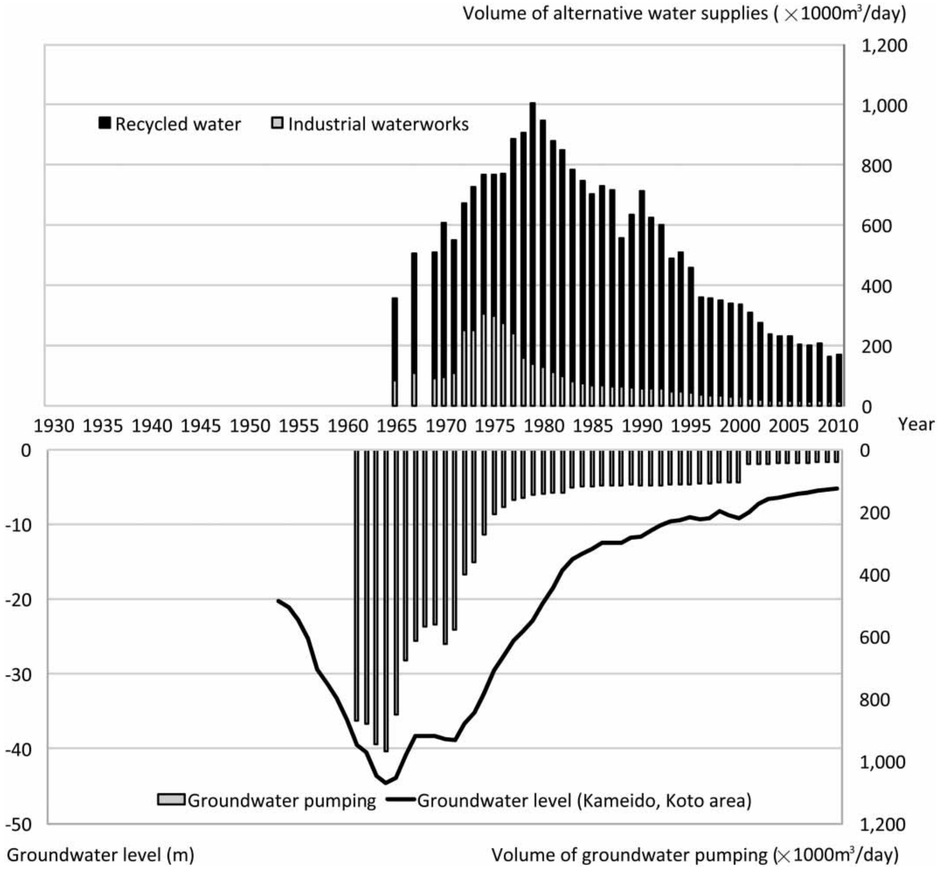


Fig. 1. Changes in groundwater pumping, groundwater level, and alternative water supplies in Tokyo.

answer these questions, the history of groundwater management in Tokyo and OCWD is addressed in the next section.

3. Groundwater management in Tokyo

3.1. A history of groundwater use in Tokyo

Tokyo is the capital of Japan. It consists of 23 special wards in the east and 39 cities or towns in the west. In this paper, Tokyo refers to 23 special wards at the center of population and economic activity (Figure 3). The eastern part of these wards sits on a soft alluvial fan, and it has suffered severe land subsidence from groundwater pumping. Groundwater development is assumed to have begun as early as the 1900s, because land subsidence was observed at that time (Tokyo Metropolitan Government City Planning Bureau, 1962; Tokyo Metropolitan Government Waterworks Bureau, 1986). Later, the Second World War destroyed almost the entire economic infrastructure in Tokyo. However, groundwater began to be used once again in the economic development era after the war. At the time,

www.manaraa.

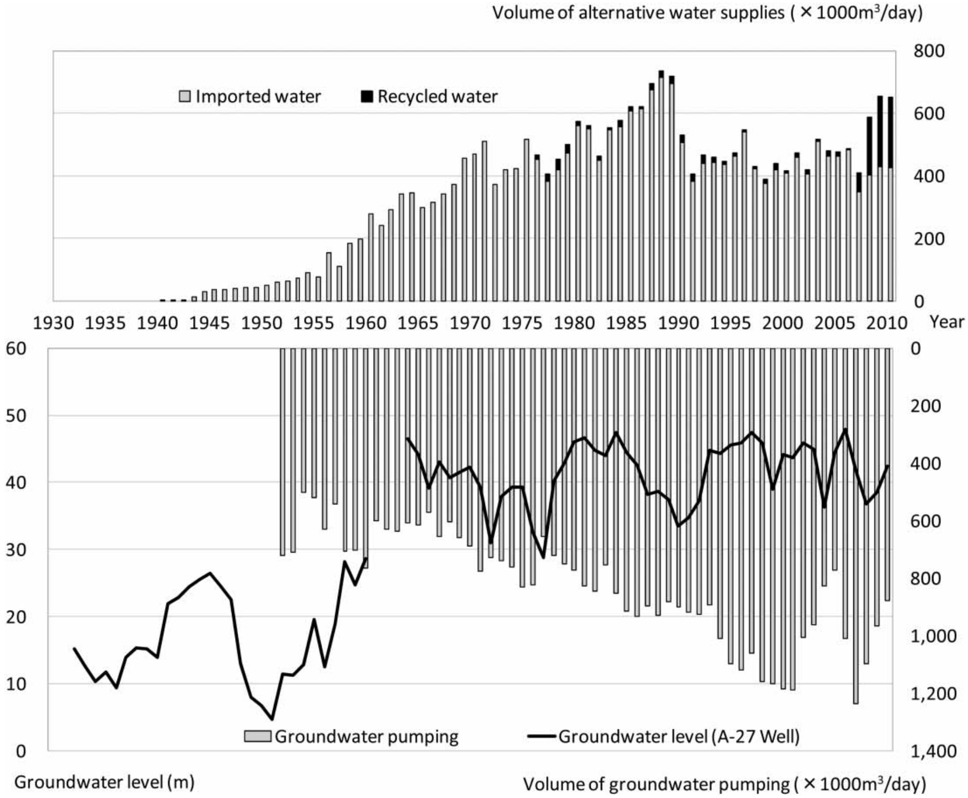


Fig. 2. Changes in groundwater pumping, groundwater level, and alternative water supplies in OCWD.

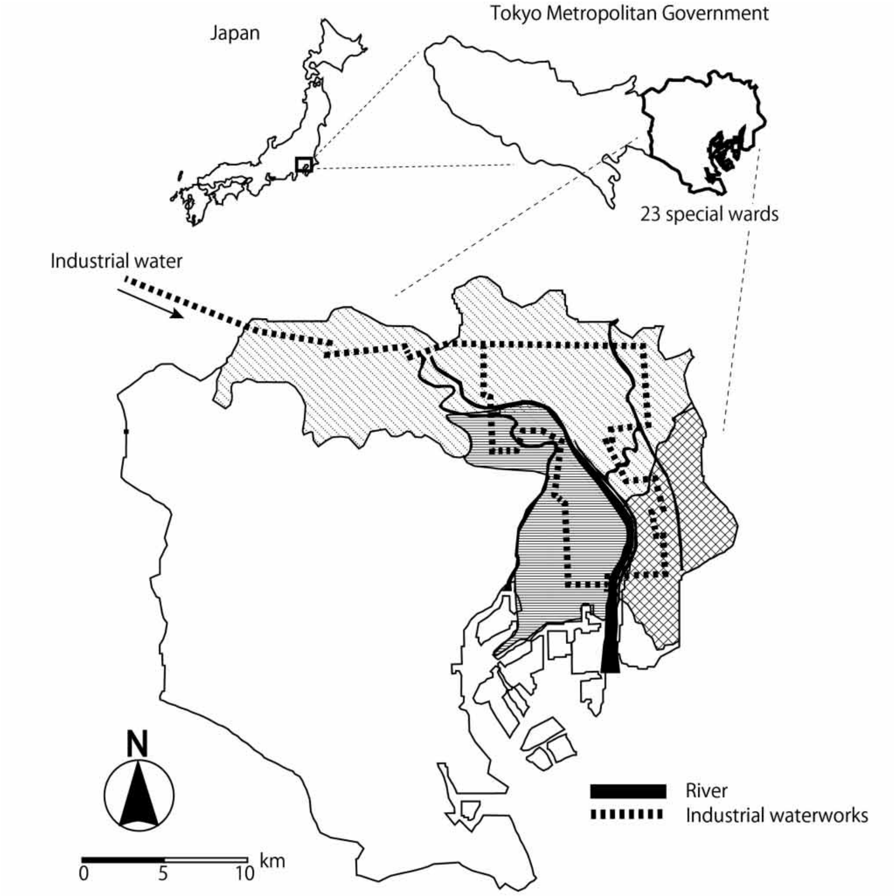
primary groundwater users in Tokyo were factories and commercial buildings. While groundwater was mainly used for cooling in the industrial sector, it was also used for flush toilets and air conditioning in the commercial sector.

3.2. Construction of waterworks and technological regulation

Serious attention was first given to land subsidence because it increased flood risk. The area of land surface below sea level expanded, especially in the coastal area, because of this subsidence. Technical regulation was introduced to cope with this situation. In 1956, the Japanese national government enacted the Industrial Water Law. This enabled prefectural governments to regulate new well construction where industrial waterworks (based on surface or recycled water) were available (Tokyo Metropolitan Government Research Institute for Environmental Pollution, 1970). Under this law, the Japanese national government first established ‘designated areas’, and anyone wishing to build a new well was required to obtain permission from the government of the prefecture in which the well was to be located. The permission criteria were well diameter and intake depth.

For example, in 1961, a part of Koto Ward (hereafter referred to as Koto area) was appointed as the first designated area in Tokyo. Since then, only wells of 21–46 cm^2 in discharge outlet size could be newly constructed. At the same time, well depth was also controlled. Although this varies inside the ward,

المنارة للاستشارات
www.manaraa.



List of technological regulations under the Industrial Water Law

Area	Pattern	Year of area designation	Accepted discharge outlet size of a well (year)	Accepted depth of a well intake (year)
Koto		1961	21-46 cm^2 (1961)	deeper than 100-250 m (1961)
			6-46 cm^2 (1962)	
			6-21 cm^2 (1971)	deeper than 550 m (1971)
Johoku		1963	6-46 cm^2 (1963)	deeper than 160 m (1963)
			6-21 cm^2 (1971)	deeper than 550-650 m (1971)
Koto (extension)		1972	6-21 cm^2 (1972)	deeper than 650 m (1972)

Fig. 3. Technological regulations and industrial waterworks in Tokyo.

some new wells have to be deeper than 250 m (Kuramochi, 1975; Tokyo Metropolitan Government Environmental Pollution Bureau, 1976; Tokyo Metropolitan Government Waterworks Bureau, 1986). The purpose of this diameter regulation was to make it difficult to carry out massive groundwater pumping. Further, depth regulation was such that well intakes were located in soil layers with less groundwater (Figure 3) (Tokyo Metropolitan Government Research Institute for Environmental Pollution, 1970).

المنارة للاستشارات
www.manaraa.

This law was the first attempt at regulation of groundwater pumping in Japan, and there were several problems. For example, the objective of the law was limited to groundwater pumping for industrial use. Groundwater pumping for air conditioning and toilets in commercial buildings was not regulated. Moreover, creation of designated areas had to meet one of the following conditions: (1) land subsidence must have already been observed in the area; and (2) industrial waterworks in the area must have already been in place or scheduled for construction within a year. Based on these conditions, the Industrial Water Law could not prevent land subsidence. Finally, the objective of the regulation was limited to new wells; existing wells were not subject to regulation (Endo *et al.,* 1975; Kuramochi, 1975).

To cope with these shortcomings, The Revised Industrial Water Law and the Building Water Law were enacted in 1962. For the former, guidelines for the installation of wells became so strictly regulated that it was nearly impossible for new wells to be built. Finally, only wells of 6–21 cm^2 in discharge outlet size were permitted, and the depth of a new well had to be more than 650 m (Figure 3). Industrial waterworks had been in operation in parts of the designated areas since 1965. Subsequently, existing wells in designated areas where industrial waterworks had already been constructed that did not fit the standard established by the government were required to be removed within 1 year (Research Committee on Land Subsidence in the Southern Kanto Area, 1974; Tokyo Metropolitan Government Waterworks Bureau, 1986).

The purpose of the Building Water Law was to regulate groundwater pumping for building uses such as air conditioning and toilets. The eastern parts of 23 special wards were appointed as designated areas under the law in 1963. Standards for the construction of new wells in the Building Water Law were similar to those in the Revised Industrial Water Law. This made construction of new wells nearly impossible. Additionally, the regulation covered new and existing wells, with the latter to be discontinued after a moratorium if they did not meet the standard requirements. With these countermeasures, existing wells were totally discontinued in April 1974 (Research Committee on Land Subsidence in the Southern Kanto Area, 1974; Kuramochi, 1975).

In summary, in Tokyo the main policy tools against excessive groundwater pumping were construction of industrial waterworks for an alternative water supply and technological regulation that hindered the construction of new wells.

4. Groundwater management by OCWD

4.1. A history of groundwater use in OCWD

Orange County is in the area farthest downstream of the Santa Ana River, the largest watershed in southern California, USA (Figure 4). It is said that artesian wells were used as early as 1868. Then, citrus farms expanded after orange trees were imported from Brazil in 1873. Additionally, a transcontinental railway increased demand for agricultural products grown in the western USA. Agricultural areas were further expanded by surface water development in the 1880s and the introduction of pumping technology in the 1890s (California Department of Water Resources, 1959). In the 1920s, decline of groundwater level became apparent and seawater intrusion was clearly observed in coastal areas (Weschler, 1968). The Colorado River Aqueduct was constructed in 1941, and a few cities in Orange County had access to Colorado River water (Blomquist, 1992). As stated above, the imported water was used for both drinking and artificial groundwater recharge. As a result of continuous

المنارة للاستشارات
www.manaraa.

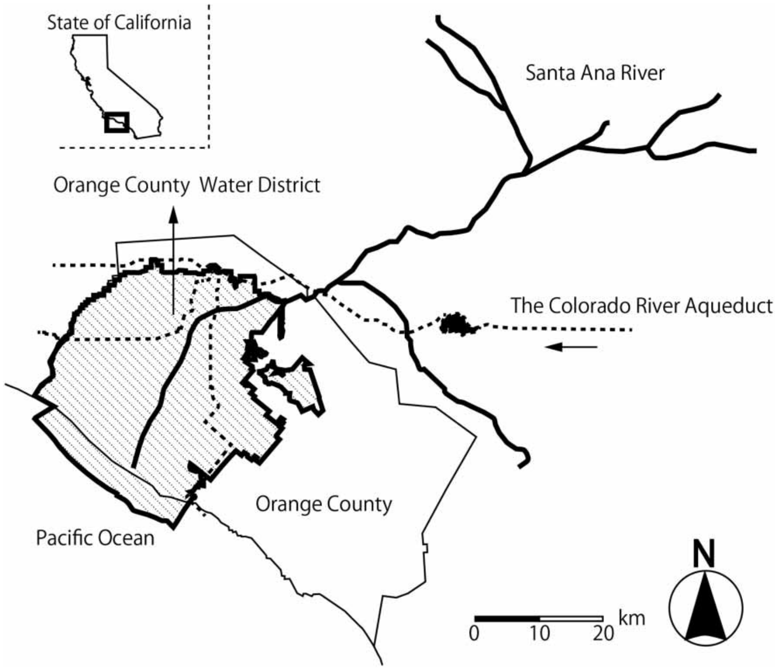


Fig. 4. Location of OCWD.

urbanization, almost all current water demand in OCWD is for municipal uses, and little agricultural demand remains. OCWD's jurisdiction area is 926.73 km^2 and it provides water for 2.5 million people. Between 60 and 70% of water demand is satisfied by groundwater, and the rest is covered mainly by imported water (OCWD, 2009).

4.2. Formation of OCWD

The primary source of water for groundwater recharge is flow from the Santa Ana River. From the viewpoint of Orange County residents, who are the users farthest downstream, augmentation of the river flow leads to recovery of the groundwater table and a stable water supply (OCWD, 2009). In 1931, water users in Orange County brought a lawsuit against upstream water users for curtailment of water diversion. Two years later, under the approval of the state legislature, an organization was formed to collect money through property taxes for the law suit. That organization was OCWD (Weschler, 1968; Lipson, 1978).

In the state of California, there are local governments called 'special districts'. Most are established to promote a single purpose, such as fire protection, mosquito abatement, and park management. There are special districts whose tasks are related to water resources. Such districts are often called water districts, and OCWD is an example. Jurisdiction of a special district is not always the same as that of a county government, because the former is established for a specific purpose. This is the case with OCWD. The district covers only the north-west part of Orange County (Figure 4) (Littleworth & Garner, 1995; Senate Local Government Committee, 2010).

المنارة للاستشارات
www.manaraa.

OCWD's main task is to secure a stable water supply through conservation of the quantity and quality of groundwater in the basin. For this purpose, OCWD was authorized by the state legislature to promote the following actions: (1) To import, sell and store water; (2) to conserve or replenish water within or outside the district; and (3) to protect water supplies through legal action or proceedings (Blomquist, 1992).

4.3. Pump tax and artificial recharge

As mentioned above, OCWD was granted powers to raise funds through property taxes. Originally, the money was used for the law suit against upstream users. From the late 1940s, based on the same revenue, the district began to purchase imported water from the Colorado River for artificial recharge, but this revenue was insufficient. Therefore, a new tax system termed 'replenishment assessment' was introduced to secure an additional budget in 1954. This assessment is often called a 'pump tax' (Crooke, 1961). This was the pioneering pump tax system in the state (Weschler, 1968).

Under this tax system, all groundwater users, no matter whether the well is for irrigation or urban uses, are required to register each well. They also have an obligation to install a meter to gauge the pumped volume and report this data to OCWD every 6 months. There is one exception to this rule: the owners of 'small wells' are exempt from the metering requirements. Here, 'small wells' means the wells from which the discharge outlet is not greater than 20.4 cm^2 in size and that provide domestic and irrigation water for an area not exceeding 1 acre (1 acre = 0.004 km^2) (Crooke, 1961; Weschler, 1968).

Basically, this information-gathering process is based on a system of honesty. The prevention of cheating is very important under this system. If necessary, OCWD checks the volume of electricity to pump groundwater and the past pump record to improve their data accuracy. In addition, information-sharing enables mutual checks among the users to prevent cheating (Ostrom, 1990). OCWD promotes mutual checks by publishing the annual pumping volume of the major groundwater users (non-irrigation users over 25 acre-feet per year) (1 acre-foot = 1,233.5 m^2).

OCWD employs engineers who investigate the groundwater conditions, especially the amount of overdraft every year. Overdraft is an estimated quantity by which the groundwater pumping exceeds natural replenishment of groundwater during a year (OCWD, 2013). The engineers calculate the quantity of water for artificial recharge necessary to eliminate the average annual overdraft for the immediate past 10 years. Then OCWD calculates the necessary budget to purchase that amount of water. Lastly, based on information on anticipated groundwater pumping in the ensuing year, they determine how much money should be levied from 1 acre-foot of groundwater pumping. This is how the tax rate is determined every year. Therefore, the tax is imposed directly on water, not on electricity. Each groundwater user is supposed to pay according to their pumped volume (Crook, 1954).

OCWD buys water for artificial recharge mainly from the Metropolitan Water District (MWD) of southern California, which operates the Colorado River Aqueduct. To be precise, OCWD buys water from MWD via the Municipal Water District of Orange County (Weschler, 1968). The water for artificial recharge is transported by the Colorado River Aqueduct for more than 480 km from the Colorado River. Some water is used directly for urban use and some for artificial recharge. The price of water for artificial recharge is cheaper than that for urban use because a treatment process is not necessary. Water for artificial recharge is discharged into the Santa Ana River upstream of OCWD. The water then percolates through the bed of the Santa Ana River. The river channel is one of the most important recharge facilities for OCWD (Figure 4) (Crook, 1954).

المنارة للاستشارات
www.manaraa.

OCWD promoted artificial recharge based on imported Colorado River water beginning in 1954. This policy was effective for raising groundwater level *on average*, but there were a few problems. Groundwater levels near the coast did not rise as expected, and the levels in the interior increased so sharply that it was feared that some locations would become swamps (Weschler, 1968).

In addition, the Colorado River water was unstable because it was not available during droughts (OCWD, 2009). Thus, OCWD tried to conserve groundwater by combining artificial recharge with other policies (Blomquist, 1992). Initially, much attention was given to the natural flow of the Santa Ana River. This was made possible by the expansion of groundwater recharge facilities. After acquiring land around Prado Reservoir on the river in 1967, OCWD constructed a number of artificial ponds for groundwater recharge along the river (OCWD, 1977; OCWD, 1983). As a result, OCWD operated 1,067 acres of recharge facilities as of 2009 (OCWD, 2009). With these facilities, both the imported water from the Colorado River and a part of the Santa Ana River flood that would be otherwise lost to the ocean were used for recharge purposes. Moreover, the district has blocked seawater intrusion into the local groundwater basin by injecting recycled water into the coastal area.

To summarize, OCWD has dealt with seawater intrusion triggered by the decline of groundwater level and promoted artificial recharge to cope with the problem. The main water source for artificial groundwater recharge has shifted from imported Colorado River water to the natural flow of the Santa Ana River and recycled water. OCWD has simultaneously introduced economic tools such as the pump tax to finance these activities.

5. Comparative analysis

5.1. Tokyo: reasons for construction of waterworks and technical regulation

Groundwater as an open-access resource is very similar to a free-buffet restaurant where the food tends to be consumed wastefully. Following this analogy, countermeasures in Tokyo were to introduce a ‘dress code’ (technological regulation) to decrease the number of ‘customers’ (groundwater users) and promote ‘upward expansion of the restaurant floor’ (construction of waterworks to supply surface water). Technological regulation works for internalization of an external diseconomy related to groundwater pumping. In the case of Tokyo, limiting the size of well diameter and controlling well depth made it practically impossible to establish a new well. However, potential demand for groundwater would have remained if there were no alternative. Industrial waterworks based on surface water were constructed to solve the problem.

These policies were made possible by subsidies from the national government. The Industrial Water Law of 1956 enabled the national government to give financial help to the construction of industrial waterworks. Areas covered by industrial waterworks were Koto and Johoku (Figure 3). In the Koto area where industrial waterworks were in operation in 1964, subsidies from the national government and Tokyo each covered 25% of the construction cost. The remainder (50%) was financed by a bond issue (Tokyo Metropolitan Government Waterworks Bureau, 1986). Conversely, in the Johoku area where industrial waterworks became available in 1971, subsidies from the national government covered 25% of the construction cost and Tokyo paid for the rest (Tokyo Metropolitan Government Waterworks Bureau, 1986). The main groundwater users in Tokyo were not individual households but factories. Therefore, factory owners could get financial support from both non-industrial water users within

المنارة للاستشارات
www.manaraa.

Tokyo and from citizens in general outside the city. Subsidies based on the general budget were justified in that stopping land subsidence would produce the public good of disaster prevention (Tokyo Metropolitan Government Waterworks Bureau, 1986). Whereas the aforementioned well diameter limitation and well depth control made it prohibitively expensive to establish a new well in Tokyo, the subsidy lowered the price of surface water from the industrial waterworks. This combination promoted the conversion of water supply from groundwater to surface water.

It is difficult to introduce a pump tax system in Japan because of the legal definition of groundwater. Groundwater in the country is regarded as a part of land ownership, and therefore public control of its use is very weak. The definition was first established by a judgment of the Supreme Court in 1896 (Judgment of Supreme Court, 1896) and strengthened by a civil law that was enacted 1 month later. Both admitted a landowner's discretion to use groundwater beneath that land. As a result, regulation of groundwater has often been regarded as an infringement of land ownership. Enactment by the national government, not by local government, was deemed necessary to introduce such regulation. During the rapid economic development era after the Second World War, a variety of environmental problems occurred, including land subsidence, and river and air pollution. Countermeasures against these problems were not integrated and regulation was generally weak because it was believed that rigid regulation would hinder economic development. It was still more difficult to introduce a pump tax in such a situation. In the late 1960s, based on considerations of land subsidence, a few plans were proposed to enact an integrated groundwater law covering general groundwater use. One of these plans included the idea of a pump tax system. However, the idea of a new groundwater law never came to fruition because the ministries involved did not reach a consensus (Working Group on Land Subsidence in Central Council for Environmental Pollution Control, 1975). For this reason, there has been no integrated groundwater law in Japan to date. The Industrial Water Law mentioned above includes a permit system, but it covers only industrial groundwater use in designated areas.

5.2. OCWD: reasons for pump tax and artificial recharge

The pump tax and artificial recharge are OCWD's main policy tools for groundwater management. To employ the restaurant metaphor again, the pump tax changes a 'free-buffet restaurant' (free groundwater) into a 'toll-buffet restaurant' (priced groundwater) to promote 'downward expansion of the restaurant floor' (artificial recharge).

No subsidy was available from the county, state, or federal governments in the case of OCWD. This is in striking contrast to the case of Tokyo. Therefore, OCWD had no choice but to secure a budget for groundwater management by itself and this led to the establishment of the pump tax. If OCWD had attempted to build an aqueduct to import water by itself, it would have been very costly, and it would have been very difficult to lower water prices without a subsidy from higher-level governments. However, the groundwater basin in Orange County is mainly recharged by the natural flow of the Santa Ana River, and it avoids the cost of constructing infrastructure to store and deliver water to end-users. This is why OCWD, which did not receive a subsidy, continued to use groundwater, a cheap local water resource.

There is no comprehensive groundwater law in California. One of the basic rules for groundwater use in California is called the reasonable use doctrine. Although it prohibits export of groundwater outside the overlying land, it admits wide discretion of the landowner (Tarlock, 1985; Blomquist, 1992). In this sense, the rule is similar to that in Japan. Nonetheless, a pump tax was introduced only in OCWD. This

المنارة للاستشارات
www.manaraa.

is because the district authority was defined more clearly than in the case of Tokyo. First, OCWD was established with the approval of the state legislature in 1933. Additionally, the pump tax authorization was given to OCWD by the same organization in 1954. Such authorization was not given in Tokyo.

Urbanization was another factor causing OCWD to pay attention to supply-side management, that is, artificial groundwater recharge. Pasadena and neighboring cities in the Raymond Basin, also in southern California, tried to solve the problem of excessive groundwater pumping by decreasing total groundwater pumping through adjudication. OCWD considered the same solution in the early 1950s, but decided against this course because it was thought that reducing groundwater pumping would not accommodate ongoing urbanization. Geological conditions were a second reason. OCWD was engaged in artificial groundwater recharge because land within the district jurisdiction has a characteristic high-infiltration rate and the Colorado River aqueduct coincidently passed near the recharge area (Crooke, 1954).

Finally, the use of recycled water should be addressed. The use of recycled water is greater in Tokyo than in OCWD (Figures 1 and 2). This has to do with the purpose of use. While a part of recycled water was sunk into the groundwater basin for future drinking purposes in the case of OCWD, the recycled water was used for cooling in the industrial sector in the case of Tokyo. What mattered with such use was temperature, not quality. For this reason, recycled water was supplied as an alternative in industrial waterworks for the Koto area. Additionally, the price structure of sewerage services was modified into an increasing rate system to reduce the total volume of sewage to aid environmental protection. This gave an incentive to factory owners to recycle water, because it helped save payments for sewerage services. This is one of the reasons why recycled water use was greater in Tokyo than in OCWD (Tokyo Metropolitan Government Waterworks Bureau, 1986).

5.3. Advantages and disadvantages

Countermeasures taken in Tokyo and OCWD have both advantages and disadvantages. An advantage of the countermeasures in Tokyo is high reliability. Figure 1 shows that groundwater pumping began to decrease not after the Industrial Water Law was enacted in 1956, but after industrial waterworks began operation in 1964. This means that whether surface water or recycled water is used, providing alternative water supplies is the fundamental solution for excessive groundwater pumping.

However, the polluter-pays principle was not completed. The idea is one of the basic principles for environmental pollution control, and stipulates that environmental protection should be at the expense of those who use the environment. As mentioned above, the construction cost of industrial waterworks was covered by the general budgets of the national government and Tokyo. Such subsidies lowered the price of industrial water to promote water supply conversion. However, because users were not obliged to pay the full cost, industrial waterworks were designed to be so large that there was a problem of oversupply. Additionally, the modification of sewerage rates incentivized factory owners to use recycled water instead of water from industrial waterworks. The industrial waterworks incurred a huge financial deficit because of these factors.

Conversely, OCWD did not promote conversion of water supply in the same way as Tokyo. Using both groundwater and surface water has an advantage in terms of risk management. Given budget limitations, OCWD chose to maximize use of the natural groundwater basin itself as a cheap infrastructure to store and deliver water. This strongly contrasts with the case of Tokyo, in which artificial water infrastructures were constructed with the aid of subsidies. In other words, OCWD uses the local ecosystem more effectively than does Tokyo.

المنارة للاستشارات
www.manaraa.

At the same time, this suggests that the pump tax in OCWD has not satisfied the polluter-pays principle in a perfect way either. While the pump tax system in OCWD was originally introduced for fund-raising, it potentially had another function, that is, internalization of external diseconomy. As mentioned above, groundwater abstraction causes an external diseconomy in the form of declining groundwater levels. That is a social cost a groundwater user does not fully bear alone, but imposes on the neighboring users unilaterally. Under the pump tax system, a groundwater user is made to take the social cost into consideration and is required to contribute to the restoration of groundwater levels in proportion with their pumped volume. This idea is in accordance with the polluter-pays principle. However, the rate has always been set lower than the price of imported water to make buyers prefer cheaper groundwater. This is why conversion of water supply has not taken place even after the pump tax was introduced (Figure 5).

This problem is mitigated by an additional demand-control tool called basin percentage production (BPP). BPP was introduced in 1968. It determines a percentage of a water supply originating from local groundwater and supplemental water from outside the basin. BPP is applied to a user who pumps groundwater at more than 25 acre-feet per year. Such a user is often a water wholesaler, such as a city or water agency. For example, when BPP for a water wholesaler is set at 70%, it can satisfy up to 70% of local water demand through cheap groundwater; the remainder should be met by expensive supplemental water such as imported water. If a wholesaler pumps groundwater at more than the BPP rate, they are required to pay another assessment called basin equity assessment for the excess. Conversely, when a wholesaler pumps less than that rate, they are rewarded by the basin equity assessment paid by another wholesaler. In summary, BPP is a system that regulates groundwater pumping through controlling the ratio of groundwater and imported water (OCWD, 2009).

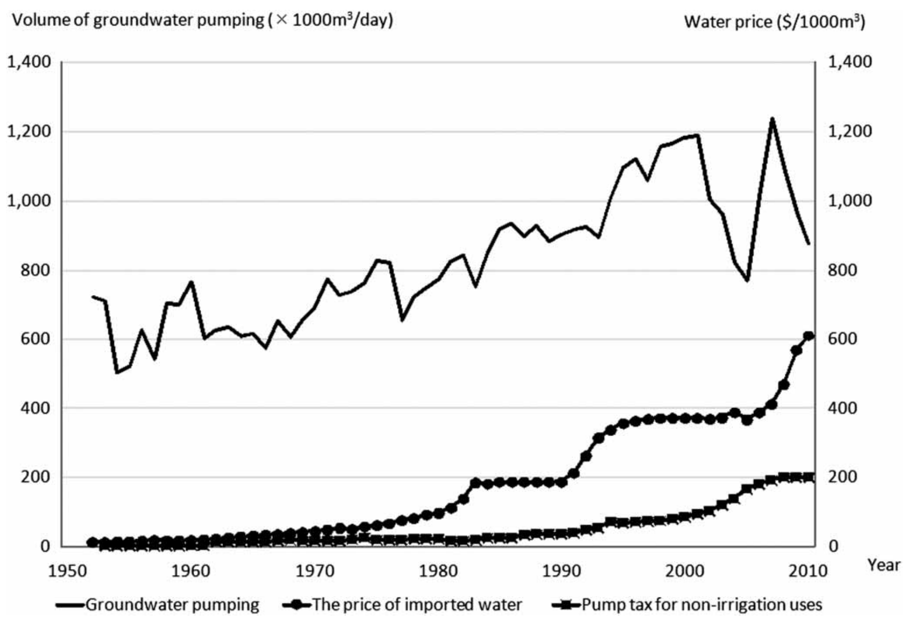


Fig. 5. Price of imported water and pump tax in OCWD.

www.manaraa.

5.4. Lessons

The following lessons can be learned from experiences in Tokyo and OCWD. First, technological regulation and a pump tax cannot regulate groundwater pumping without conditions. Tokyo succeeded in halting excessive groundwater pumping by providing alternative water supplies, in addition to technological regulation. The OCWD experience implies that whether or not a pump tax reduces groundwater pumping depends partly on the relationship between the tax rate and price of the alternative water supply.

Second, attention should be paid to the legal definition of groundwater. The pump tax in OCWD was designed to cover any groundwater use, regardless of purpose; however, 'groundwater' in the Industrial Water Law meant for industrial purposes only. Although the major groundwater users in Tokyo were industrial in the 1950s, groundwater was also used in commercial buildings for toilets and air conditioning. Therefore, the Industrial Water Law failed to control overall groundwater pumping because such municipal uses were omitted from the regulation. In 1962 the Building Water Law was enacted to get round the loophole in the regulation. This suggests that artificial classification of groundwater limits the effectiveness of pumping regulation.

Third, although there are many possible policy options, the real availability is limited by legal and social factors. As mentioned, it was difficult to introduce a pump tax in Japan because of the existing rules. Even though the idea of a pump tax was proposed after the country experienced severe land subsidence, it was never realized because of disagreement between the relevant ministries. The OCWD experience suggests that it is easier to introduce a pump tax system in urban areas than in rural areas. Agricultural wells are often scattered in a wider area than are urban wells. Therefore, it is very costly for the relevant authority to monitor and get accurate data on the volume of pumped groundwater. In the case of OCWD, urbanization increased the number of groundwater users and prompted them to concentrate in a limited area. Moreover, water consumption per person was reduced in the process because the volume of water usage for urban use was much less than that for agricultural use. These factors decreased the tax burden per person because OCWD could secure funds by collecting a small amount of tax from a large number of groundwater users. Such a low burden helped people to accept the tax. These conditions are difficult to find in agricultural areas (Herndon, 2013).

Lastly, although halting excessive groundwater pumping is important, a complete switch of water supply may provoke another problem. Almost all groundwater pumping was eliminated in Tokyo, which caused groundwater as a cheap, local, natural resource to be unused. Large-scale development of subsurface space began in Tokyo in the 1960s because of the rapid urbanization and limitations of surface area. This was a period during which the groundwater level was at its lowest. Therefore, as that level rises, there is concern that groundwater buoyancy will negatively affect subsurface infrastructures. A railway company has no choice but to put heavy weights on platforms to prevent a railroad from moving upward because of this buoyancy (Tokunaga, 2008). It is important to bear in mind that short-term groundwater management may provoke such a long-term, unexpected outcome.

To put it another way, the water supply should not be completely converted, but rather, setting a range of groundwater pumping should be considered in groundwater management. Of course, this range will vary with location. Experience in OCWD provides an example. As mentioned, there was no complete conversion of water supply in that district. While OCWD set the pump tax rate lower than the price of imported water, it introduced the BPP to cope with this problem. In other words, OCWD did not eliminate groundwater demand, but tried to prevent excessive groundwater pumping by setting the supply ratio of groundwater and surface water. This is what OCWD calls 'Operating Range' (OCWD,

www.manaraa.

2009). Although this idea may complicate institutional design, it is a good example of conjunctive uses of groundwater and surface water.

6. Conclusion

This paper has compared excessive groundwater pumping in Tokyo and OCWD, with a special focus on countermeasures, institutional background, and effectiveness. Both regions experienced depletion of groundwater through land subsidence or seawater intrusion in the 1920s, and began to take countermeasures in the 1950s. However, the countermeasures were completely different. Tokyo tried to cope with the problem through technical regulation and construction of waterworks, while OCWD did so with a pump tax and artificial recharge. This caused a subsequent sharp difference between Tokyo and OCWD in groundwater use.

The difference was caused by subsidy systems, legal rules of groundwater pumping, and local government authority. The countermeasures in Tokyo worked well to stop land subsidence, but they provoked unexpected by-products such as unused groundwater and a chronic financial deficit of industrial waterworks. The countermeasures in OCWD can be evaluated positively in terms of diversity of water sources, also satisfying the polluter-pays principle to some extent. Moreover, OCWD makes maximum use of the local ecosystem. However, the pump tax does not reduce groundwater demand because the tax rate is set lower than the price of imported water.

The following policy lessons can be deduced. First, neither technological regulation nor a pump tax provides a perfect solution. Second, artificial classification of groundwater curtails the effectiveness of pumping regulation. Third, although there are many possible policy options for groundwater management, the real availability is limited by legal and social factors. Fourth, complete conversion of water supply may cause a problem of a too-high groundwater level.

Although such groundwater problems are of worldwide concern, it is in a local area such as a watershed that practical solutions are taken. These solutions vary depending on the political, economic, and social backgrounds of each area. This paper addresses two kinds of policy combination, revealing the advantages and disadvantages of each. Nevertheless, the policy choices for groundwater management are not limited to those addressed herein. For example, a tradable permit system should also be considered. Information should be collected through case studies to promote appropriate policy-making at the local level, and this paper is a first step toward such integrated research.

Acknowledgements

This research was supported by the research project ‘Long-term vision for the sustainable use of the world’s freshwater resources’ (Director: Shinjiro Kanae, Professor, Tokyo Institute of Technology) under CREST (Core Research for Evolutional Science and Technology) funded by the Japan Science and Technology Agency (JST). Special thanks are due to Mr Roy L. Herndon, chief hydrogeologist, OCWD, for providing the data. The views presented here are those of the author and should be in no way attributed to JST or OCWD. Lastly, I would like to thank the reviewers for their useful comments. Responsibility for the text rests entirely with the author.

المنارة للاستشارات
www.manaraa.

References

Agrawal, A. & Lemos, M. C. (2007). A green revolution in the making? Environmental governance in the 21st century. *Environment 49*(5), 36–45.

Babel, M. S., Das Gupta, A. & Domingo, N. D. S. (2006). Groundwater resource management in Bangkok. In: *Sustainable Groundwater Management in Asian Cities*. Freshwater Resources Management Project, Institute for Global Environmental Strategies (ed.). Institute for Global Environmental Strategies, Kanagawa.

Blomquist, W. (1992). *Dividing the Waters, Governing Groundwater in Southern California*. ICS Press, San Francisco.

California Department of Water Resources (1959). *Santa Ana River Investigation*. California Department of Water Resources, Sacramento.

Charbeneau, R. J. & Kreitler, C. W. (2011). Management issues for the Edwards Aquifer, Texas (USA). In: *Groundwater Management Practices*. Findikakis, A. N. & Sato, K. (eds). CRC Press, Leiden.

Colby, B. G. (2000). Cap-and-trade policy challenges: a tale of three markets. *Land Economics 76*, 638–658.

Crooke, H. W. (1954). Orange County inaugurates first tax for pumping water from underground basin. *Western City Magazine* October issue.

Crooke, H. W. (1961). Ground water replenishment in Orange County, California. *Journal American Water Works Association 53*(7), 831–837.

Endo, H., Ogawa, I., Kanazawa, Y., Shiono, H. & Takahashi, Y. (1975). On groundwater law. *Jurist 582*, 16–42 (in Japanese).

Glennon, R. (2002). *Water Follies, Groundwater Pumping and the Fate of America's Fresh Waters*. Island Press, Washington, DC.

Green, T. R., Taniguchi, M., Kooi, H., Gurdak, J. J., Allen, D. M., Hiscock, K. M., Treidel, H. & Aureli, A. (2011). Beneath the surface of global change: impacts of climate change on groundwater. *Journal of Hydrology 405*, 532–560.

Hardin, G. (1968). Tragedy of commons. *Science 162*, 1243–1248.

Herndon, R. L. (2013). *Personal interview regarding groundwater management in Orange County Water District*. Orange County, California, USA, 9 December 2013.

Howe, C. W. (2002). Policy issues and institutional impediments in the management of groundwater: lessons from case studies. *Environment and Development Economics 7*(4), 605–616.

Jago-on, K. A. B., Kaneko, S., Fujikura, R., Fujiwara, A., Imai, T., Matsumoto, T., Zhang, J., Tanikawa, H., Tanaka, K., Lee, B. & Taniguchi, M. (2009). Urbanization and subsurface-environmental issues: an attempt at DPSIR model application in Asian cities. *Science of the Total Environment 407*(9), 3089–3104.

Judgment of Supreme Court (1896). *In Old Supreme Court Civil Cases*. Book 2, Vol. 3, 27 March, 111–115 (in Japanese).

Kataoka, Y. (2006). Towards sustainable groundwater management in Asian cities - lessons from Osaka. *International Review for Environmental Strategies 6*(2), 269–290.

Kuramochi, F. (1975). Status quo of subsidence and its countermeasures – an example of Tokyo. *Water Science 19*, 1–43 (in Japanese).

Lipson, A. J. (1978). Efficient Water Use in California: The Evolution of Groundwater Management in Southern California. Rand Corporation Report No. R-2387/2-CSA/RF, Santa Monica.

Littleworth, A. L. & Garner, E. L. (1995). *California Water*. Solano Press Books, California.

Lorphensri, O., Ladawadee, A. & Dhammasarn, S. (2011). Review of groundwater management and land subsidence in Bangkok, Thailand. In: *Groundwater and Subsurface Environments: Human Impacts in Asian Coastal Cities*. Taniguchi, M. (ed.). Springer, Tokyo.

Olson, M. (1965). *The Logic of Collective Action, Public Goods and the Theory of Groups*. Harvard University Press, Cambridge.

Orange County Water District (1977). The Annual Report. Orange County Water District, Orange County.

Orange County Water District (1983). The Annual Report, 50th Anniversary Edition. Orange County Water District, Orange County.

Orange County Water District (2009). 2009 Update, Groundwater Management Plan. Orange County Water District, Orange County.

Orange County Water District (2013). 2011–2012 Engineer's Report on Groundwater Conditions, Water Supply and Basin Utilization in the Orange County Water District. Orange County Water District, Orange County.

www.manaraa.

Ostrom, E. (1990). *Governing the Commons, the Evolution of Institutions for Collective Action*. Cambridge University Press, New York.

Ostrom, E., Stern, P. C. & Dietz, T. (2003). Water rights in the commons. *Water Resources IMPACT 5*(2), 9–12.

Research Committee on Land Subsidence in Southern Kanto Area (1974). *A History of Research and Countermeasures on Land Subsidence in Southern Kanto Area* (in Japanese). Research Committee on Land Subsidence in Southern Kanto Area, Tokyo.

Sato, C., Haga, M. & Nishio, J. (2006). Land subsidence and groundwater management in Tokyo. *International Review for Environmental Strategies 6*(2), 403–424.

Senate Local Government Committee (2010). *What's So Special about Special Districts? A Citizen's Guide to Special Districts in California* (Fourth Edition). Senate Local Government Committee, Sacramento.

Shah, T., Bhatt, S., Shah, R. K. & Talati, J. (2008). Groundwater governance through electric supply management: assessing an innovative intervention in Gujarat, western India. *Agricultural Water Management 95*, 1233–1242.

Tarlock, A. D. (1985). An overview of the law of groundwater management. *Water Resources Research 21*(11), 1751–1766.

Tokunaga, T. (2008). Groundwater potential in the central district of Tokyo. In: *Groundwater Management in Asian Cities: Technology and Policy for Sustainability*. Takizawa, S. (ed.). Springer, Tokyo.

Tokyo Metropolitan Government City Planning Bureau (1962). Land Subsidence and Industrial Waterworks, A Research Report on Industrial Waterworks in 1961 (in Japanese). Tokyo Metropolitan Government, Tokyo.

Tokyo Metropolitan Government Environmental Pollution Bureau (1976). *Current Situation of Land Subsidence and its Countermeasures* (in Japanese). Tokyo Metropolitan Government, Tokyo.

Tokyo Metropolitan Government Research Institute for Environmental Pollution (1970). A Report on Land Subsidence in Tokyo (in Japanese). Tokyo Metropolitan Government, Tokyo.

Tokyo Metropolitan Government Waterworks Bureau (1986). *A History of Tokyo Metropolitan Government Industrial Waterworks* (in Japanese). Tokyo Metropolitan Government, Tokyo.

Wada, Y., Van Beek, L. P. H., Van Kempen, C. M., Reckman, J. W. T. M., Vasak, S. & Bierkens, M. F. P. (2010). Global depletion of groundwater resources. *Geophysical Research Letters 37*, L20402.

Weschler, L. (1968). Water Resources Management: The Orange County Experience. Institute of Governmental Affairs, University of California, Davis.

Working Group on Land Subsidence in Central Council for Environmental Pollution Control (1975). On preventive measures against land subsidence. *Jurist 582*, 55–56 (in Japanese).

Wright, K. K. (1952). Underground water problems in California. *Journal American Water Works Association 44*(8), 662–668.

Received 27 March 2014; accepted in revised form 30 June 2014. Available online 11 August 2014

www.manaraa.

Reproduced with permission of copyright owner. Further reproduction prohibited without permission.

www.manaraa.