Quantification of Water Distribution in California: A Case Study for Other Regions in the World

Amrith Gunasekara, PhD, Director of Science and Research, California Farm Bureau, California Bountiful Foundation, 2600 River Plaza Drive, Sacramento, CA 95833
agunasekara@cfbf.com
279-977-2963

Abstract

Data for water distribution by the urban sector, environment, and agriculture across the world is not readily available, publicly accessible, or quantitatively evaluated. It is critical for any society to define and transparently account for regional water distribution in a state or country to facilitate accurate information sharing with the public. Water use in California has been criticized for the past two decades, especially during the historic 2012-2016 drought, with agriculture labeled as the largest water user. Various media sources state that California agriculture uses 80% of the region's water. This study, using publicly available data, reveals that agricultural water use in California constitutes only 12% of the total water the state receives in a wet year, a year in which the precipitation exceeded the historic average total precipitation. In a dry year, with precipitation less than that of the historical average total precipitation, agriculture water use is only 29% of total water. Agriculture water use in California was found to be four times that of the urban/domestic sector. Additionally, the study shows that the environment, not agriculture, receives 80% or more of all the water that arrives in the state. Continued and increased water allocations and increased storage for agriculture could be facilitated and should be considered since California leads the nation in food production and plays a fundamental role in regional and global food security. Other states and regions must work to quantify their total precipitation and water distribution to the different sectors to realize the value of water for food production and security.

Introduction

Climate change is changing weather patterns across the globe and affecting local and regional moisture patterns. For example, California has experienced two historic droughts in the past 20 years, along with record-high moisture levels in other years as a result of climate change [1]. The quantitative extremes from climate change, on top of already episodic moisture events that are found in Mediterranean regions, can result in the poor collection, allocation, and distribution of water to different social and economic sectors. For instance, many media sources can be found stating that agriculture receives 80% of the water in California [2, 3, 4]. Organizations use the 80% value referenced in the media [5] and still reference the same values with clarifying statements such as “80% of California’s developed water supply” without further explanation of how “developed” is defined [6]. Research and governmental organizations have stated that agricultural water use is 40% of total water in California [7, 8]. The discrepancies in the values for California agricultural water use in the media (e.g., 80%) and those that are presented by research and governmental agencies (e.g., 40%) have led to a confused and poorly informed general public.

More accurate quantification and classification of water are needed to ensure that information distributed to the general public and policymakers in California and elsewhere worldwide is accurate, precise, and easily accessible with adequate scientific translation. This study evaluated, using publicly available data, the distribution of total water received in California by the three major social and economic sectors; environmental, urban, and agricultural sectors. The study shows that California's agricultural water use is overestimated while environmental water is greatly underestimated. Accurate information distribution will help water consumers and the general public to understand the benefits of their water collection and distribution systems, any efficiencies made in each sector, the use of any technologies for further water efficiency, and how the sectors are essential for social and economic growth.

Analysis

Total, Captured, and Uncaptured Water

Any analysis of water distribution in California or elsewhere in the world must begin with how much total water, or precipitation, the region receives. Table 1 below provides the data on water received and distributed in California by the three main beneficial use sectors; agriculture, the environment, and the urban/domestic sectors. The first observation is that California receives, on average, approximately 200 million acre-feet (MAF) of water from precipitation such as rainfall and snow. Some of the 200 MAF is captured and used for storage. The remaining water is not captured. How much is captured via dams and reservoirs depends on how much water arrives in the state through precipitation, and this amount varies depending on the year, as evident from Table 1.

Table 1. Distribution of water in California. MAF is million acre-feet (sent as separate file).

Fig 1. The amount of water California receives on average annually (1998-2005; inset) and how much of that water is captured for multiple beneficial uses depending on whether it’s a wet or dry year. The red color denotes water not captured, while the blue color denotes water captured and stored for use throughout the year. The 200 MAF is the state's average precipitation, calculated over several years (e.g., 1998 to 2005). The value for average precipitation can vary greatly depending on California falling into either a wet year (over 200 MAF) or a dry year (less than 200 MAF).

Wet Years and Dry Years

California is one of five Mediterranean regions in the world. The climate can be defined as mild cool winters with a defined rainy, hot, dry summer. California has experienced precipitation variations in recent decades due to climate change. In some years, precipitation in the State has been high, while in other years, it has been lower. The lower years of precipitation, when combined together, fall into the definition of a drought.

There are no specific definitions for what constitutes a “wet” year or a “dry” year. For the purposes of this study, however, a wet year constitutes any precipitation greater than the total precipitation received over time or quantitively established as 200 MAF from 1995 to 2005. Subsequently, a dry year will constitute precipitation less than the total precipitation received over time or less than 200 MAF calculated from 1995 to 2005. For example, 2011 can be considered a wet year since the state received 134% of its average or approximately 248 MAF.

In contrast, 2014 is considered a dry year where the state received 56% of average rainfall or approximately 102 MAF. Fig 1 shows that in 2006, the state received 254 MAF, while in 2014, at the height of the State's historic drought, California received only 103 MAF, or roughly half of what the state receives on average.

Table 1 and Fig 1 show the amount of captured and uncaptured water in California. In a wet year, for instance (e.g., 2006), the State captured 103 MAF through dams and water storage projects. This capture does not include groundwater recharge or flood-managed aquifer recharge (Flood-MAR) on farms, which is becoming commonplace to address the California Sustainable Groundwater Management Act, a regulation to bring groundwater basins into sustainability over a specific amount of time [13].

Results

Uncaptured Water

The uncaptured water in 2006 accounted for 59% of the state's total precipitation. The same uncaptured water flowed out to the ocean during winter surface runoff and spring snowmelt through the state's streams and rivers. In 2014, a limited amount of water was captured even during a drought year. In 2014, as observed in Fig 1, only 60% of the total water, or 62 MAF, was captured. Another 40% or 41 MAF was not captured and flowed out to the ocean and the environment through California's streams and rivers, especially during winter rain events through surface water runoff. Although this uncaptured water should be considered "environmental" water since it flows through the state's streams and rivers, providing a beneficial winter "environmental" use on its way to the Pacific Ocean, it is not defined or accounted for as "environmental" water. Rather, only water that is captured and then allocated to the environment to comply with state and federal rules for endangered species is referenced as "environmental" water. This sort of classification has unintended consequences on water distribution to other sectors, as evidenced in this study.

Water Distribution to the three Social and Economic Sectors in California

Water in California is allocated amongst three beneficial use sectors. These beneficial uses are water for agriculture, the environment, and urban (also known as domestic) sectors. What is evident in Table 1 is that the urban and the agriculture sectors get allocated similar amounts of water regardless of wet or dry years on a consistent basis from the amount of captured water. This water distribution is highlighted in Fig 2. In 2006, a wet year, from the amount of captured water, the agriculture sector water allocation was 30 MAF. This distribution increased slightly to 35 MAF in the dry year of 2014. On average, California allocates approximately 32.5 MAF, as observed from Table 1, in any given year for agriculture. The percentage distribution of water allocation for agriculture, as observed in Fig 1, differs greater and ranges from 29% in a wet year to just over half of total captured water as observed in a dry year (53%; 2014).

Fig 2. Allocation of captured water in California for a wet year (2006) and dry year (2014) by the three beneficial use sectors; agriculture, urban, and environment. The brown color denotes water use in the agriculture sector, the green color refers to water in the environmental sector. The purple color is water use in the urban and domestic sectors.

Similar observations are evident for urban and domestic uses of water. Regardless of a wet or dry year, Table 1 and Fig 2 show that the urban sector receives 8 MAF of water. By percentage, in a wet year, this amounts to 8% of captured water, while in a dry year, it amounts to 12% of captured water.

Water allocation to the environment is the sector whose allocation differentiates the most between a year and a dry year, compared to the other two sectors. In a wet year (2006), the water allocations for the environment from captured water is 64 MAF from a total captured amount of 103 MAF. The environmental allocation is by far the largest allocation of water among the three sectors. The remaining 39 MAF are distributed amongst the agriculture and urban sectors. The environmental water allocation value is reduced to 22 MAF during a dry year (2014). In a dry year, approximately 22 MAF out of 62 MAF captured water is used for the environment. This environmental allocation of water is less than the agricultural allocation in a dry year but twice as much as in a wet year. Regardless of a dry or wet year, the urban and agriculture sectors get allocated approximately the same amount for captured water (Fig 2). Fig 2 also shows that in a dry year, there continues to be a commitment to providing water to ensure food security and support urban drinking water.

In general, in a wet year, more water is released while in a dry year, less water is released from storage systems consistent with any regional water storage system. Water storage systems such as dams cannot hold an indefinite amount of water, and in a wet year in California, water has to be released on a consistent basis throughout the year to make additional storage space for melting snowpack from the Sierra-Nevada Mountain range within the State. The data shows, however, that in wet years, water allocation for agriculture does not increase greatly, similar to environmental allocations. Existing water policies, therefore, seem to prioritize the environment receiving more water than agriculture does (parley due to lack of storage), with allocations of water for agriculture actually declining in a wet year compared to a dry year by 5 MAF; 35 MAF in a dry year (2014) compared to 30 MAF in a wet year (2006). The allocations of captured water for agriculture should be reversed, with the agriculture sector receiving more water in a wet year than in a dry year to ensure agricultural food security and provide for other beneficial ecosystem services such as Flood-MAR.

Agricultural Water Efficiency in California

Another noticeable finding from Fig 2 is that the agriculture sector receives a little under four times as much water as the urban sector. For example, in a wet year (2006), the agriculture sector received 30 MAF compared to the urban sector allocation of 8 MAF. This value is just over three times as much water as domestic urban use. Similar observations can be made for a dry year, with the agriculture sector receiving just under four times as much water as the urban sector. These values for agriculture highlight the efficiencies in water use that the agriculture sector in California is known for. Over 55% of the total irrigated acres in California are under some sort of efficient irrigation (sprinkler, drip, and subsurface irrigation), according to the California Department of Water Resources [7]. This percentage value is predicted to be much higher given that the DWR data is based on 2010 information, and drastic increases in agricultural water efficiency have been observed. Fig 3 shows how gravity-based irrigation methods (e.g., flood and furrow irrigation) management practices for irrigating crops have declined by over half since 1991; 70% of the State's irrigation for agriculture was flood and furrow irrigation in 1991 while it was approximately 30% In 2010. A downward trend in irrigation methods for sprinkler irrigation is also observed from 17% in 1991 to 13% in 2010. Inversely, upward trends for low volume and other irrigation methods are observed from 1991 to 2010. A three-fold increase in low-volume irrigation for California agriculture is observed from 1991 to 2010. Low-volume irrigation includes irrigation management practice that utilizes drip irrigation and micro-sprinkler irrigation. An upward trend in other irrigation management practices is also observed over time. These irrigation management practices include subsurface drip irrigation. It is hypothesized that efficient irrigation methods (drip, micro-sprinkler, and subsurface irrigation) will continue to increase after 2010 since the state has experienced two historic droughts, which have pushed farmers in California to conserve water even more with the advent of the Sustainable Groundwater Management Act which requires groundwater basins to begin compliance by 2022 and over the next 20 years.

Fig 3. Trends in irrigation methods used in California agriculture over time [10]. Other irrigation systems include subsurface drip irrigation.

Accurate Representation of California Water Distribution

Despite the use of water efficiency technologies to lessen the water footprint of agriculture in California, media outlets continue to, and in the past, inaccurately claim that California agriculture uses "80%" of the water (2-4). The 80% reference to agricultural water use is inaccurate. One way to arrive at this value is to consider how much water is allocated between the agriculture sector and urban domestic use and compare these two sectors with each other, as presented in Fig 4. This is a gross misrepresentation of water use since this method ignores California's captured water contributions to the environment that must be made as part of its efforts to keep endangered species, such as the salmon, alive and migrating upstream from the ocean, in addition to fulfilling its other "environmental" beneficial use obligations. This methodology also ignores uncaptured water runoff from the region's total precipitation.

Fig 4. Comparison of domestic/urban and agricultural sectors only in California. The methodology is used incorrectly to state that agriculture uses 80% of the water in California. The brown color denotes water for agriculture use and the purple color refers to water use in the domestic urban sector. This methodology excludes required captured water allocations to the environment and uncaptured water that flows to the environment.

The percent distribution in Fig 4 is further misleading since the values do not add up to 80%, as many news outlets claim. For a wet year, the agricultural distribution of water is only 73%, while in a dry year, that number increases to 78%. It is hypothesized, therefore, that when the current reporting on agriculture water use is reported, the referencing entity mathematically rounds up the existing values to 80%. This is a convenient yet inaccurate method of valuing water for agriculture, food production, and food security.

Fig 5. Percent distribution (%) of captured and uncaptured water (total) by sector. The brown color denotes water use in the agriculture sector, the green color refers to water in the environmental sector, and the purple color represents water use in the urban and domestic sectors. Agriculture water ranges from 12% or less in a wet year (2006) to 34% in a dry year (2014). The environment (water that flows via streams and rivers to the Pacific Ocean) receives the largest allocation ranging from 58-85% from captured and uncaptured water. The top image shows the environmental distribution of captured and uncaptured water, while the bottom image shows the environmental distribution of 58-85% of the total water the state receives.

Large Allocations of Water for the Environment in California

Fig 5, whose data is also summarized in Table 1, shows that the environment and not agriculture receives approximately 80% or more of water in a wet year. The 2006 wet year, despite high precipitation, is expected to have less water than the 2022-23 water year when an abundance of moisture arrived in California. Data presented currently in the popular media and even academia do not represent total water in the state in the figures described in Fig 5. One reason is that water that is not captured is not classified as "environmental" water even though it flows into the environment. Winter runoff and spring melt into rivers and streams constitute a significant fraction of the uncaptured water that flows into the environment. Fig 5, then, is a more accurate representation of water distribution in the State where both captured and uncaptured water is accounted for and distributed into the three classifications of water for agriculture, the environment, and urban domestic use.

In contrast to the statements made in the general media, agriculture does not receive 80% of the water in California and instead receives only 12% of that water in a wet year. In a dry year such as 2014, agriculture receives 34% of the total water that arrives in the state. This value is only four times that of urban domestic use, highlighting the infrastructure investments in water use efficiency in California agriculture systems. California is also the leading agriculture state in the nation for food production and produces 14 crops not grown anywhere else in the country [14]. According to state agricultural statistics, over 200 different crops are grown in the State. California is also one of five unique Mediterranean regions in the world best known for its agricultural production. These conditions make agricultural crop production ideal and place California as a foundational region for national food security.

Alignment with Water Quality Definitions

Water quantification in California is primarily completed in alignment with the major economic, social, and environmental sectors. However, water quality regulations provide many more categories in defining "beneficial uses" [15]. For example, one category under this definition is "Flood Peak Attenuation/Flood Water Storage." It is further defined as using riparian wetlands in floodplain areas and other wetlands that receive natural surface drainage and buffer their passage to receiving waters. However, the quantification of water for this category is not widely available. Several other definitions make water quantification challenging. Therefore, there is a need for the State and Federal agencies to provide a high level of quantification for all the categories listed under the beneficial use definition. The lack of this information has led to the generalization of water use by category and the manipulation of that data to victimize specific sectors as heavy water uses regardless of the multiple benefits it may provide (e.g., agricultural food security). More research and data into the detailed quantification of water by sector could prove useful to understanding water distribution in the State. Additionally, winter use of uncaptured water through agricultural management practices such as Flood-MAR or flooding of dormant agricultural fields with sandy soils to replenish depleted groundwater basins will contribute positively to using uncaptured water for other beneficial uses besides the environment. The environment does not require such high flows (often threatening to compromise existing levees) in winter months, and other beneficial uses (e.g., Flood-MAR) will reduce pressures from winter and spring flooding in wet years.

Conclusions

The data presented here show that water in California needs better quantification into all its beneficial uses and increased storage. The environment in California receives the largest allocation of water, which can be greater than 80% in a wet year. Agriculture water use is only four times that of urban domestic use. Greater water allocations, storage, and other beneficial uses for winter runoff can be helpful to ensure food security in the future. It also will ensure less fallowed land, which contributes negatively to rural economies and growth. This study also highlights the need for water distribution data to become more available so similar studies can be conducted elsewhere to understand and prepare for the extreme episodic weather changes that climate change induces in regions across the world.

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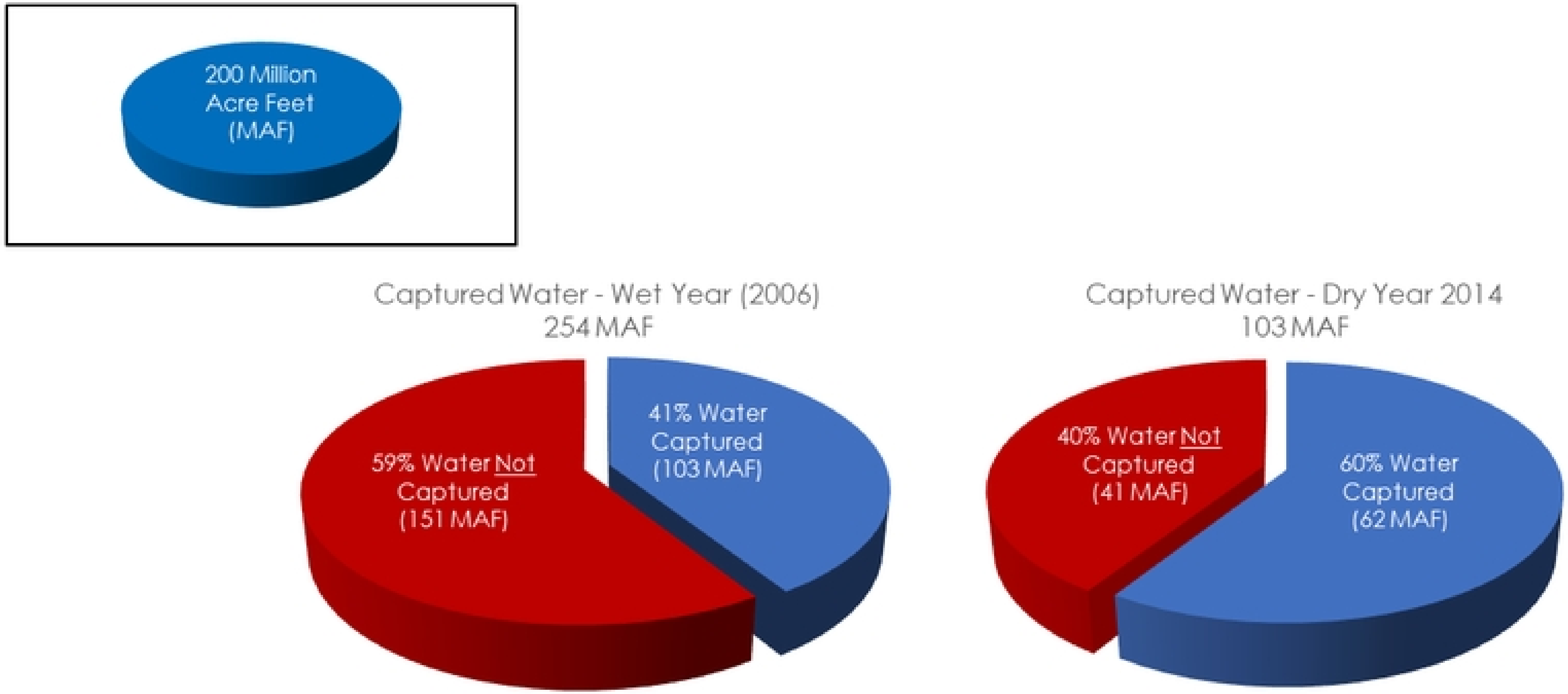
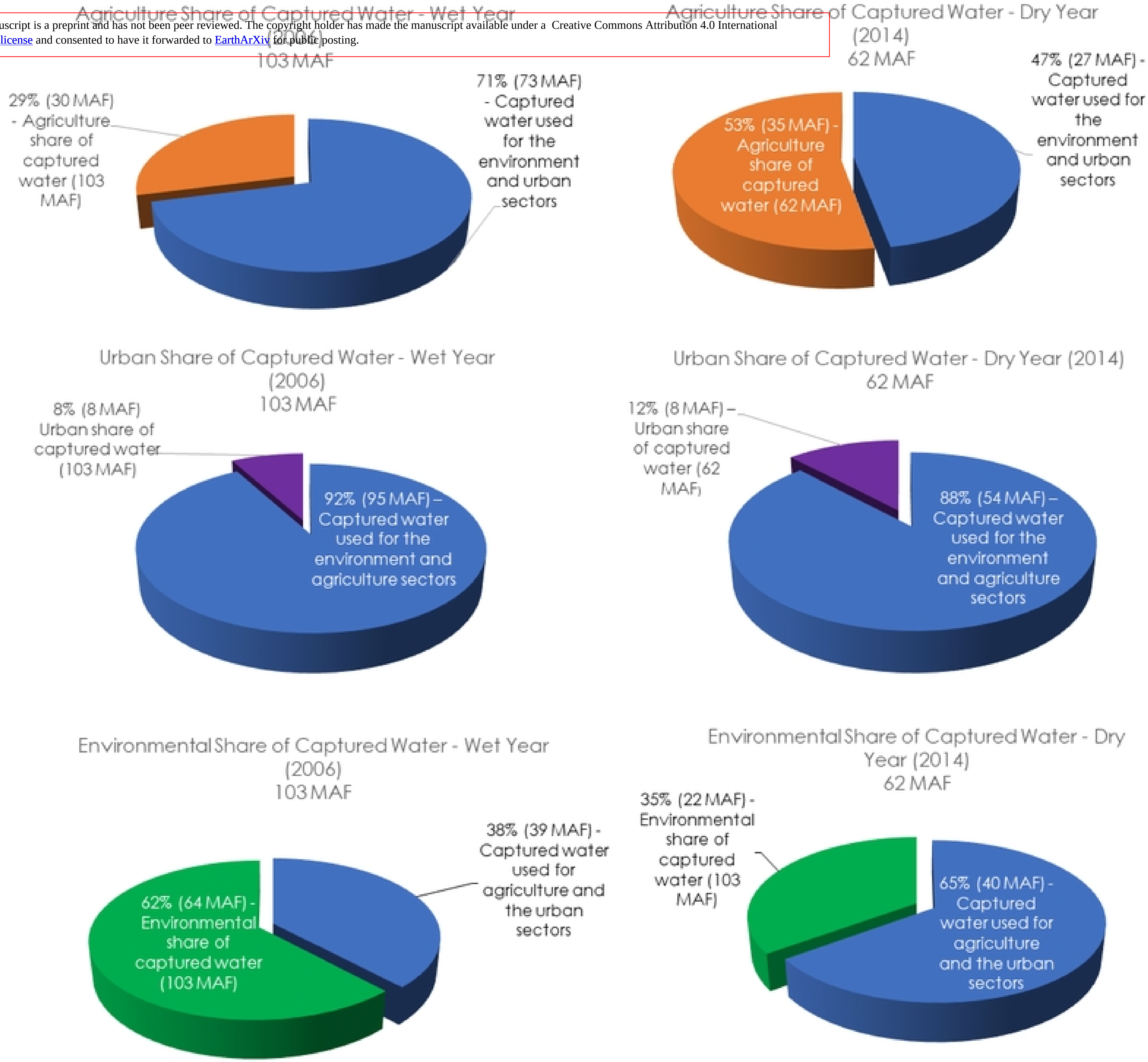
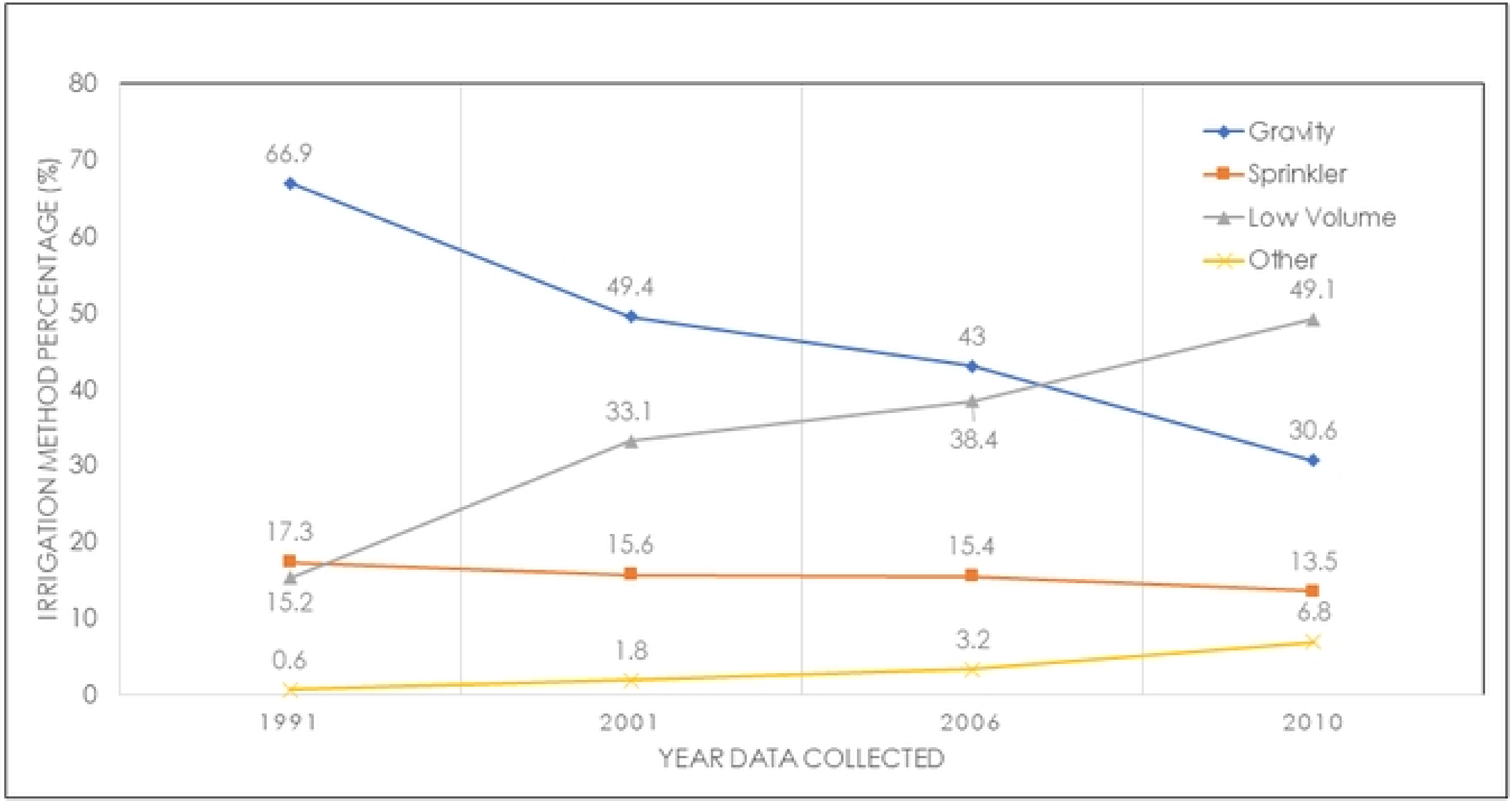

200 Million
Acre Feet
(MAF)
Captured Water - Wet Year (2006)
254 MAF
41% Water
Captured
(103 MAF)
59% Water Not
Captured
(151 MAF)
Captured Water - Dry Year 2014
103 MAF
40% Water Not
Captured
(41 MAF)
60% Water
Captured
(62 MAF)

Fig 1



Agriculture Share of Captured Water - Wet Year
(2006)
103 MAF
29% (30 MAF) - Agriculture share of captured water (103 MAF)
71% (73 MAF) - Captured water used for the environment and urban sectors
Agriculture Share of Captured Water - Dry Year
(2014)
62 MAF
53% (35 MAF) - Agriculture share of captured water (62 MAF)
47% (27 MAF) - Captured water used for the environment and urban sectors
Urban Share of Captured Water - Wet Year
(2006)
103 MAF
8% (8 MAF) Urban share of captured water (103 MAF)
92% (95 MAF) – Captured water used for the environment and agriculture sectors
Urban Share of Captured Water - Dry Year (2014)
62 MAF
12% (8 MAF) – Urban share of captured water (62 MAF)
88% (54 MAF) – Captured water used for the environment and agriculture sectors
Environmental Share of Captured Water - Wet Year
(2006)
103 MAF
62% (64 MAF) - Environmental share of captured water (103 MAF)
38% (39 MAF) - Captured water used for agriculture and the urban sectors
Environmental Share of Captured Water - Dry
Year (2014)
62 MAF
35% (22 MAF) - Environmental share of captured water (103 MAF)
65% (40 MAF) - Captured water used for agriculture and the urban sectors

Fig 2



80
70
60
50
40
30
20
10
0
IRRIGATION METHOD PERCENTAGE (%)
Gravity
Sprinkler
Low Volume
Other
66.9
49.4
43
30.6
49.1
33.1
38.4
17.3
15.6
15.4
13.5
15.2
6.8
0.6
1.8
3.2
1991
2001
2006
2010
YEAR DATA COLLECTED

Fig 3

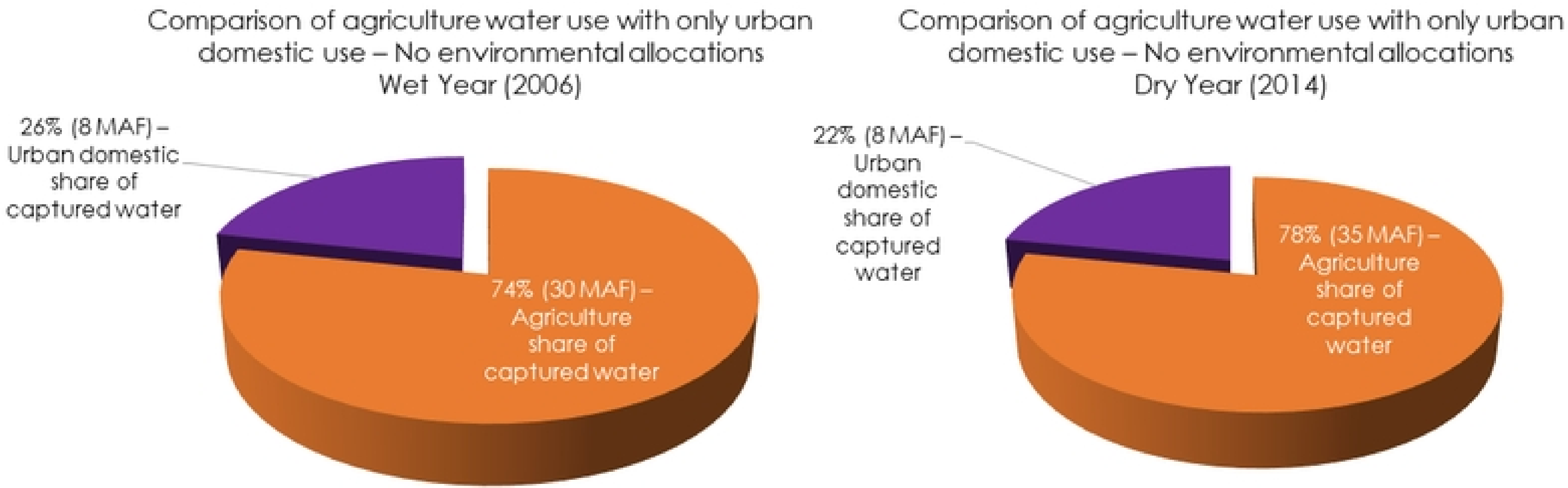

Comparison of agriculture water use with only urban domestic use – No environmental allocations Wet Year (2006)
26% (8 MAF) – Urban domestic share of captured water
74% (30 MAF) – Agriculture share of captured water
Comparison of agriculture water use with only urban domestic use – No environmental allocations Dry Year (2014)
22% (8 MAF) – Urban domestic share of captured water
78% (35 MAF) – Agriculture share of captured water

Fig 4

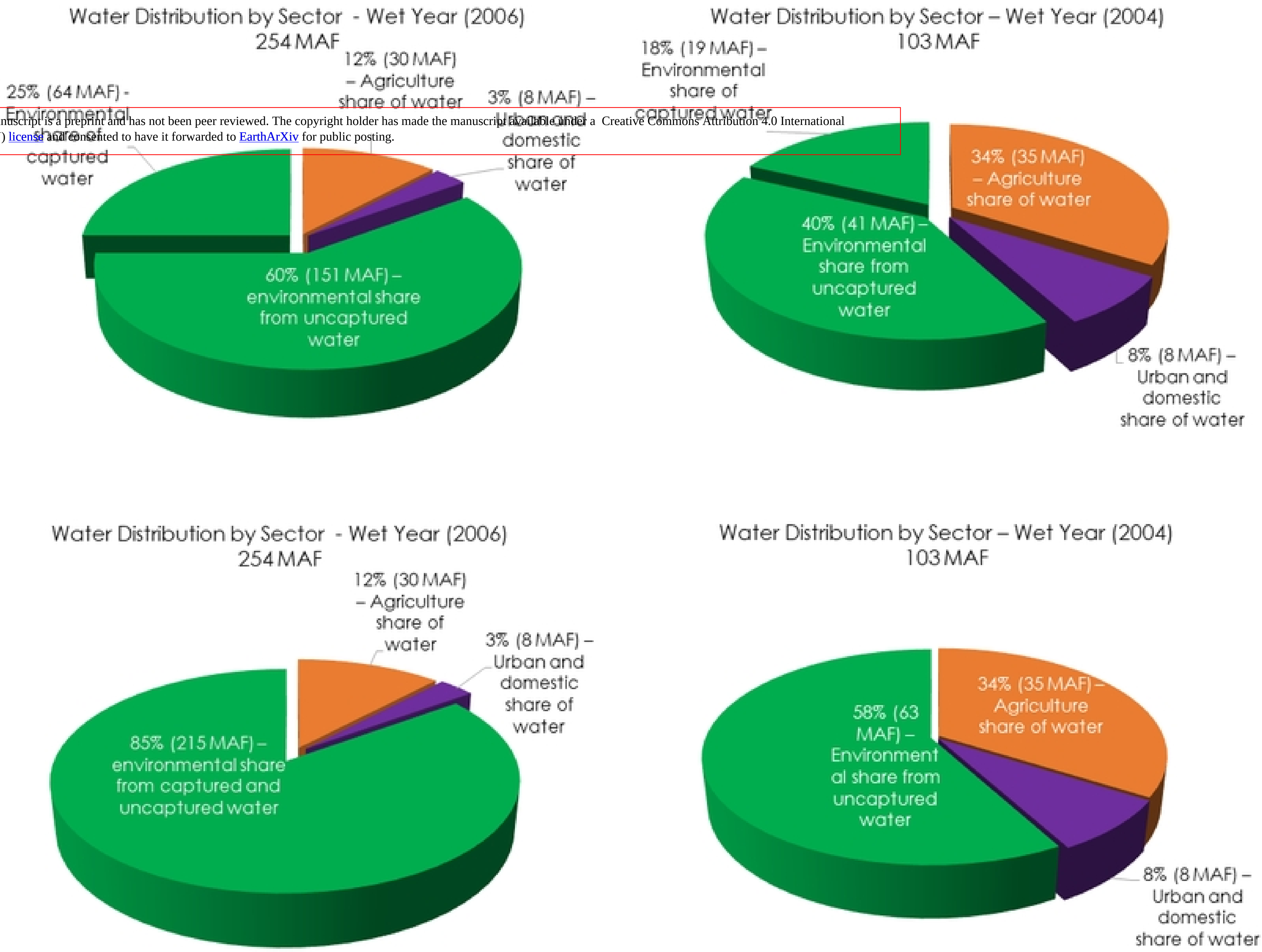

Water Distribution by Sector - Wet Year (2006)
254 MAF
12% (30 MAF) – Agriculture share of water
3% (8 MAF) – Urban and domestic share of water
25% (64 MAF) - Environmental share of captured water
60% (151 MAF) – environmental share from uncaptured water
Water Distribution by Sector – Wet Year (2004)
103 MAF
18% (19 MAF) – Environmental share of captured water
34% (35 MAF) – Agriculture share of water
40% (41 MAF) – Environmental share from uncaptured water
8% (8 MAF) – Urban and domestic share of water
Water Distribution by Sector - Wet Year (2006)
254 MAF
12% (30 MAF) – Agriculture share of water
3% (8 MAF) – Urban and domestic share of water
85% (215 MAF) – environmental share from captured and uncaptured water
Water Distribution by Sector – Wet Year (2004)
103 MAF
34% (35 MAF) – Agriculture share of water
58% (63 MAF) – Environmental share from uncaptured water
8% (8 MAF) – Urban and domestic share of water

Fig 5