Original Research

A Framework for Supporting the Conservation of Water Resources as Derived in Taiwan

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Abstract

This paper examines Taiwan's water resources and finds that over-exploitation of ground water has led to land subsidence at an annual rate of 7.4 cm/year for some coastal regions. Each m^3 of water used for agriculture contributes only NT$ 15.58 (US$ 0.5), much lower than that for industrial production (NT$ 2,220, equivalent to US$ 71.6). This paper suggests that the increase in recharge area (water infiltration area) and the greenness-covered area (e.g. forestation) play vital roles in conserving water resources, and thus aqua-culture ponds should be suspended in operation and serve as constructed wetlands through incentive systems.

Keywords: wetlands, ground water, recharge, surface water

Introduction

Water is an essential element affecting our life and the environment. A sufficient water supply is the vital determinant in supporting both human living systems and ecosystems, since water plays an unavoidable role for metabolic use in the internal process of living organisms. Unfortunately, water has become a scarcie resource due to over-exploitation of groundwater, unevenly distributed rainfalls across regions, polluted water resources, etc. Water scarcity has gradually becomes a severe problem when water of acceptable quality is not sufficient for domestic, industrial, and other uses [1]. Koehler has noted: "We are witnessing a steadily worsening situation of rapidly decreasing freshwater resource availability which threatens 1.1 billion people around the globe lacking sufficient access to safe drinking water" [2]. More than 40% of the world's population is experiencing chronic water shortage, thus degrading human health. A World Bank study estimates that 3 billion people in more than 90 countries are expected to face water-related illness by 2025 [3]. A sufficient water supply is critical to both the human living system and ecological systems.

A growing awareness of water scarcity has focused on solving the problem, but most of them focus is on environmental factors that impact water resources. Some researchers analyze the techniques to resolve hydrological problems such as aquifer boundaries, groundwater flow paths, or hydro-chemical components [4-6], or to identify geochemical controls on composition [7].

Wetlands have gained greater attention because of their important impact on water supply and water quality control. Many researchers see wetland functions as the result of interactions between hydrological characteristics, structure, and processes. Min et al. [8] attempted to understand the interaction between wetland surface water and adjacent upland groundwater by observing four depressional wetlands. Zhang and Mitsch [9] examined hydrologic processes of four different low-through-created freshwater wetlands, by using a mass-balance water budget model. The simulation results find that "this wetland has developed a hydroperiod with more than sufficient flooding to ensure that it will meet the hydrologic criteria of a formal jurisdictional wetland definition in the USA." Kazezyelmaz-Alhan

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and Medina [10] investigated the effect of surface/ground water interactions on wetland hydrology for different wetland conditions using the wetland model WETl and Solute TrANsport Dynamics (WETSAND). The simulation results find that the interaction effect on surface water depths is more dominant on wetland sites with high slopes and low vegetation. Nahlik and Mitsch [11] made an experimental test on five tropical treatment wetlands for comparison of their effectiveness in treating organic matter and nutrients in the Parismina River Basin in eastern Costa Rica. The test results found that concentration of ammonia is reduced by 92% in the wetland, nitrate nitrogen removal was variable, phosphate phosphorus was effectively reduced through the wetland, and dissolved oxygen in the wetland outflows were ≤2 mg/l in three of the sampled wetlands. Based on the test results, the authors present recommendations on tropical wetland design and management. Mitsch, et al. [12] employ 112-ha flow-through *Raphia taedigera* (*Arecaceae*) forested wetlands to examine the effectiveness of carbon sequestration and methane generation, and several treatment wetlands to improve water quality of effluents. The results find that "carbon sequestration by the wetland appears to be substantially higher than similar flow through temperate zone wetlands" and "water quality was substantially improved in all of these wetlands except the landfill leachate wetland."

Even though substantial results of academic research have discovered the positive impacts of wetlands on water resources, very few papers focus on the application of the academic results on the hydrology of wetlands for the conservation of water resources. And thus, this paper develops a framework in which some proposals are presented to improve the water management system aimed at sustainable use of water resources.

The Water Cycle

The total quantity of water on earth is fixed and given. Water flows from one place to another and from one phase to another. The water cycle consists of processes including evaporation from land and ocean, transpiration from plant leaves of water extracted from soil and transported throughout the plant, condensation, precipitation to land, infiltration into soil, percolation through the soil and permeable rock formations to groundwater storage areas, and runoff to the sea, powered by the sun and gravity [3]. In the water cycle, most fresh water and wasted water returns back to oceans in which salted water accounts for about 97% of water. Ocean water is too salty for drinking, irrigation, or industry uses except as a coolant [3]. The evaporation rate from oceans is almost constant, but it is variable from the surface depending on the weather and environmental conditions. Transpiration from plants and evaporation from the ground are affected by the area covered by forests or other plants (called greenness-covered areas in this paper). After precipitation, trees absorb a portion of rainfall into their bodies. Another portion of water infiltrates into the soil and percolates into the groundwater storage. The major portion of rainfalls runs off to oceans if lands are covered by impervious surfaces.

In the water cycle process, precipitation, evaporation, transpiration, runoff, and groundwater recharge may affect the balance among ocean, surface water system, and ground water storage (Fig. 1). Some precipitation infiltrates the ground and percolates downward through voids in rock, and eventually forms a part of groundwater storage. Among these factors affecting water supply, groundwater storage serves as a buffer tank, providing insufficient water supply in drought seasons and absorbing heavy rainfalls in flooding seasons.

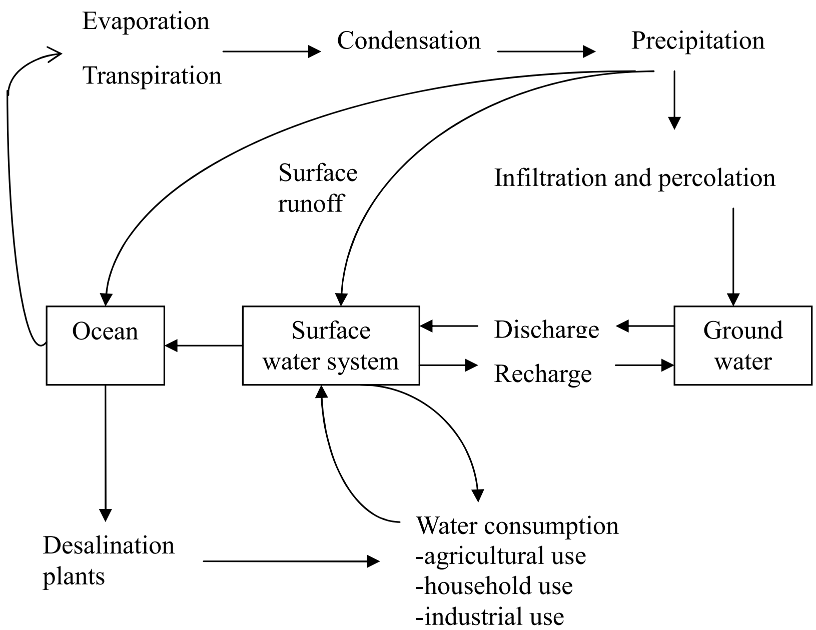

Fig. 1. The water cycle diagram.

Table 1. Water supply and consumption in 2008 (unit: 10^6 m^3).

Water supply			Water consumption		
Surface water	Subtotal	12,152.19	Agricultural use	Subtotal	12,960.11
	River	8,724.60		Irrigation	11,212.18
	Dam	3,427.59		Farming	101.16
Groundwater		5,831.93		Aquatic	1,646.77
Others (e.g. desalination)		0.83	Household use		3,357.30
			Industrial uses		1,667.54
Total supply		17,984.95	Total consumption		17,984.95

Source: Water Resource Agency, MOEA [13].

In theory, groundwater discharge and recharge should be carefully evaluated as it is important to the functioning of groundwater systems. Groundwater discharge can help maintain the base flow of streams, and provide base flow to wetlands and lakes. Without the water provision from the discharge of groundwater, rivers keep little water. When industrial sectors or agricultural sectors (e.g. pig farms) discharge wastes or pollutants like organic chemicals illegally into a stream, the water quality declines and the ecological system is promptly destroyed.

The Status of Water Resources in Taiwan

Annual precipitation in Taiwan varies across regions and is unevenly distributed in time even though rainfalls are abundant. The observed rainfalls in Taiwan ranged from 5,222 mm in Ali Mountain to 967 mm in Penghu in the rainy season, and from 4,510 mm in Ali Mountain to 755 mm in Penghu in drought season [13]. Generally, rain participation in winter is more than in summer. As water supply is unevenly distributed over geographical regions and over time, water insufficiency occurs locally and temporarily.

Table 1 indicates that fresh water extracted from rivers is 8,724.6 m^3, accounting for 48.5% of total water supply. The flow in rivers is rapid and thus it is hard to keep baseflow of streams due to the steep geography in Taiwan. Rainfalls are quick to flood and flow to the sea in a short time. Because of uneven distribution of rainfalls in time and space, stream flows vary across seasons and thus affect the assimilative capacity of the river. In rainy seasons, water quality is polluted by storm water runoff that carries sediment from upland erosion, and nutrients from agricultural fertilizers. In drought seasons, the rivers keeps almost no water because the rivers are cut for the irrigation of agriculture or reserve by the up-streamed reservoir. Most rivers faced exhaustion due to over consumption (diverting to irrigation or being captured by a dam). Water quality in rivers reflects the ability to conserve water resources and the ecological systems in the river.

Water supplied from dams is 3,427.59 m^3 (Table 1), accounting for 19.1% of total water supply. 100 dams have been completed and are operating with total capacity of 2.845 million m^3 (2010) [13]. The dams provide some benefits by facilitating agriculture and power generation, and storing water for household uses. The construction of dams, however, has been challenged for the adverse effect on ecological systems by environmental groups. Some countries have attempted to recover the destroyed ecological systems by modifying the flow downstream from the dam.

The supply of groundwater is 5,831.93 million m^3, accounting for 32.4% of total water supply 17,984.95 million m^3 (Table 1). Groundwater is a major source to support agricultural irrigation, withdrawn to grow crops, raise cattle, and provide urban dwellers and industries. In 2006 more than 2,013 wells were under operation and withdrew groundwater for agriculture, industry, and household uses, while totally 2,077 sets of water supply wells were run with total yield of 240,718 m^3/hr (Water Resource Agency [13]).

It is costly to convert salted water to fresh water. The water supply from desalination plants is only about 0.83 million m^3, accounting for 0.0046% of total water supply (Table 1). The desalination plants are in general installed in isolated water plants as Penghu, where rainfall is relatively lower, or the costal regions where fresh water is salted. Until now, More than 20 sets of desalination plants have been installed with production capacity of 25,640 tons/day fresh water. Totally these plants produced 4.776 million tons of fresh water totally in 2005 and 3.978 million tons in 2009 [13]. The process of desalination not only consumes a lot of energy and but also generates negative warming effect due to a large amount of CO_2 emissions.

On the other hand, Taiwan's total water consumption is of 17,984.95 million m^3 in 2008. Agricultural use for including irrigation, farming, and aquaculture consumes 12,960 m^3, accounting for 72% of total water consumption of 17,984.95 million m^3 in 2008. The irrigation water is withdrawn from rivers, lakes, and aquifers. Agricultural products require a large amount of water. About 60-80% of the water irrigated to the crop field either evaporates into the air or seeps into the ground before reaching crops. Households consume water in the amount of 3,357.2 million m^3, accounting for 18.67% in 2008. Each Taiwanese consumes about 145 m^3 of water for showering, cleaning, washing, etc., annually.

Table 2. The status of subsidence of Taiwan's coastal regions.

Region	Subsidence# rate in 2009	Subsidence# rate in 2005	Number of water wells* (sets)	Total yield in 2009* (m^3/hr)
Changhwa	5.7	11.0 cm/year	55	8,313
Yunlin	7.4	11.6	540	76,821
Chiayi	4.6	7.0	24	1554
Tainan	5.5	4.0	24	1554
Yilan	0.8	3.3	115	13,702
Pingtung	2.7	2.2	833	76,648

#Source: Water Resource Agency, MOEA, [13]
*Source: Council of Agriculture [32].

In agricultural regions, groundwater has been withdrawn at rates in excess of recharge. At present, the water infiltration rate into groundwater storage is estimated to be about 4,000 m^3 annually, less than the extraction rate of 5,831 m^3. This means that groundwater over-exploitation is about 1,831 m^3 in Taiwan.

Such over-exploitation brings about land subsidence (water table falling) due to underground aquifers declining too quickly to be replenished. Western Taiwan along the costal areas has serious subsidence. The accumulated depth of land subsidence and the subsidence rate is listed in Table 2. For example, the land subsidence (water table declining) rate was 11.6 cm/year in 2005 and 7.4 cm/year in 2009 for Yunlin County, a poor region located in south-central Taiwan. The accumulated land subsidence depth in some costal areas has been up to 2.51 m (Changhwa Country) and 2.43 m (Yunlin County) by 2009 [13].

It is roughly estimated that the adverse effects of land subsidence has a direct correlation with the number and total yield of the installed water wells (Table 2). The depth has reached more than 140 m for 1.2% of the operating water wells [13]. Groundwater over-exploitation is also accompanied with water quality degradation and decreased groundwater discharge to streams due to aquifer depletion, aquifer subsidence (sinking of land), and intrusion of salt water into aquifers.

The Proposal to Enhance Water Resources

If the water consumption rate is higher than the replenishment rate of water resources of either surface water or groundwater, water scarcity takes place and may affect both environmental and economic development. In general, short-term strategies to increase water supplies include:

- to build dams and reservoirs to store rainfall runoff
- to bring in surface water from another area
- to withdraw groundwater
- to convert salt water to fresh water (desalination)
- recycling of gray water

Recycling of gray water has been encouraged by many researchers. For example, Chen [14] developed a framework for recycling household gray water for gardening and irrigation use and argues that household gray recycling can be a major supply source. However, few people have adopted this practice. All these short-term strategies for water supplies except for recycling of gray water have a variety of problems and found adverse effects on the environment (see "the status of water resources in Taiwan"). We present a framework in Fig. 2 in which the long-term strategies are proposed by focusing on the conservation of water resources. Since precipitation is out of our control, the key factors to affect the conservation of water resources may be attributed to:

(1) the storage of surface water
(2) the storage of groundwater (Fig. 2)

Lane and D'Amico [15] use remotely-sensed Light Detection and Ranging (LiDAR) data to estimate potential water storage capacity of isolated wetlands in north-central Florida and find that the water storage capacity of isolated wetlands is 1619 m^3/ha on average, with a median measure of 876 m^3/ha. Based on the research results, we can derive the relationship among wetland area, storage capacity, and wetland characteristics, and then estimate the minimum area of wetlands needed for the conservation of water resources and ecological system services.

Groundwater storage is determined by the balance between groundwater input (water infiltration and percolation from rainfalls) and output (groundwater moving downhill through rock pores and seeps out into streams and lakes, eventually reaching the sea, or extracted by pump for human use). The recharge of groundwater depends on the capacity of infiltration and percolation that is in general affected by the recharge area[1]. And thus, the solving method for the conservation of groundwater storage is to increase the recharge area for the enhancement of infiltration and percolation rates (Fig. 2).

Wetlands may play an efficient role in groundwater recharging in addition to forest and plant areas, and have a significant impact on surface water flow and downstream

[1]Any area of land where water passes downward or laterally into an aquifer is called a recharge area.

water quality [16]. They are a key element affecting the management of the fresh water supply. Many researchers have focused on the interaction between groundwater and surface water systems such as streams, lakes, and wetlands [17], and find that the interaction between groundwater and surface water plays an important role in wetlands affecting the dynamics of wetland hydrology [18].

Wetlands can serve as a buffer tank for extreme water flows after heavy rainfall to reduce the storm water runoff rate and the consequent disaster occurrence. It is seen as an effective practice method to decrease the runoff peaks and improve the surface runoff water quality [19, 20]. On the other hand, a decline in water quality may cause a reduction in many native species in the river and destroy the whole ecological system.

Wetlands play a positive role in maintaining fresh water resources for drink water supply, sanitation, agriculture and food as it can provide nutrients necessary for biological productivity and help groundwater conservation. Basically, wetlands contain numerous living animals or plants and provide positive impacts on the groundwater system. For example, the mangrove community including *Clerodendrum inerme* (glory bower), *Hibiscus tiliaceus* (cuban bast), and *Excoecaria agallocha* (milky mangrove) can be found among other coastal plants such as *Bolboschoenus planiculmis* (salt marsh weed), *Sporobolus virginicus* (more commonly known as marine couch, sand couch, coastal rat-tail grass, salt couch grass, saltwater couch, or nioaka), *Spinifex littoreus* (littoral spinegrass), *Scaevola taccada* (naupaka kahakai or beach naupaka), etc. In addition to the plants, birds, fish, crabs, and shells are also part of the mangrove forest. And thus wetlands can help ecosystems regulate ecological processes to attain a healthy environment, serving as cradles of biological diversity to maintain biodiversity and the production of wetland goods. Wetlands also are helpful for climatic stabilization as wetland plants like mangrove can adsorb CO_2, build the land, and clean pollution [16].

In the framework of Fig. 2, the increase in wetlands plays a vital role in affecting successful management of conservation of resources. The consequent increase in recharge area and surface water storage can provide a sus-

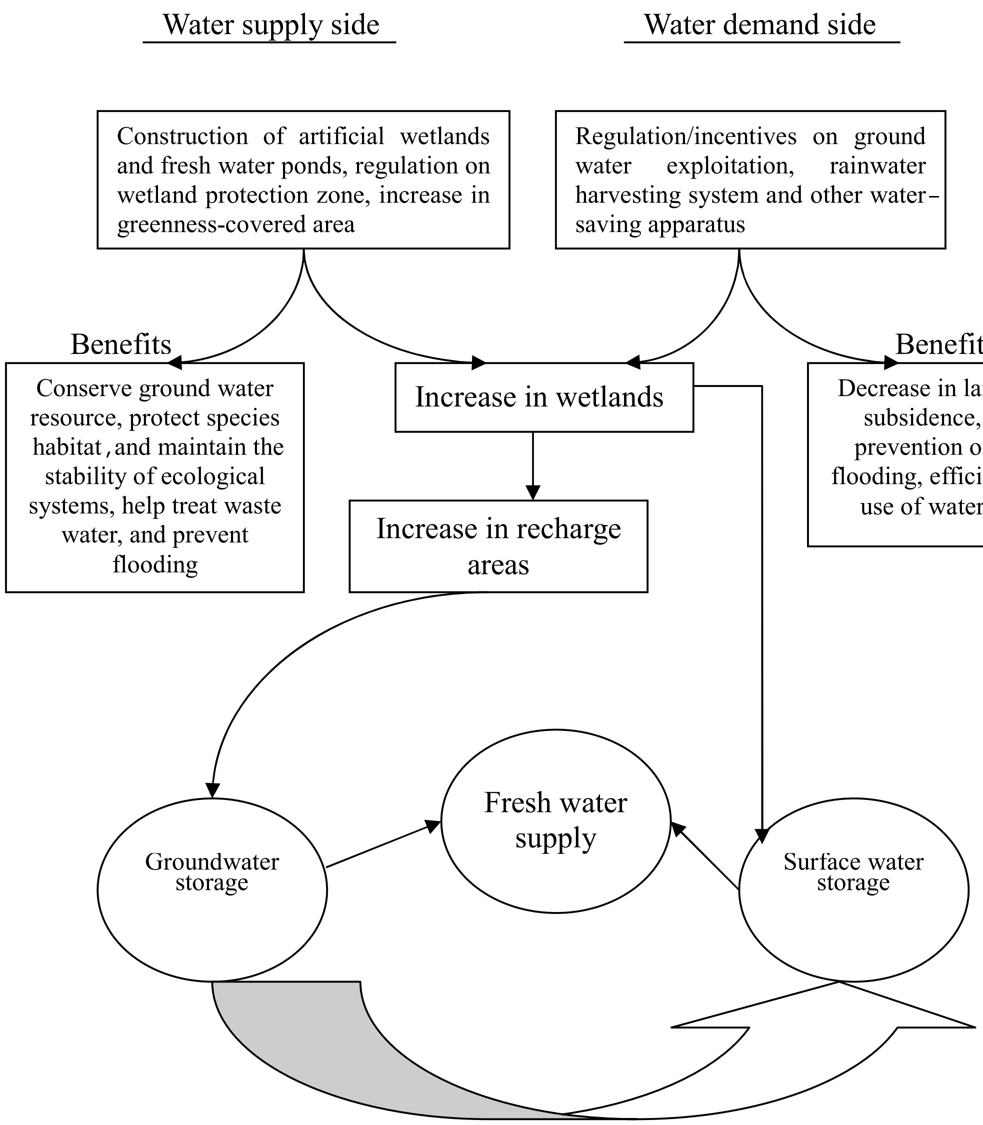

Fig. 2. A framework for the conservation of water resources.

tainable life of the water system and its related ecological system. In detail, the proposed strategies include:
(1) the construction of artificial wetlands
(2) regulation on the creation of wetland protection zones
(3) the motivation to build fresh water ponds near agricultural fields
(4) the motivation to increase green areas.

On the other hand, we proposed that the strategies from the water-demand side should be focused on the reform of water policies, which may include:
(5) groundwater management to avoid groundwater over-exploitation, and
(6) incentives on the establishment of water harvesting systems and water saving apparatus.

The Construction of Artificial Wetlands

Artificial wetlands may be used as a best management practice for the conservation of water resources playing vital roles in amphibian conservation[2] [21]. Additionally, they also can serve as an auxiliary instrument for waste water treatment and stabilizing ecological systems [22, 23]. Modern sewage plants are in general expensive and thus constructed wetlands can help solve a portion of the waste treatment problem. Nutrient-rich waste discharged from households or heavy metal accompanied with the treated effluent from industrial zones is more or less environmentally destructive. If these effluents are released into water systems either legally or illegally, they disrupt the ecological balance and create incredible algae blooms. Fish in the river cannot survive in low-dissolved oxygen water with high BOD due to cultural eutrophication.

The Taipei County government has constructed an artificial wetland along Tahan River, totaling 132 hectares, and gained successful experience. It is a surface flow wetland, designed to help the treatment waste water from industrial zones. In practice, the treated waste water discharged to the river by industrial zones only complies with the minimum environmental standards regulated in order to minimize waste water treatment costs. As most rivers become droughty in normal seasons, the total pollutant concentrations in the river after receiving the treated industrial waste water are always beyond the limit that a whole ecological system can handle. The Tahan wetland treatment system looks like a natural wetland in function and appearance. The processing capacity of this wetland treatment system is 6,000 m^3/day, removing pollutants through flocculation and sedimentation when waste water flows through stands of aquatic plants growing in shallow water. It efficiently reduces BOD from 54.5 mg/l to 8.2 mg/l (85.4% of BOD removal rate), suspended solid (SS) from 44.9 mg/l to 6.1 mg/l (77.5% of SS removal rate), and NH_3-N from 39.5 mg/l to 5 mg/l (85% of NH_3-N removal rate). The treated water is discharged into the Tahan River at the end of the process. The artificial wetland has been proved to offset the negative effect of the waste water legally discharged and improve the water quality in the Tahan River with a high increase in dissolved oxygen by approx. 15 times, from 0-0.5 mg/l to 7-9 mg/l [24].

The artificial wetland constructed by Taipei County is relatively simple and easy to operate and maintain. At the bottom, a filtration layer composed of mud, sand, and different sizes of stones is constructed. Plant species are selected, made up of several hundred species, for planting in the wetlands for bio-decomposing the wastes and obtained locally so that these wetland plants can tolerate local climatic conditions, pests, and diseases with high pollutant removal capacity. In brief, these plants are adopted to filter out suspended materials or to absorb the pollutants or toxic metals from the waste water, by directly assimilating the pollutants or indirectly transforming the nutrient pollutants into nitrogen (nitrification via root-zone oxygen release and denitrification via production of carbon substrates). As a consequence, this constructed wetland system can effectively remove NO_3-N through denitrification, transform nutrients and sunlight into plant growth, release oxygen through photo synthesis, filter out impurities through plant roots and stems to trap and gather sediments, and prevent algal blooms and deoxygenation in aquatic environments. The special feature of this wetland waste treatment system does not use any chemical, but consumes very little electricity power to pump waste water from one cell to another. Due to the rich biota resources in this area, the government has designated this area as the wetland park to provide residents with a better leisure environment and to serve as a public education place for citizens to understand the unique wetland fauna and flora.

Many regions in Taiwan's agricultural zones currently are still lacking sewer systems in Taiwan and thus most households discharge their sewage directly into the neighboring river. Compared to waste water treatment plants, an artificial wetland has lower maintenance and operating costs [25]. According to the evaluation model constructed by Trepel [26], wetland restoration is a cost-efficient strategy for nutrient load reduction compared to a waste water treatment plant. Cohen [27] argues that the conventional treatment technology by means of chemical precipitation to remove pollutants may produce large volumes of wet sludge that require further treatment of sludge concentration. Recent developments and improvements in wetland treatment systems result in more effective treatment on metals and acidity removal through the construction of bioreactors. This artificial wetland system can serve as a small-scale residential wastewater plant in the agricultural zones, where the land price is much lower and more available.

The Building of Freshwater Ponds

Freshwater ponds serve as a buffer tank for the conservation of fresh water resources, but also provide important habitat for amphibians, fish, birds, and beneficial insects.

[2]Shulse et al. [21] survey 49 artificial wetlands and find that cricket frogs (*Acris crepitans*), bullfrogs (*Lithobates catesbeianus*), and leopard frogs (*Lithobates blairi*/sphenocephalus complex) each occur in more than 80% of surveyed wetlands.

These ponds can be designed to capture runoff from the landscape, and serve as an important media for the conservation of groundwater. At present, very few wetlands (such as ponds, pools, lakes, swamps, etc.) can be found throughout the Taiwan Island. Most wetlands are filled or developed or modified for higher profitability production as they are often perceived to have little or no value compared to other uses. Many lakes, ponds, or swamps have been converted into residential and commercial locations and are gradually disappearing in Taiwan. And thus, an incentive mechanism is required to motivate the construction of a pool or pond around agricultural fields. The increase in water pond or pool will create a virtuous cycle to lessen the competition for scarce water resources.

The Regulation on Wetland Protection Zones

The protection of wetlands is an effective method to preserve and sustain the quality of fresh water resources for the well-being of human communities, to enhance ecosystems for biodiversity, and to build long-term climate resilience. Many wetland areas are, however, experiencing immense pressures. Most wetlands are filled and developed for other uses, or modified for higher profitability production, and eventually are degraded, abandoned, or destroyed due to the lack of profitability for land owners of wetlands and the priority choice of the "development policy." The major threats leading to wetland degradation include drainage for agriculture and settlement, excessive exploitation by local populations, and improperly planned development activities [28]. Some environmental pressures threaten the continual survival of wetlands as well as species in its ecological system due to aggravated pollution, increased water extraction for agriculture, and the construction of dams.

Since the maintenance of wetlands and effective use of water resources is beneficial to both humans and the natural environment, the wetland protection zone is needed to induce a sustainable development over the long term. In general, the goal of wetland protection can be attained through governmental regulations and economic instruments (for example, monetary incentives and tax deductions). Unfortunately, Taiwan has not yet imposed any regulation on the protection of wetlands. Until now, a wetland protection zone has not been designated and listed in the classification code of land use zones/types. The land use is categorized into the use for construction, arable and pasture, forest, aqua-culture, irrigation, ecological and conservation, protection and conservation, special purpose, salt industry, mining industry, pottery industry, transportation and communication, recreation, historical site, cemetery, and others. Furthermore, Taiwanese government has neither investigated the amount of wetland loss over the past several years nor evaluated the impact of wetland loss.

If the wetland protection zone is designated by a legal regulation, a large amount of wetlands and marsh transition habitat will be restored[3] and increased land subsidence near the costal areas will be terminated. Wetland protection also can lead to comprehensive, integrated watershed protection through the cooperation of all stakeholders. Such a regulation also can help attain a sustainable management system by integrating water, land, and wetland resources.

Motivation for Green Areas

A great portion of the ground in Taiwan is covered by impervious surfaces like cement, and thus the infiltration and percolation area is gradually reduced. For example, the front yards of most private buildings or playgrounds in schools have been paved by concrete or asphalt to avoid the growth of grass and the consequent bites of mosquitoes. The asphalt-paved road seems a necessary evil to support traffic systems, even though the 'paved' areas may reduce the function of water infiltration and percolation into the soil and aquifers. And thus, groundwater recharge is reduced and surface water runs off into the sea directly.

Forests are seen as a natural well and help humidify air through transpiration and form a virtuous water cycle, and thus play important roles in helping water conservation, flooding prevention, and warming gas mitigation. Furthermore, the protection of forests provides benefits of biodiversity conservation, recreational values, and economic values. Because of inappropriate forest management, trees are clear cut over a great number of areas in Taiwan's mountains, and substituted by high-value vegetables. The tree clear-cutting may be a major factor leading to mud-mixed-with-stones flows recently occurring in Taiwan. The eldery recognized that Yueshan Mountain (the highest mountain in Taiwan) and Ali Mountain (a famous recreation site) in the past was much greener. Forest management has significant impacts on water quality [31]. Appropriate control and management on timber harvesting can reduce sediment yield, and eventually can help the conservation of water resources.

Regulation of Groundwater Exploitation

Groundwater is an important resource to replenish insufficient water supplies in drought seasons. Aqua-culture and other agricultural production are seen as major factors threatening groundwater quality and result in the over-consumption of groundwater.

Comparing water intensity and water contribution between agricultural and industrial sectors, we conclude

[3]The restoration technique has been refined and developed in recent years. Many researchers have attempted to investigate the effectiveness of restored wetlands in replacing the ecological functions of those lost to development [29]. For example, Brooks et al. [30] use the measures of hydrologic, soil, and biodiversity characteristics to develop a conceptual model of wetland degradation and restoration. The results show that wetland diversity and variability often become more homogeneous through the degradation process of wetlands. Based on the data collected from reference wetlands, policy makers can assess the condition of degraded wetlands and improve the design and performance of mitigation projects.

Table 3. The contribution of agricultural and industrial sectors to Taiwan's GDP.

Year	Total GDP*	Agricultural sector* (% of total GDP)	Industrial sector* (% of total GDP)
2002	10,411,639	188,436 (1.82)	3,151,983 (30.38)
2003	10,696,257	183,581 (1.71)	3,346,187 (31.2)
2004	11,365,292	190,733 (1.68)	3,609,198 (31.75)
2005	11,740,279	195,833 (1.67)	3,676,297 (31.26)
2006	12,243,471	197,589 (1.61)	3,835,932 (31.33)
2007	12,910,511	191,621 (1.49)	4,030,668 (31.38)
2008	12,698,501	201,950 (1.60)	3,701,980 (29.25)
2009	12,512,678	195,008 (1.55)	3,740,438 (29.79)
Water use in 2008#	17,984.95	12,960.11 (72.06)	1,667.54 (9.3)
Water intensity in 2008	$1.42 \cdot 10^{-3}$ m^3/NT$	0.064 m^3/NT$	$0.45 \cdot 10^{-3}$ m^3/NT$
Water contribu. in 2008	NT$ 706/ m^3	NT$ 15.58/ m^3	NT$ 2,220/ m^3

Source: Council of Agriculture [32].
*Unit: 10^6 NT$
#Unit: 10^6 m^3

agricultural production is water-intensive industry and contributes little to GDP (Table 3). The GDP contributed by the agricultural sector is NT$ 201.95 billion, about 1.6% of total GDP only in 2008, but the agricultural sector consumes 12,960.11 million m^3 of water, accounting for 72.06% of total water consumption. In contrast, industrial sectors contribute 29.25% of total GDP by consuming 1,667.54 million m^3 water, accounting for 9.3% of total water consumption in 2008. The water intensity[4] is $1.42 \cdot 10^{-3}$ m^3/NT$ for all sectors, 0.064 m^3/NT$ for agriculture sectors, and $0.45 \cdot 10^{-3}$ m^3/NT$ for industrial sectors. Each m^3 of water can contribute NT$ 706 to Taiwan's GDP. Agricultural sectors contribute NT$ 15.58 only by consuming each m^3 of water while the industrial sector contributes much more in the amount of NT$ 2,220 (Table 3).

In a similar way, the value of aqua-culture production is NT$ 4.3 billion, accounting for 1.03% of total agricultural production (NT$ 417.5 million) only, but water consumption for the aqua-cultural industry is 1,646.77 106 m^3, accounting for 12.7% of total water consumption for agriculture (Table 4). The water intensity[5] in 2008 is 0.031 m^3/NT$ for agricultural production and 0.382 m^3/NT$ for aqua-cultural production. Each m^3 of water can yield NT$ 32.2 of production value for all agricultural sectors, but NT$ 2.61 only for aqua-culture (Table 4).

The above results imply that we have to seek an efficient agriculture sector that creates more value by using fewer environmental resources like water. The policy should direct agricultural industries to enhance long-term productivity and protection of the biological and physical resource base. In 2009 the cultivated land area was 8,154 km^2, accounting for 22.65% of total land area of 36,188 km^2, including 4,157 km^2 for paddy fields, and 3,997 km^2 for upland fields [32]. The aqua-cultural area is in total 4,301 km^2, including 127 km^2 for shallow sea culture, 206 km^2 for brackish ponds, 190 km^2 for fresh water ponds, 3,765 km^2 for cage culture, and 13 km^2 for other types of aqua-culture. Considering the low production value of aqua-culture, an incentive system is required to suspend the operation of the aqua-culture ponds with high water intensity. These suspended ponds can serve as natural wetlands for the conservation of water resources and ecological systems and may mitigate the land subsidence rate or even stop it.

In order to restrict over-exploitation of groundwater through governmental regulation, the development of a safe minimum standard (SMS) working as a policy tool is proposed to control the continual subsidence of groundwater. For example, the high subsidence rate regions like Yunlin County should be regulated to extract groundwater. The management authority should determine criteria of over-exploitation by consulting with hydrologists to evaluate the groundwater status at required intervals. Artificially recharging groundwater can be considered to conserve groundwater resources.

Basically, the regulation must at least include the tasks of compulsory registration of all the water wells, the establishment of criteria to determine the serious regions of over-exploitation, monitoring on the groundwater level, and the report on the extraction of groundwater to the authority in the serious regions periodically. The party involving the

[4]Water intensity in this table is calculated by the ratio of water consumption to GDP, and water contribution is the inverse of water intensity.
[5]Water intensity in this table is calculated by the ratio of water consumption to the production value, and water contribution is the inverse of water intensity.

Table 4. The production value of aqua-culture industry.

	Agricultural production	Aqua-cultural production (share of total agriculture)
2006	NT$ 376,953·10^6	NT$ 4,063·10^6 (1.08%)
2007	NT$ 388,294·10^6	NT$ 4,587·10^6 (1.18%)
2008	NT$ 417,500·10^6	NT$ 4,300·10^6 (1.03%)
2009	NT$ 407,169·10^6	NT$ 2,802·10^6 (0.69%)
Water use in 2008#	12,960.11·10^6 m^3	1,646.77·106 m^3 (12.7%)
Water intensity in 2008	0.031 m^3/NT$	0.382 m^3/NT$
Water contribu in 2008	NT$ 32.2/ m^3	NT$ 2.61/ m^3

Source: Council of Agriculture [32].

illegal exploitation of groundwater should be fined or jailed. The management authority is also empowered to cut off the power supply in case of emergent concern on the loss of groundwater storage.

Constructing a Rainwater Harvesting System

A rainwater harvesting system equipped in households, offices, schools, etc. may overcome the irregular or poor-quality water supply by storing rainwater in an underground tank for future use. After primary treatment, rainwater can be used for gardening, car washing, and other domestic activities. If the treated rainwater meets the regulated sanitary standard, depending on seasonable climatic conditions, then it can serve as potable water.

The technique for rainwater collection and storage has been developed and thus the rainwater harvesting system can serve as a major alternative source for fresh water, especially when the groundwater level is depleted. Due to high land costs in urban regions, it seems difficult to implement a compulsory regulation on the dwellers for the construction of rainwater harvesting systems. However, it is possible to encourage environmentally concerned people to build rainwater harvesting systems in rural regions (especially for large buildings) by providing subsidies. Of course, it requires some incentives to motivate households to construct rainwater tanks.

Discussion and Conclusions

In fact, the effective use of wetlands is beneficial to both humans and the natural environment, as it can induce sustainable development over the long term. The modification or conservation of private wetlands is often driven by economic motives. And thus, the governmental policy on the protection of wetlands should reflect the land-owners' interests. Incentive systems are required to motivate private land owners to maintain a wetland or to construct a new one. However, Taiwan's water management practice operated currently is fragmented as the dominating power is shared and involves various organizations that in general have different or even conflicting policy objectives. For example, Twain Water Company aims at the sufficient supply of tap water for household use and neglects the environmental impact or water conservation. The river management authority (water resource management, MOEA) cares much more about the prevention of flooding and thus focus on the construction and reinforcement of banks in negligence of the conservation of water resources and ecological systems. And thus, future water management practices have to integrate all the parties to overcome the conflicting objectives, overlapping responsibilities and gaps in responsibilities. For example, the aims of water management must recognize its connection with climate change adaptation through regional cooperation and co-ordination to share the transboundary water resources. The governance structure should encourage efficient use of water and conserve natural resources by integrating the planning of land use, agriculture, forestation, and economics to have integrated objectives of water management that at least may include sharing of information, the protection of ecological systems, and the conservation of water resources. Such an improvement on water management practice should aim to establish clear and consistent objectives (among dominating organizations), resulting in a more cooperative and compatible approach to resource management, and eventually producing a sustainable future for water and ecological systems.

This paper highlights the important role of wetlands for the conservation of water resources and stability of ecological systems. The results emphasize that the increase in recharge area (water infiltration area) and the green area is vital to conserve water resources. Eventually some strategies are presented to solve the problem of water scarcity at the source by using a prevention principle.

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