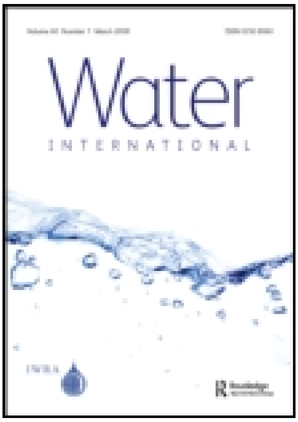

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Harald Dixen Frederiksen [a] & Richard Glen Allen [b]
[a] Consultant, Eugene, OR, USA
[b] Extension and Research, University of Idaho, Kimberly, ID, USA

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A common basis for analysis, evaluation and comparison of offstream water uses

Harald Dixen Frederiksen[a]* and Richard Glen Allen[b]

[a]*Consultant, Eugene, OR, USA;* [b]*Extension and Research, University of Idaho, Kimberly, ID, USA*

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Many analyses of water uses and their impacts on available resources fail to reflect the contribution of return flow to existing supply, misuse the term "efficiency", and assume immediate savings by changes in irrigation. Sound resources management requires a method of analysis applicable to all classes of offstream water uses. Drawing on previous analysis, a Water Uses Assessment Equation is proposed: a methodology founded on the principle of rigorous water accounting. Examples of applications are provided together with misleading analyses and conclusions that might be avoided in the future through use of the equation.

Keywords: water management; water uses; analyses; consumptive; return-flow

Introduction

The expanded interests of the public and governments in the environment, the condition of their water supplies and the interrelationships with their economic and social objectives encourage a range of enquiries and assessments concerning water-resources management. The blend of concerns has spawned several analytical methodologies.

Inevitably, some analyses and resulting conclusions are not founded on sound principles; most often absent are the hydrologic and the economic. Actions based on these methods lead to misguided programmes and more importantly, to diverting attention from the evaluation of viable solutions to a given situation, a solution that often requires more time and funds.

Additionally, the leadership in some countries does not have an independent highly skilled government unit with sufficient data to study the country's specific situation, advise on policy and formulate effective viable programmes. The result is an accelerating problem that can be exacerbated by flawed advice originating in some developed countries and the broader international community.

Misguided advice and water management decisions based on factual data and rigorous analyses are found side by side in the United States. This provides an opportunity to compare the approaches examined in this paper, beginning with a proposed analytical methodology that applies to all common consumptive uses of water.

Efforts relating to formulating improved water-use analyses

The evaluation of water uses should be based upon sound physical data, rigid consistent analysis of the water quantities involved and their disposition. The methodology and

*Corresponding author. Email: haralddf@Comcast.net

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findings should be such that they can easily be understood by political leaders, interest groups and the public. To that end, it is proposed that a universal Water Uses Assessment Equation ("WUA equation") be utilized for the analysis of the primary "offstream" uses of water as categorized by the United States Geological Survey (1988, 1993, 2004), the preeminent United States water resources authority.

The proposed WUA equation provides a common basis for evaluating water-resources management options and their hydrologic impacts among users in the same class of use or among different classes, in different situations and at different levels of overall management. The analyses are expressed in simple terms of physical measurements as volumes of water or percentages of the total quantity of water diverted and its disposition.

Offstream uses include: aquaculture, domestic self-supply, public supply (a supply service to several classes of uses), commercial, industrial, mining, thermoelectric-generation and irrigation/livestock. Many jurisdictions, where the climate creates demands for substantial water diversions critical to the economy, define urban water use to include water for domestic, municipal and industrial purposes that, together with irrigation, dominate water demands.

Instream uses include: environmental, fish, hydro-generation, navigation, recreation and similar activities. The quantity of water consumed by the instream group is assumed to be an insignificant portion of the flow, though minimum stream flows may be legislated or stipulated in court decisions. Water quality, an instream concern, is not a factor in the WUA equation except when a discharge from an offstream user to a water body renders it unsuitable for other uses. Government entities are responsible for regulating the quality of instream water and introduced effluents. These efforts and results vary greatly among countries and some may have to modify the WUA equation to address detrimental levels of polluted effluents discharged into water bodies by incorporating a term for the quantities of unsuitable water or more likely, devise a subroutine.

Basis for the offstream WUA equation and definition of terms

The WUA equation requires the analyst to algebraically account for the entire quantity of water withdrawn from a source and all components of each water use. The WUA equation is essentially an expansion of the Fractions Equation developed for analyzing irrigation uses presented in a paper by Willardson and others (1994). The parameters of the WUA equation are appropriate to defining and analyzing all offstream water uses as follows:

Water use: an application of water for a beneficial purpose that is defined in most jurisdictions by water use rights.

Water Demand or Net Water Use by offstream users: the amount of water withdrawals needed by a water-service entity to meet requirements of its service area. It is the sum of consumed water (for example evapotranspiration of applied irrigation water), and the irrecoverable water lost from the provider's system and the outflow of "return flow" leaving the service area. The sum does not include reuse of water within a service area. (This definition is similar to that found in California Department of Water Resources [2009a] and earlier Water Plans.) The definition of demand applies equally to an individual use drawing water from a service provider's system or directly from a water source.

Withdrawals (Q_W): the quantity of water extracted from aquifers, streams, lakes and associated storage. Withdrawals by a water district, service provider or individual user are limited to their water rights or the equivalent based upon their permitted demand. There are few areas in the world where withdrawals may exceed these limitations. In practice, drought and changing environmental requirements may prevent fulfilling some demands.

The disposition of withdrawals to satisfy demands of offstream uses include:

(1) *Consumed water quantity (Q_{CF})*: withdrawn water that is evaporated or transpired for an intended purpose and water incorporated into products, for example: evaporation from a cooling tower, transpiration from an irrigated crop and beverages. This would also include water not directly beneficial that is incidentally evaporated or transpired in the course of pursuing the purposes. Q_{CF} does not include the component of evapotranspiration supplied by precipitation internal to the service area or user, but applies only to the withdrawn water.
(2) *Non-consumed recoverable water quantity (Q_{RF}):* water that can be captured and reused, for example: discharged to drains that flow to a river system; percolation from irrigated fields and urban uses to accessible aquifers of suitable quality water; properly treated/blended return flows from sewerage systems to streams and accessible aquifers of good quality; and advanced treatment and blending of urban effluent suitable for recycling as a portion of the urban water supply.
(3) *Non-consumed, non-recoverable water quantity (Q_{NRF}):* comprising water that is neither beneficially consumed nor available/suitable for further use, for example: discharge to saline sinks, saline groundwater or to the sea.

Proposed assessment equation

The proposed WUA equation is simple, yet extremely important in function. It adds the three dispositions defined above to close the water balance and account for all water withdrawn. This is an essential physical requirement for quantifying water use in algebraic form: a requirement for sound water resources management. The WUA equation also describes the relationship among the three components. In terms of the quantities of water the WUA equation is:

$$Q_W = Q_{CF} + Q_{RF} + Q_{NRF} \tag{1}$$

In terms of the fractions of the total quantity diverted, the WUA equation is:

$$1 = Q_{CF}/Q_W + Q_{RF}/Q_W + Q_{NRF}/Q_W. \tag{2}$$

Ratios in the right-hand side of the second form of the WUA equation can be referred to individually as consumed fraction (CF) = $Q_{CF}/\ Q_W$, recoverable fraction (RF) = $Q_{RF}/\ Q_W$ and the non-recoverable fraction (NRF) = $Q_{NRF}/\ Q_W$.

In specific situations, these equations can be expanded with additional subscripts to detail each different component of the principle factors: Q_{CF}, Q_{RF} and Q_{NRF} as appropriate, for example surface water versus groundwater components of Q_{RF} . It may also be helpful to establish more than one equation for an individual user if the user has multiple sources of water supply (Q_W) or categories of use.

Measurement and evaluation of results derived using the WUA equation

The portion of diverted water that is consumed productively (Q_{CF}), the portion that is not consumed but recoverable for use by others (return flow) (Q_{RF}) and the portion that is not recoverable and lost to the resource system (Q_{NRF}) can be expressed for an urban use as percentages or as quantities per capita, or as per category of service connections, or other parameters for a city useful in managing its water supply service. Available data may also allow the findings to be segregated as home, outdoor, commercial or industrial usage. WUA equation quantities can be expressed for an irrigation use as percentages, or as quantities per unit of cropped land, or per unit of product.

The impacts on a given water resource by the disposition of diverted/withdrawn water become more apparent when examining the relationships in the WUA equation. This can help focus deliberations about present or proposed actions. A few important outcomes that become evident from applying the WUA equation are noted:

(1) A user's quantitative impact on a water supply will diminish by reducing the "consumptive use" and/or reducing "non-recoverable water losses".
(2) Reductions in the "recoverable volume (return flow)" of one use will not free up "new" water for another use since, with few exceptions, such water already constitutes the supply to other users – seepage that replenishes groundwater is an example.
(3) Urban effluent from inland cities (return flow) becomes a supply to other users directly or by blending with other supplies.
(4) A coastal city discharging all effluent to the sea removes 100% of its diversions from the total water supply – the largest percentage of any user's diversions from a fresh water source.
(5) The quantitative impact on the water resources by most subsidy programmes aimed to alter practices in irrigation and urban areas are location-specific.

Example applications

Four examples are provided where agencies have long applied the basic principles to depict and analyze water uses as underlie the WUA equation. A literature search would find more examples in other countries.

The California Department of Water Resources applied the same principles when defining the water purchases by its 1991 "Governor's Emergency Drought Water Bank" from farmers that would fallow land and sell the associated irrigation water (California Department of Water Resources 1991). The Bank would pay a farmer only for the quantity of water that would have been consumed by the crops historically produced on the land to be fallowed – not for the total quantity diverted. The remaining quantity would maintain the historical return flows.

The State of Colorado, as most other states in the western United States that allow the transfer of water rights, applies similar principles; the only quantity of water that may be transferred is the historically consumed portion of a water right and there may be no "third party" impacts. These provisions do not apply internally to Colorado agencies that import the water from another river basin (State of Colorado Statutes n.d.).

In 1994, California Department of Water Resources followed the principles in diagrams to explain the interrelationships among urban and agricultural water uses and reuses and the effects of location (California Department of Water Resources 2009a).

In the document, Figure III-A (p. 136) presents an example of a total river withdrawal of 100 units of water for use in an isolated service area with good-quality surface water drainage back to the supplying river. The five service area users utilized the 100 units of withdrawn river water together with their internal return flows from surface water and recycled groundwater seepage to meet their 151 units of demands. A net return flow of 12 units from the last user in the service area flowed back to the river showed a net impact on the river of the 88 units of the users' consumptive use. Application of the WUA equation yields $100 = 88 + 12 + 0$; $CF = 88/100 = 88$ percent.

Figure III-B (p. 137), presents the same example but with all return flow of the last two users flowing to a saline sink, leaving a net impact on the service area of 88 units of consumptive use and 12 units lost to a saline sink resulting in 100 units removed from the river, 12 units more than the first example. The WUA equation would yield $100 = 88 + 0 + 12$; $CF + NRF = 100$ percent.

This example illustrates the impact and extent of internal reuse common in areas served by a service entity. However, applying the WUA equation to the sum of individual return flows from all uses within the service area would give meaningless values since the majority of return flows are repeatedly reused internally. Each individual use with their different characteristics can separately be evaluated.

Using 1985 data, the United States Geological Survey (USGS) applied the principles in reporting on the year's water use within the United States in Circular 1004 (USGS 1988). These reports are issued every five years. A copy of the figure depicting the findings on freshwater use is included as Figure 1.

Three phases of a freshwater use were described by the USGS in terms of quantity and percent: (1) the two sources of withdrawals (groundwater and surface water); (2) water withdrawals by offstream sub-sectors (domestic / commercial, industrial / mining, thermal power and agricultural); and (3) disposition (consumption and return flows). (Irrigation use set out in the figure includes water for crop production, golf courses and public recreation areas.)

The USGS definitions of water "withdrawals", "water use", and "consumptive use" are essentially the same as used in the WUA equation. The United States Geological Survey definition of "return flow" is the same as the "Non-consumed recoverable fraction". The USGS does not account separately for the quantity classified in the WUA equation as "non-consumed, non-available / unsuitable" water. It was assumed to be minor in the United States; the major saline water uses are dealt with separately.

In spite of population and economic growth in the United States from 1985 through 1995, the quantity of water diverted remained essentially constant while the consumptive use increased from 27.3% to 29.3% and return flows decreased from 72.7% to 70.7%. The 2000 and 2005 water-use reports only present data on the quantities diverted.

The total annual freshwater withdrawals and the involved sources noted in Figure 1 inherently include return flows except for those return flows discharged directly to the ocean. Only a few withdrawals, such as the irrigation of pasturelands and service to small villages in the uppermost basin headwaters might not contain return flow while the percentage of return flow in withdrawals increase downstream in the typical river basin.

The issue of the availability of return flows is of greatest concern during the high-demand periods, typically the hot dry season but even more important during extended periods of drought. However, the portion of the total annual surface water return noted in Figure 1 that is fully used during periods of high demand can only be determined by analyzing seasonal data from individual states.

Return flows are fully used in situations where there is an annual overdraft of groundwater and in locations where there is no uncommitted surface water flowing to the sea during critical periods of use.

Essentially all groundwater is recharged by variable precipitation, seepage from rivers and by return flow seepage from overlying uses. Some areas recharge groundwater with imported and recycled water. The annual total quantity of groundwater return flows is fully used unless there is a persistent long-term rise in the elevation of the groundwater. Groundwater overdraft is evident in regions of most countries. The large areas of the Midwest and Western United States are examples.

Except during periods of floods, surfacewater return flows are essentially fully committed in all arid regions of the world; it is apparent in the western United States, but also in several temperate climate states. The situation is more serious in Central Asia, the Middle East, sub-Saharan Africa and most of South Asia and East Asia. The many rivers that run dry before reaching the ocean are dramatic examples. It would appear that climate change may worsen these situations.

Examples of deficiencies in analyses

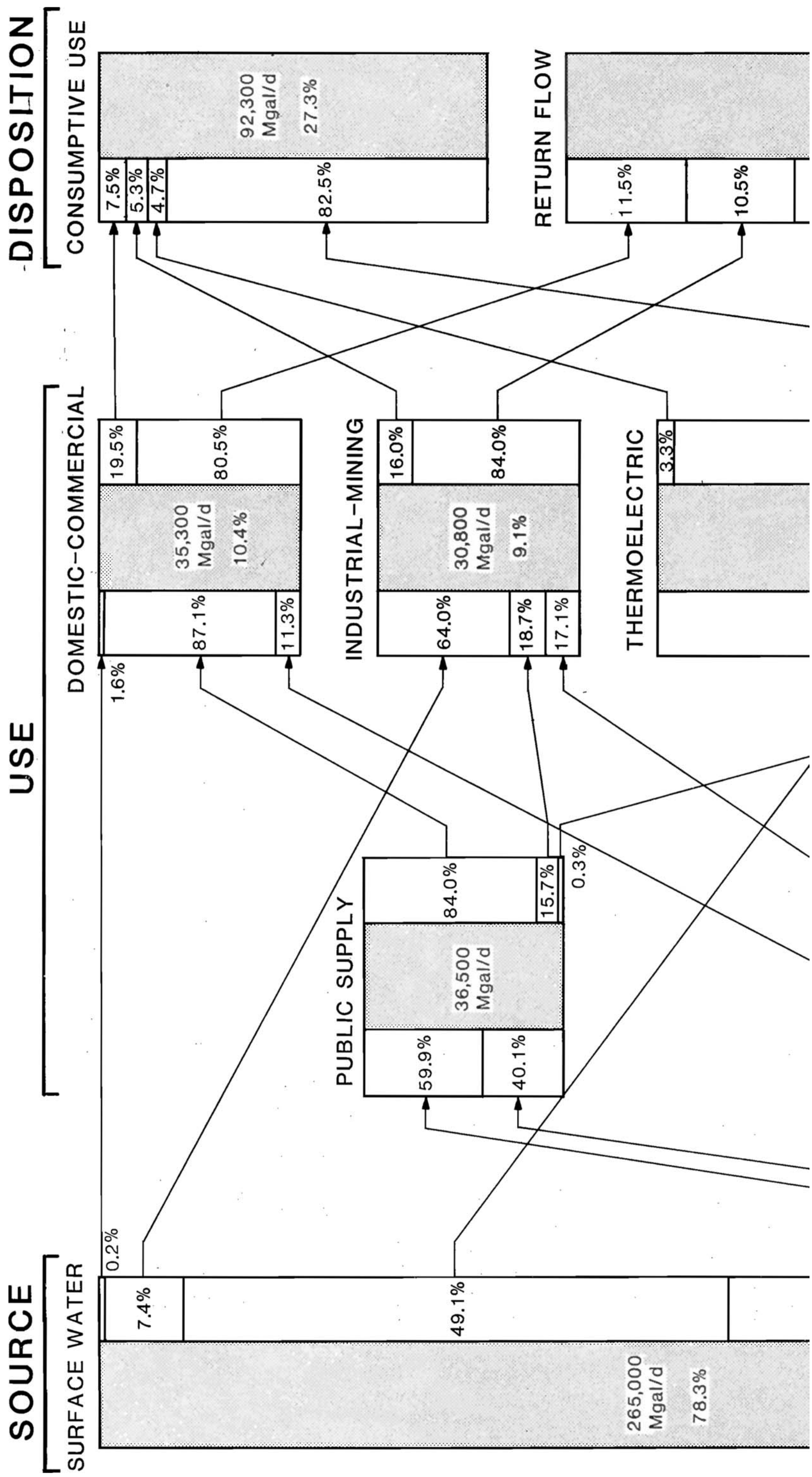
Today's rapid and multiple means of communications make all views on matters of water-resources management important in developed and developing countries. By the sheer volume of proposals, the developed countries and international entities carry a responsibility to ensure the validity of their advice for solving shortages in developing countries.

Many proposals to meet expanding water demands commonly include improving the "efficiencies" of existing and future uses and in some evaluation methods, the "conservation" of return flow. On the surface this sounds sensible, however "efficiency", without quantifying the impacts is an undefined measurement. Ignoring the role of return flows is but one missing step. These errors have led many to believe that improving irrigation methods will free up large quantities for other uses.

A 2010 report issued by the Pacific Institute provides an example of using flawed analyses in a recent assessment of California's water management (Pacific Institute 2010). McKinsey and Company issued a document describing means to expand supplies in developing countries to meet their water needs in a little over 20 years using similarly flawed analyses (McKinsey 2009). In parallel, others in the community offer the questionable concepts of "virtual" water, water "footprints" and coloured waters to allegedly advance analyses (Wichelns 2010a, 2010b). These types of analyses only divert attention and funds from the effective actions needed in developing countries.

It is useful to discuss the report by Pacific Institute ("Report") in detail, because the findings and conclusions appear in advice circulating in many countries. Here they can also be compared to those of the State of California's water-resources management agency.

Several questions arise regarding the validity of the Report's analyses and anticipated water savings by their proposed programmes. The impacts of proposed changes to urban water use are not universal, but vary depending on location. Recycling treated effluents to supply to recreational spaces are not adequately discussed. Their proposed potential for conserving water by capturing "return flows" ignores the fact that return flows are already part of the downstream water supply during high-demand periods. There are no considerations of supplies to survive a 10-year drought or meeting future demands. The findings that millions of acre-feet (AF) of water can be freed up in California by changes to the farmers' operations lack an understanding of irrigation and the nature of the industry as well as flawed analyses. Indeed, a key tenet of the Report (Pacific Institute 2010) is that large quantities of new water can be freed up by improving current irrigation practices.


SOURCE
SURFACE WATER
265,000 Mgal/d 78.3%
7.4%
49.1%
0.2%
USE
PUBLIC SUPPLY
36,500 Mgal/d
59.9%
40.1%
84.0%
15.7%
0.3%
DOMESTIC–COMMERCIAL
35,300 Mgal/d 10.4%
1.6%
87.1%
11.3%
19.5%
80.5%
INDUSTRIAL–MINING
30,800 Mgal/d 9.1%
64.0%
18.7%
17.1%
16.0%
84.0%
THERMOELECTRIC
3.3%
DISPOSITION
CONSUMPTIVE USE
92,300 Mgal/d 27.3%
7.5%
5.3%
4.7%
82.5%
RETURN FLOW
11.5%
10.5%

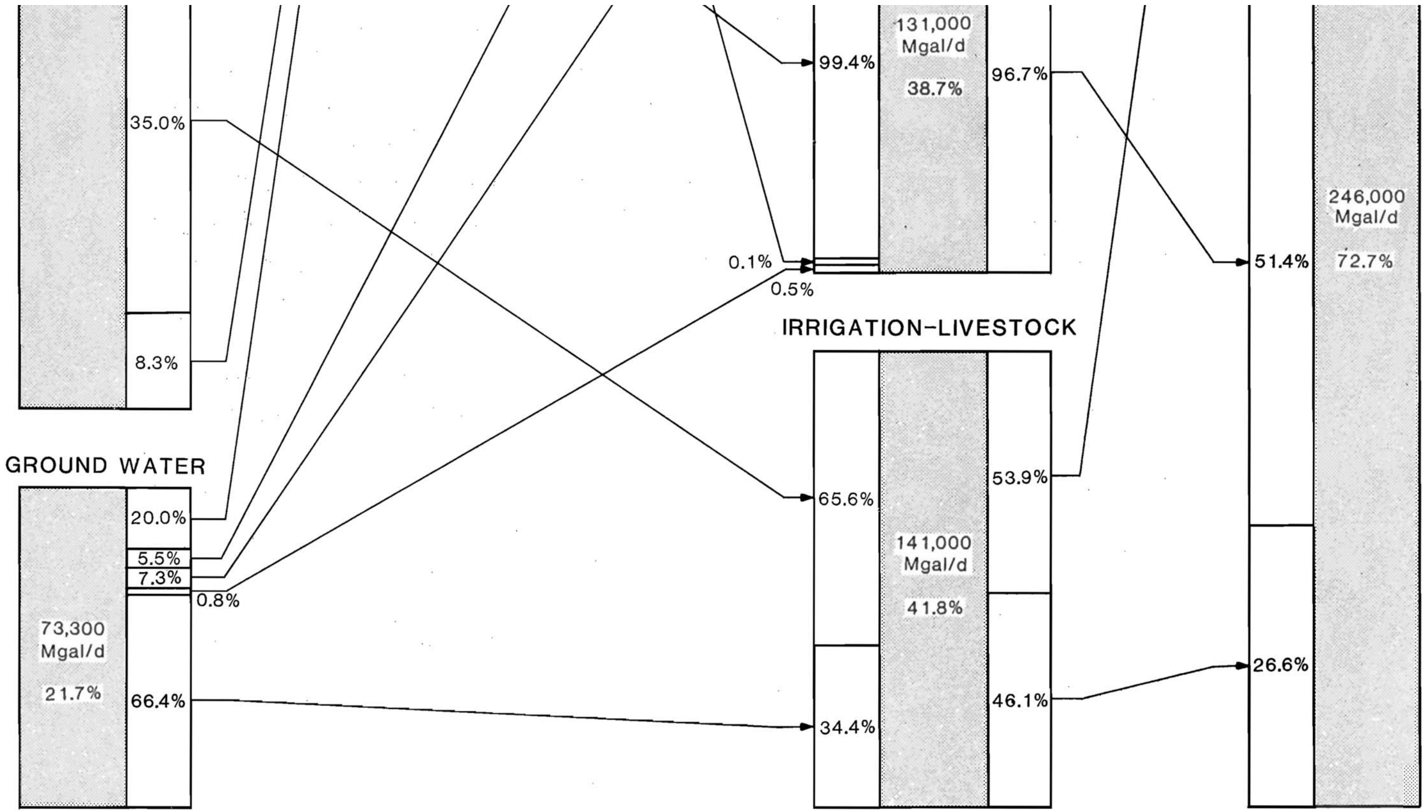


Figure 1. Source, use, and disposition of freshwater in the United States, 1985. One Mgal/d = one million gallons per day = 3786 m^3/d. Source: USGS (1988, p. 55, fig. 21).

These questions are addressed after providing a synopsis of the Report. The Conclusion of the Report (portions cited below, with SI units of m^3 inserted) summarizes the means and assumed results of the Institute's proposed action programme, arguments that are amplified by other statements in the document.

> Conclusions: Water conservation and efficiency must be a central component of a portfolio of solutions for California's water problems. Improved efficiency can help meet California's water needs for decades to come while still satisfying a growing population, maintaining a vibrant agricultural and industrial sector, and restoring the health of the Sacramento-San Joaquin Delta and other threatened ecosystems. This assessment identifies 1 million acre-feet (1.2 billion m^3) per year of potential water savings, split between the agricultural and urban sectors, which can be achieved with existing technology, and we recommend strategies for moving forward quickly to capture these savings. (p. 24)
>
> Overall, we recommend technologies and strategies that will let California quickly save 1 million acre-feet of water at lower cost than current proposals to develop new supply, and with far fewer social and environmental impacts . . . These conservation and efficiency improvements are much cheaper than many proposed new surface storage projects. (p. 7)
>
> These studies [various early assessments by Pacific Institute] find that existing, cost-effective technologies and practices can reduce current state demand for water by six-to-eight million acre-feet (7 to 10 billion m^3) per year, or around 20% statewide. (p. 6)
>
> Unlike proposed new water storage projects, the efficiency improvements recommended here often pay for themselves as a result of the many co-benefits that water conservation and efficiency provides. (p. 7)
>
> Water savings are available through a wide variety of water-efficient practices in the urban and agricultural sectors. In the urban sector this includes replacing old, inefficient devices with high- efficiency models, as well as lawn conversion, residential metering, and rate structures that better communicate the value of water. In the agricultural sector, best water management practices include weather-based irrigation scheduling, regulated deficit irrigation, and switching from gravity or flood irrigation to sprinkler or drip irrigation systems. (p. 8)
>
> These water savings are a combination of "consumptive" and "non-consumptive" uses (see box below). Both kinds of savings are valuable, despite claims by some water analysts of the need to focus solely on reducing "consumptive" water uses. In particular, saving non-consumptive uses may be especially cost-effective and helpful for restoring instream flows for certain highly damaged aquatic ecosystems and for reducing energy use associated with on-farm or urban water systems. (p. 9)
>
> The water literature is rife with confusing and often misleading terminology to describe water use, e.g., water withdrawal, consumptive use, non-consumptive use, etc. (p. 9)
>
> Confusion about consumptive and non-consumptive water use has led many planners to grossly underestimate the value of conserving non-consumptive water use and, consequently, overall water-conservation potential. Some water planners believe that conservation measures that produce savings in non-consumptive water uses are less important than that from consumptive water uses. They argue that water that is used non-consumptively is available for reuse by downstream users and thus conserving this water does not produce any new water. These planners, however, fail to realize that any demand reductions reduce the amount of water taken from ecosystems and the need for new infrastructure investments to capture, store, treat, and distribute water. (p. 8)

Reuse of return flows during high-demand periods of the year must be reflected in all analyses. Figure 1 illustrates that the nature of most water uses inherently incur substantial return flows. There is not a type of irrigation that does not. Domestic uses generate return flows. That is the nature of showers, washing and other activities. These return flows as such are not consumptive.

Water, while being conveyed to offstream uses, can meet instream uses, including ecological. In the Sacramento River, all stored flood water in Oroville Reservoir flows

Table 1. An illustration of quantities of reservoir releases and consumptive use under various percentages of return flow.

33% Return flow	U_1	U_2	U_3	U_4	Dl	Total
Demand by designated user	3	3	3	3	1	13
Water consumption by designated user	2	2	2	2	1	9
Return flow passed downstream	1	1	1	1	0	4
Return flow quantity utilized by designated user	0	1	1	1	1	4
Resv. supply quantity utilized by designated user	3	2	2	2	0	9
Total resv. supply flow in river upstream of user	9	6	4	2	0	
20% Return flow	U_1	U_2	U_3	U_4	Dl	Total
Demand by designated user	2.5	2.5	2.5	2.5	1	11
Water consumption by designated user	2	2	2	2	1	9
Return flow passed downstream	0.5	0.5	0.5	0.5	0	2
Return flow quantity utilized by designated user	0	0.5	0.5	0.5	0.5	2
Resv. supply quantity utilized by designated user	2.5	2	2	2	0.5	9
Total resv. supply flow in river upstream of user	9	6.5	4.5	2.5	0.5	
0% Return flow	U_1	U_2	U_3	U_4	Dl	Total
Demand by designated user	2	2	2	2	1	9
Water consumption by designated user	2	2	2	2	1	9
Return flow passed downstream	0	0	0	0	0	0
Return flow quantity utilized by designated user	0	0	0	0	0	0
Resv. supply quantity utilized by designated user	2	2	2	2	1	9
Total resv. supply flow in river upstream of user	9	7	5	3	1	

to the terminus in the Sacramento/San Joaquin Delta, where the water is pumped to meet demands of urban uses from the San Francisco Bay area to San Diego. Similarly, 90% of such water released from the United States Bureau of Reclamation's Shasta and Folsom dams in the Sacramento Basin flows to the Delta for export to the San Joaquin Valley. In another setting, diverting a major proportion of river flow can have a local ecological impact on a segment of the river. Without a reduction in the consumptive portion, the remedy must be a reduction in total withdrawals that will also reduce return flows with the net impact of no water savings below the entry of historical return flows.

Table 1 presents the results of three calculations using a constant quantity of "consumptive water", a constant quantity of "reservoir releases", and varying user demands that are determined by the constant consumptive use plus quantity of different return flow percentages of 33%, 20% and 0%. Four offstream water users are designated as "U_1" through "U_4". "Dl" is the outflow requirement in the river delta. Resv. supply is the portion of the river flow released from an upstream reservoir to serve these users. Demand is defined by California Department of Water Resources [2009a], which includes evapotranspiration and associated needs and return flow.

This example is simple and assumes complete reuse of return flows downstream, with no timing effects. Such results are common to most large river systems. As evident, only a reduction in the consumptive portion in this example frees up new water. The reservoir releases remained at nine units in all cases. Unfortunately, most uses entail return flows greater than 33% and many far greater.

Actions proposed in the Report by the Pacific Institute (2010)

The following actions and "water savings" were proposed in the Pacific Institute Report.

Summary of urban water savings (p. 11)		
Replacement of existing plumbing fixtures	277,430 AF	342 million m^3
Cooling tower pH control	21,900 AF	27 million m^3
Pressurized water brooms	7,670 AF	9 million m^3
Converting 12,000 acres (5000 ha) of residential lawns and gardens	28,000 AF	35 million m^3
Total quantity of water freed up	320,000 AF	395 million m^3

The proposed actions in the Report for the irrigation sector to free up water include:

> For this analysis, we chose among the simplest, proven agricultural water-use efficiency measures available, which include: (1) weather-based irrigation scheduling, (2) regulated deficit irrigation, and (3) efficient irrigation technologies, e.g., drip and sprinkler systems. (p. 15)

Summary of agricultural water savings (p. 16)		
Irrigation scheduling	291,000 AF	359 million m^3
Regulated deficit irrigation	170,000 AF	210 million m^3
Conversion to drip/sprinkler irrigation	238,000 AF	294 million m^3
Total quantity of water freed up	699,000 AF	862 million m^3

Total quantity of urban and agricultural water savings were assumed to be equivalent to additional new floodwater captured in a new reservoirs: 1, 019,000 AF (1.26 billion m^3). Yet the following statement is made below the listing of measures in irrigation:

> It is important to note that these savings are a combination of consumptive and non-consumptive water uses, and therefore they are not necessarily available for re-allocation or use elsewhere. However, as noted above, reductions in water demand often provide important co-benefits (p. 16)

Analysis of Report methodology and finding of 'new' water

Urban water use (domestic, garden, recreational areas and commercial)

The actions that may alter the consumptive portion of each use, water discharged as return flows and the quantity of water rendered unavailable to further uses can be adequately defined and are measurable. Water utilized in gardens and open space is largely consumed (as evapotranspiration), returned as surface runoff or seeps to groundwater depending on location and climate.

The vast majority of water used in washing machines, showers, toilets and similar appliances is not consumed and remains in a city's effluent. Commercial uses may entail consumption (evaporation or water incorporated into products), as well as return flow in the case of hotels and similar activities.

The un-consumed portion of water delivered to most coastal urban areas is discharged as effluent to the ocean except in those cities that practise recycling. Thus, any reduction in the supply delivered to these areas by reducing water use in appliances and other such uses noted in the Report will free up "new" water.

The urban domestic effluent from inland cities, in contrast to coastal cities, becomes available to and is currently used by other "downstream" users, whether withdrawn from streams or from groundwater. A reduction in water used in appliances does not free up any significant quantity of water in such settings. The California Department of Water Resources, State Water Plan (2009) expands on urban uses and water savings:

> Climatological factors help explain much of the (urban) water use in different regions. Other factors affecting water use range from economic to esthetic factors and cover a wide range of activities (income, water price, water meters, community make-up, residential density, etc.).
>
> In the San Joaquin Valley, most indoor uses of urban water do not result in the loss of the water. Indoor uses of water (kitchen, bath, etc.) result in the capture of the utilized water, ultimately this water is treated and reused (septic systems percolate the used water back into the groundwater). This water is either recharged into local groundwater or piped and re-used for non-potable purposes (usually landscape or crop irrigation).
>
> Water that runs off into the gutter from overspray in landscaping or washing the family car is usually captured and directed to local residential ponds and allowed to recharge the local groundwater.
>
> The primary loss or depletion of water in the urban sector occurs as a result of irrigation (seasonal use) through plant water use of turf and other landscaped greenery and the evaporation of water from overspray on hard surfaces/runoff. However, due to the concentration of agricultural and the associated processing facilities in the San Joaquin Valley, a significant amount of water is also lost in the processing of various commodities from cooling, washing, etc. as well as in other industrial and commercial ventures requiring cooling, washing, and in the case of the Kern County, the petroleum industry. Many of these industrial and commercial (car washes) uses of water have been reduced by technological advances through on-site water recycling. Landscape irrigation accounts for as much as 90% of the residential sector's and as much as 84% of the non-residential sector's annual outdoor water use and as the dominant use during the summer and seasonal water use in the San Joaquin Valley accounts for as much as 60% of the total urban water use for the year. (California Department of Water Resources 2009b)

Obviously, recycling of urban water use in the coastal cities should be a priority. A reduction in consumptive water use by urban gardens and recreational space in regions with arid seasons is a net savings regardless of location and can free up significant quantities of water during the critical summer period. However, it is not possible to assess the total reduction in urban consumptive and non-recoverable water in the Report without additional information.

Irrigation water use

Irrigation involves the largest consumptive use of water in most arid regions having a large agricultural economy and is by far the most complex use of water. Water is the key factor in crop yield and a major cost component of production. Farmers seek a combined blend of the available water supply and its reliability, water application methods, soil preparation, plant selection and level of crop husbandry tailored to their markets to maximize income. The mix reflects the risks of surface water supply reductions from drought, commonly greater than one year in four. Whenever a farmer can free up water by modifying practices, he will examine ways to utilize this water elsewhere within his operations since they are also the most vulnerable to supply reductions due to government decisions to increase urban supply or environmental flows. The Monterey Agreements (California Department of Water Resources 1995) provide evidence of this in California.[1]

Additionally, the expansion of conjunctive management of surface and groundwater, an important advance, influences the selection of application methods. As an example, one water-services agency enforces firm rules for the farmers. In periods of ample surface supply, the agency assesses substantial charges to farmers for any groundwater pumping to encourage use of surface water supply. However, during a prolonged drought the district may be forced to halt a portion or all surface water deliveries. By encouraging aquifer recharge during the rainy season and system seepage during periods of surplus, the agency tries to build adequate groundwater reserves so that it can allow farmers, without charges, to pump when needed under announced drought conditions and thus sustain normal production of high-value tree crops and vegetables. Clearly, the recharge of unconsumed surface water via seepage is a significant and valuable source for the aquifer.

With these considerations in mind, the Report's suggested actions to reduce irrigation water consumption will be discussed with regard to the potential for freeing up new water in settings similar to California. The water-use characteristics of various application methods are discussed in Clemens *et al*. (2008) and their advantages vary from drip to flood-irrigation depending on the overall production costs and markets.

(1) *Improvements in irrigation scheduling.* Improved scheduling requires a robust control of the supply and generally does not reduce the consumptive portion of applied water for most crops. The dominant gravity supply in developed countries – meeting 24-hour advance requests by farmers for delivery (with priority for high-value crops during peak demand) – allows a flexibility that attains most potential benefits of scheduling including fulfilment of the consumptive-use requirements. There may be a potential in some settings for additional improvements aimed to better meet timing of and quantities of water demands, however, that can increase consumption of water in two ways. Better scheduling may reduce any crop stress and therefore increase total evapotranspiration. Improved control of water application may result in a more uniform field application and thereby potential water consumption. It is highly unlikely that more robust irrigation scheduling in areas with the described supply will significantly reduce consumptive use, unless intentionally managed to reduce evapotranspiration, however, that usually reduces crop yield (see point 2). The crop production on many projects in the developing countries would definitely benefit from more reliable and suitably scheduled supply. This also would increase water consumption on these lands.

(2) Farmers face some similar water-service considerations for *regulated deficit irrigation (RDI).* Studies suggest that deficit irrigation may significantly reduce water use by some tree and grape crops. The California Department of Water Resources notes its reservations:

> Wine grapes are a clear example: Mild stress imposed through the growing season decreases canopy growth, but produces grapes with higher sugar content, better color, and smaller berries with a higher skin to fruit-volume ratio. This is a very common practice in the premium wine regions of California.
>
> RDI has been primarily used as a production management practice, and the extent of its application in California, in terms of crops and acreages under RDI, has not been quantified. Before RDI can be applied to other crops, information on its costs, risks, long-term impacts, and potential benefits, including water savings, must be determined. Once that is done, practical guidelines for growers on how to initiate, operate, and maintain RDI should be developed and disseminated. (California Department of Water Resources 2009c)

The alleged quantity of water freed up by RDI as new water – 170,000 AF (210 million m^3) – remains in question by California Department of Water Resources.

It would also be incorrect to treat the entire RDI quantity as a reduction in consumptive use since a portion would be return flow.

(3) *An additional shift from surface irrigation supply /application to drip irrigation* will be influenced by several factors. Drip irrigation requires frequent water applications. Depending on the extent of the surface wetted by the drip system, the evaporation component which is not effective in producing crop yield, may increase consumption due to the longer duration of a wet soil surface (Burt *et al*. 2002).

Drip requires a highly reliable supply for permanent crops. The potential drought-inflicted curtailment of surface-water delivery is a serious risk for drip irrigation of permanent crops. Many aquifers, the preferred source, are already in overdraft. Indeed, seepage from surface irrigation, much of that with water imported from outside basins, is a major contributor to aquifer recharge reducing the rate of overdraft in California's Central Valley (United States Geological Survey 2009) helping to sustain its groundwater supply.

There may be other benefits from drip irrigation, however, it is doubtful that there is a significant reduction in consumptive use of water. Any reduction in seepage to actively exploited groundwater cannot be considered a "savings" that translate into new water. This places in doubt the entire quantity of 238,000 AF (294 million m^3) of water savings assumed for drip irrigation in the Report.

Experiences with drip irrigation are illustrative of a range of issues.

Drip or microspray irrigation may be popular on some crops, yet in some regions better yields and economics have been obtained with surface irrigation techniques. For example, in the Reedley/Dinuba area of central California, there was a large-scale conversion to drip and microspray on stone fruit (peaches, nectarines, plums) approximately 20 years ago. Most of those orchards have reverted back to furrow irrigation. Central Arizona also saw large shifts to microirrigation on cotton 20+ years ago. Nearly all of that land has reverted to surface irrigation because the expected yield increases used to justify the added irrigation system cost did not materialize (Clemens *et al*. 2008, p. 2).

(4) *Sprinkler application can be and is now utilized to replace furrow or flood irrigation.* The relative advantages of sprinkler as with drip application, depend upon other production factors, location, seasonal weather and source of water. In some regions farmers may augment the crop water supply with available precipitation. Basin irrigation for tree crops is an example in areas where late Spring rains are captured and stored while also providing benefits from the effectiveness of this type of irrigation.

In summary, of the four improvements to irrigated agriculture recommended in the Report, only regulated deficit irrigation may reduce water consumption, though it is unclear that RDI can consistently sustain high crop production other than for grapes and some tree crops. The other three improvements will essentially only reduce diversions and return flows in equal portions. Only where the location of irrigation is directly upgradient of the ocean or other saline sink, will savings occur.

Even a reduction through using RDI will have minimal impacts since, as explained earlier, most farmers will use any freed-up water within their operations by altering crops or expanding production rather than losing water allocations. Therefore, the potential total savings in the irrigated agriculture sector is substantially less than 170,000 AF (210 million m^3) of RDI savings and far less than the 699,000 AF (862 million m^3) estimate provided in the Report.

This analysis of irrigation savings proposed in the Report produces a conclusion similar to those reached by the California Department of Water Resources (California Department of Water Resources 2009d).

Application by the Pacific Institute investigators of the WUA equation for assessing both urban and agricultural uses would have provided a clear basis for describing their characteristics and defining their impacts on resources. Such analyses would have indentified the importance of the location of the use for purposes of setting policies and incentives. The potential for freeing up water would have become evident and the conclusion more helpful in deliberations of California's situation.

As mentioned earlier, the evaluation of the Report's analytical methods and recommendations highlights similar misguiding advice offered to developing countries, particularly the potential to rapidly change irrigation practices. Farmers in developing countries already apply irrigation practices tailored to their conditions just as farmers in developed countries and for the same reasons. Irrigation in Latin America is comparable with the United States industry. Farmers in India's Northwest and its Eastern Ganges basin just as farmers in China and South East Asia, fully utilize their resources as supply and weather allow. An example is flood irrigation of rice that utilizes excess monsoon floodwater that cannot be used for other crops or purposes.

Several factors constrain advances in these countries. In many, large irrigation schemes, many centuries old, are common. Highly populated rural areas may have farms averaging one hectare or fewer. A 100,000 ha scheme may serve 100,000 farmers. The schemes usually have distant supply sources and complex canal networks requiring a three to five day water travel time. Famers must submit irrigation schedules three to five days in advance of their delivery cycle and allow one week for delivery.

Unfortunately, the weather forecasts on which these are based may differ widely from the actual event. Many automatic water-regulating works and computer aids installed in the 1970s save little water. Land preparation equipment has reduced pre-irrigation water used to "loosen" baked soils. The situation in sub-Sahara Africa is even more complex. Organizations in developed countries and international lending agencies that offer advice must understand the conditions that will not change for decades.

Closing

Several currently applied methods for analyzing offstream water uses and management by prominent organizations lead to serious errors in projecting present and future water needs and supplies. The alleged ease of executing the faulty recommendations, lulls people to delay efforts to formulate viable realistic programmes, secure the associated financing and execute the effective programmes. People will pay a high price for any false sense of water security.

Many of the most consequential actions in agriculture recommended in the Report and much international advice reflect the erroneous view by the public, many interest groups and investigators that the world's farmers are not competent businessmen. The lack of this understanding is evident in the commonly publicized measure to allegedly free up large quantities of new supplies.

Any use of the term "efficiency" in discussions of associated policies and actions should be accompanied with quantitative hydrologic analyses of the water uses and the impacts. The use of the term "efficiency" alone in deliberations carries risks of faulty decisions. Sound analyses will show that only a reduction in consumptive use and water lost to saline sinks and the ocean or water rendered unsuitable for reuse can free up water for new uses. The primary options are to transfer the consumptive portion of existing agricultural allocations to other uses, now evident in most countries; construction of desalination facilities – most suitable as a supply to coastal cities; and the creation of additional storage of surplus floodwaters. Only the latter option provides additional water to supply the expanding needs.

The methodology proposed in this paper constitutes a defined procedure for presenting and evaluating all offstream water uses in consistent quantitative terms. It provides a common approach for comparing categories of uses and highlighting the influence of their source, location and characteristics. A rigorous analysis of water conditions at all levels can inform leaders and the public of their situation and the viability of proposed solutions. The focus of efforts to increase supply must shift to deliberating, formulating and executing viable programmes tailored to the level and schedule of water needs.

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Note

1. The California Department of Water Resources Websites (http://www.water.ca.gov/) includes extensive documentation including the Monterey Agreement B132-95, Chapter 1, Summary (1995); DWR Bulletin 1322-96, Chapter 1; Executive Summary (1996); and Comments to DWR, Office of Environment Compliance.

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