Inquiry into water use efficiency in Australian agriculture

Submission by Dr Chris Perry,

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I wish to present two comments to the Inquiry. The first relates to Submission 6, which is currently based on selective quotations from the relevant literature. The second relates to the effectiveness of "buy backs" of water rights as a means of releasing water to the environment, and includes an example from the United States.

1. Comment on Submission 6

Submission 6 to the Inquiry from Netafim (Australia) includes the following statement:

> In another recent report the international Sustainable Agriculture Initiative (SAI) states "Drip irrigation remains without any doubt the most efficient irrigation technique and most powerful solution towards improving water productivity and ensuring food security".

This quotation is drawn from a report from the Sustainable Agricultural Initiative's Technical Brief on Water Conservation – TB 15 – *Drip irrigation and water scarcity*. That Technical Brief is of particular relevance to this Inquiry because it addresses the impacts of drip irrigation beyond the farm boundary.

The quotation has rather different (indeed opposite) implications when placed in its context in the SAI report. The full quotation from the SAI report is as follows (emphasis in the original):

> Finally the report concludes that **drip irrigation remains without any doubt the most efficient irrigation technique and**

most powerful solution towards improving water productivity and ensuring food security but due to the popular confusion in water accounting terminology, reports on efficiency gains have to be looked at carefully. **It is thus important to always carefully assess what potential impacts the introduction of drip irrigation and planned increase of local crop production have on the overall water availability at watershed scale and the water flows left to other water users in the basin.**

The concern the SAI report raises relates to the fact that drip irrigation technologies frequently result in *increased* local water consumption, and in consequence *reduced* return flows to aquifers and drains.

Excess water supplied to "inefficient" flood irrigators does not disappear. Some may evaporate unproductively. The rest returns to the system as groundwater recharge or drainage flows. Investments to improve local efficiency and reduce "losses" that ignore such return flows exaggerate "savings". This is the point being raised in the SAI report, which the highly selective quote in Submission 6 has misrepresented.

I am submitting the full SAI report as it is of direct relevance to your deliberations.

2. **Comment of the effectiveness of "buy backs"?**

Similar considerations apply to the evaluation of "buy backs" – where the water entitlement of an irrigator are bought by the state, retired from consumptive use, and hence apparently released to the environment or other uses.

The US State of Idaho pursues similar objectives. In a recent case, an irrigator was applying irrigation water to a depth of 1365mm to his crops. He was interested to sell this water right to the State. The State commissioned a study of the *consumptive* use of water in the irrigator's fields and concluded that this was not more than 984mm.

The State was therefore only willing to compensate the irrigator for the 984mm of consumptive use, on the grounds that the additional water applied to the field was already returning to the environment.

In this case, the irrigator was pumping water from an aquifer and irrigating by centre-pivot—a relatively "efficient" irrigation technology, where the ratio between water applied to the field and water consumed by the crop would be close to unity. For flood irrigation, especially of rice, the ratio of water *applied* to water *consumed* would usually be much higher—further reducing the actual benefits of a "buy back" to the environment.

The implications for Australia's objective to meet a certain level incremental environmental water are clear: only the net consumptive use can reliably be counted as an incremental contribution to the environment.

I am submitting the brief summary of the Idaho case study, downloaded from their website.

(https://www.idwr.idaho.gov/files/gis/water-rights-buy-back.pdf)

WATER CONSERVATION TECHNICAL BRIEFS

TB 15 - Drip irrigation and water scarcity

SAI Platform

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WATER CONSERVATION TECHNICAL BRIEFS

TB 15 - Drip irrigation and water scarcity

Out of the anthropogenic freshwater withdrawals from surface water and groundwater bodies, 70% goes into agriculture. If we only consider the "consumptive water use" (deducting from withdrawals the "returned flows", e.g.: in hydro-power generation), the agricultural sector accounts for 85% of global freshwater consumption. Therefore agriculture is often criticised as a wasteful water user, especially in water scarce areas. Drip irrigation is widely recognised as the most efficient irrigation technique and often portrayed as the best solution to increase agricultural production whilst reducing the demand for water. However, the terminology used for irrigation water accounting is often flawed, failing to distinguish properly between evaporation, transpiration and potentially reusable return flows. When taking these flows properly into account, it becomes clear that the magnitude of saving water through advanced irrigation technologies is much more limited than popularly believed. Once reasonable levels of agricultural practice are in place, increases in agricultural yield are linearly correlated to the water consumption. Consequently even though advanced irrigation technologies like drip irrigation allow using water more efficiently, savings rarely occur in the magnitude suggested in the popular debate. It is furthermore highly important to assess the impacts on other water uses in the basin including the ecosystem when introducing powerful irrigation techniques such as drip irrigation, as cutting all flows other than the ones to the irrigated crops may cut the water flows that were previously available for use at some other point in the basin.

The SAI Water Conservation Technical Briefs TB1 and TB8 discusses the different irrigation systems and the use of Drip Irrigation respectively, encouraging the adoption of surface and subsurface drip irrigation due to its higher water efficiency and crop productivity compared to other irrigation systems. Based on these findings this Technical Brief first brings clarity into the widespread confusion in terminology around water accounting and evapotranspiration. Second it examines how water availability increases crop production and discusses several possible interventions to optimise biomass water productivity. Third it compares the individual rational of a farmer who invests into a new irrigation technique with the possible impacts this will have on the other water users in the catchment.

Finally it concludes that **drip irrigation remains without any doubt the most efficient irrigation technique and most powerful solution towards improving water productivity and ensuring food security** but due to the popular confusion in water accounting terminology, reports on efficiency gains have to be looked at carefully. **It is thus important to always carefully assess what potential impacts the introduction of drip irrigation and planned increase of local crop production have on the overall water availability at watershed scale and the water flows left to other water users in the basin.**

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SECTION 1: CONFUSING TERMINOLOGY

A) Water Accounting

Hydrology and irrigation engineering are two distinct fields with their own merits. They have both developed water accounting terminologies, which are sometimes misleading.

Field	Hydrology (including hydrogeology)	Irrigation engineering
Description	The study of the movement, distribution and quality of water throughout the earth.	The study of interventions designed to utilise surface/ground water flows for crop application where rainfall is insufficient to meet crop demand.
Unit of analysis	Catchment basin, hydrological cycle	Individual fields, irrigation projects
Major merits	Understanding of water flows	Design and operation of irrigation systems

When assessing the impacts of changes in water management in a region of water scarcity, the use of analytical frameworks of irrigation engineers is often misleading. It does not take the law of conversation of mass into account where no water is created or destroyed, but only transferred spatially in the form of liquid or vapour. For example when irrigation engineers talk about efficiency losses they do not take into account that "losses" at the scale of an irrigation project are not necessarily lost in the hydrological sense, because the "lost" water may be available for use at another point in the basin or aquifer. A good example is the monsoon climate, with extreme inter annual rainfall variability, where the irrigation "losses" recharging the aquifers during the wet season improve the ground-water availability during the dry season.

This shows that improving irrigation efficiency and reducing losses might not result in increasing the water availability for other uses. This is counter-intuitive as in every other context (such as energy-efficient fridge or fuel efficient car) improving efficiency means that we consume less and the term "efficient" implies being "good".

"Efficient" domestic supply systems involve nor minor consumptive use – outflows can be treated and returned to the river system. "Efficient" irrigation systems however result in significant consumptive use – over 85% are evapotranspired by the crop.

In order to overcome this confusion in terminology and scale of water accounting, Perry (2007) proposes in close collaboration with the International Commission on Irrigation and Drainage (ICID) a **terminology suitable for unambiguous use to all types of water use**, consistent with the science of hydrology, applicable at any scale without modification and using a value neutral terminology (not value laden like "efficiency"):

Water use: any deliberate application of water to a specified purpose. It does not distinguish between use that precludes further use (evaporation, transpiration…) and uses with little impact on further uses (navigation, hydropower…). Water is used according to the following categories:

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Consumed fraction	Non-consumed fraction
- *Beneficial consumption*: water evaporated or transpired for the intended purpose. Example: transpiration from an irrigated crop, evaporation from a cooling tower - *Non-beneficial consumption*: water evaporated or transpired for other purposes than the intended use. Example: evaporation from water surfaces or wet soils, unwanted riparian vegetation	- *Recoverable fraction*: water that can be captured and reused. Example: percolation from irrigated fields to aquifers, return flows from sewage systems - *Non-recoverable fraction*: water that is lost for further use: flows to saline ground water sinks or economically not exploitable deep-water aquifers, flows to the sea.

Those two fractions added together are equal to the total amount of freshwater in a specific water system. The ICID terminology brings clarity to the analysis of water resources management. It becomes for example clear that the closer the outflows are to the sea, the more important it becomes to minimise return flows, which could not be recovered for other uses.

Additionally to the ICID terminology it is important to clarify one final area of confusion by giving an unambiguous definition of **water use efficiency** as a productivity term: **output of crop per unit of water** (Jones, 2004). It should be noted that this term is widely confused with irrigation efficiency (the proportion of water used that is consumed by the crop, without distinguishing evaporation and transpiration).

B) Transpiration and Evaporation

Transpiration and Evaporation are processes where water "disappears" from the local hydrological cycle as it evaporates and is spatially dislocated through air parcels.

Transpiration is the flow of water vapour from stomata of leaves causing that replacement water flows from the soil through roots and stems to the leaves. The water vapour is lost as a "by-product" of photosynthesis, where plants bind carbon dioxide and release water and oxygen. This is the primary process of plant growth. If sufficient nutrients and energy are available, transpiration is directly correlated with production of biomass.

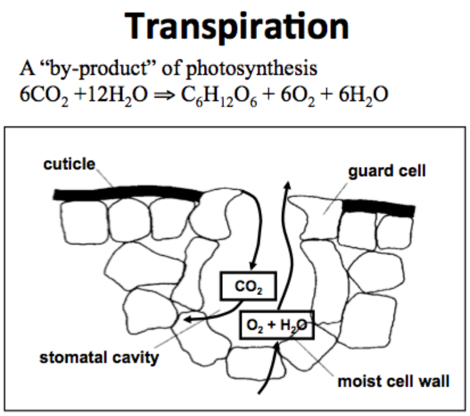

Figure 1: Transpiration and Photosynthesis

Evaporation is the conversion of water into vapour when the wet leaves, humid soil or the water surface is exposed to drier air (the air parcel above needs to have a relative humidity lower than 100% and once saturated, the air parcel has to be carried away by wind in order that the evaporation process continues) and radiant heat (about 2.5 mega joules of energy are needed to evaporate one litre of water – this huge amount of energy comes from solar radiation and the air temperature and is often a limiting factor to evaporation).

Evapotranspiration (ET) is defined as the sum of direct evaporation (E) and transpiration (T) of soil water through plant systems and into the atmosphere. Because this generally happens at

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great magnitude, ET is an important part of the hydrological cycle and of the water balances. **Understanding, evaluating and influencing ET is consequently an important element of local water resources management.**

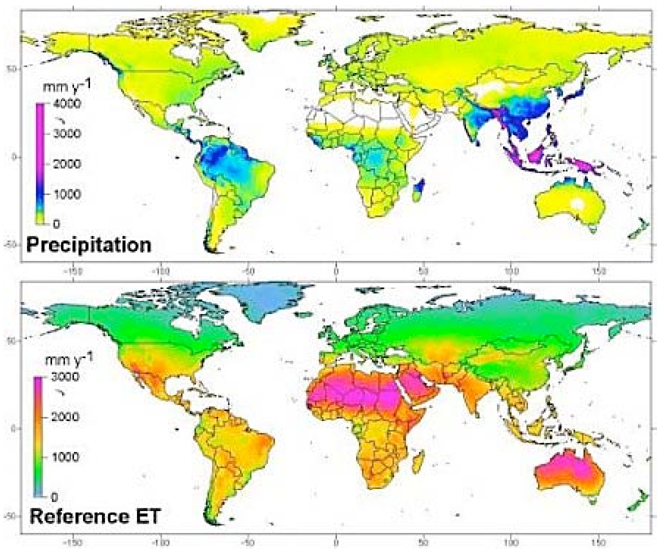

Figure 2: World precipitation and potential evapotranspiration rates

Reference ET rates refer to the maximum ET from an extensive surface of fully watered vegetation. This potential ET tends to be greatest in areas with highest hydrological water scarcity due to the negative feedback between general water scarcity and climatic aridity. Actual ET (as opposed to potential/reference ET) is the managed outcome of irrigated crops and the unmanaged outcome of rainfall, rain-fed crops and natural vegetation.

Irrigation aims at making sufficient soil water available to meet the T requirements of a specific crop taking the local climate and the stage of growth into account. If crops grow in water deficit conditions they first reduce canopy growth and then close their stomata. This in return reduces T, carbon assimilation, biomass production and harvestable yield under the potential. As for a fully watered crop a maximum ET value is defined by the environmental energy, any increase in E must result in an offsetting decrease in T, which reduces the water use efficiency. **In regions where the potential E is greater than the actual E it is thus advisable to recur to strategies allowing to obtain shifts from E to T**, such as surface mulching, reduction in frequency and spatial extent of surface wetting, reducing tillage and increased plant densities.

SECTION 2: HOW WATER AVAILABILITY INFLUENCES CROP PRODUCTION

The **beneficial consumption** of a crop is represented by the fraction of **water transpired (T)** by the crop itself. The **non-beneficial consumption** refers to the **water evaporated from soil and other surfaces (E)**. As mentioned before, data on water use efficiency often lack to distinguish between the two and we have therefore defined the water productivity (WP) of a crop as the ration between the amount of a crop produced and the amount of water consumed to produce such a crop: Biomass **$WP_{(ET)}$ = (kg biomass)/(m^3 water evapotransipred)**

Numerous studies (Tanner and Sinclair, 1983; Howell, 1993) have demonstrated that for a given situation **the water productivity of a plant is a linear function**. The slope of this relationship varies amongst different locations and seasons. It is for example obvious that in climatic conditions with reduced evaporative demand (such as little wind, low solar radiation, low temperature or high relative humidity) will reduce both beneficial and non-beneficial consumption. Also seasonality influences the evaporative demand.

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There are several **options available to improve the biomass WP of a field crop (see Fig.3)**:

1) Reducing the non-beneficial water consumption E and maintain T (Fig. 3b);
2) Grow crops with reduced evaporative demand by shifting crop seasons or area of growth and thereby increasing the water productivity (Fig. 3d). Example: moving spring crops into winter seasons;
3) Controlling the climate variables and thereby increasing the water productivity (for example greenhouses reduce the evaporative demand by about 60% compared to open fields) (Fig. 3a);
4) Genetically improved crops: loss (through pest/disease or drought) after significant consumption of water is reduced (Fig. 3a);
5) Capturing more water in the soil by using varieties with deeper rooting system and soil moisture control practices (Fig. 3c).

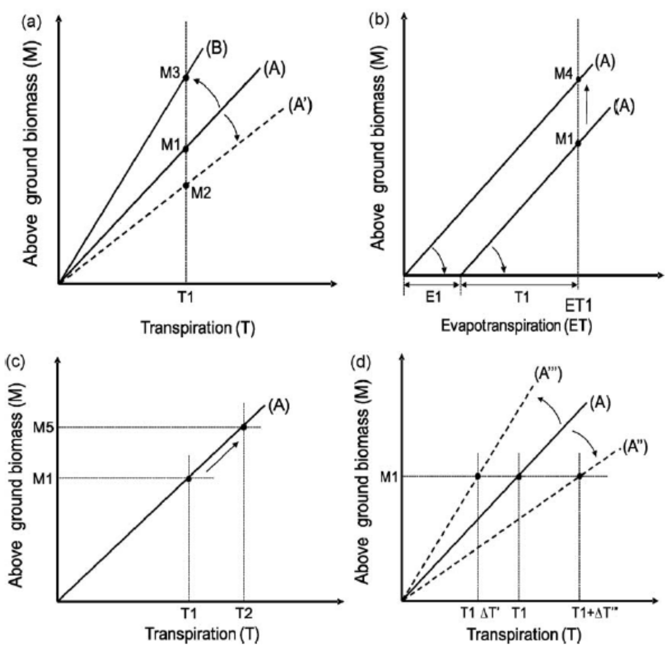

Figure 3: Biomass vs. water consumption relationship (Perry et al, 2009, p.1522)

However, for a specific crop and climate provided that sufficient nutrients are available the biomass water productivity in terms of beneficial consumption (T) is extremely stable and difficult to improve.

a) Conceptual relationships for a given crop in non-limiting nutrient conditions (A), poor nutrient conditions (A^{I}) and with genetically improved varieties (B) illustrating that under constant T the biomass production (M) can be influenced.

b) Total water consumption (ET1) is split in beneficial (T1) and non-beneficial (E1). Technologies (such as mulching) reduce E1, which can now be used for crop production (T) increasing biomass production up to M4.

c) A crop variety with deeper roots capturing more water from the soil profile was introduced. The biomass WP is not changed, but a higher transpiration (T2) leads to higher biomass production (M5): higher production translates into higher water consumption.

d) Shows how water consumption and production changes for areas or seasons with a higher atmospheric evaporative demand (A^{II}) or lower atmospheric evaporative demand (A^{III}).

When moving from biomass to yield water productivity, some important additional considerations have to be made: Whilst short-term water stress has very limited impact on biomass WP, it may have a **considerable impact on the yield if the water stress occurs during critical growth stages** (e.g. by reducing the number of reproductive organs). **Regulated deficit**

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irrigation is a technique that reduces water deliveries when field is relatively insensitive to stress, whilst ensuring full water supply at critical periods for the different crops and situations (Feres and Soriano, 2007). Whilst requiring a high level of management skills and having a high risk of damaging the crop by accidental over-stress, this technique is promising at reducing crop water use while ensuring maximum yield in water stressed areas.

SECTION 3: NEW IRRIGATION TECHNIQUES: A FARMER'S CHOICE

The installation of a new irrigation technology is ultimately decided upon at the farm-level. There are **several reasons why a farmer should be recommend to implement a modern irrigation technology (as DI/SDI)** and not all of them are water related:

- **Reduced evaporation losses and improved water productivity**: this point is widely described in the pages above
- **Increased income**: More yield tonnage/quality or higher value crops
- **Risk aversion/flood security**: Irrigation makes farmers less dependent from uncertainties related to rainfall variability or related to unreliable delivery of surface water
- **Convenience**: Especially commercial farmers may find it more convenient to deliver fertiliser more precisely through "fertigation" and not to get up in the middle of the night to receive project water delivery
- **Reduce costs**: Reducing delivery losses and system pressure (DI/SDI can operate at significantly lower pressure than conventional overhead or sprinkler irrigation systems) may reduce water-pumping costs. This new technology may also be less labour intensive.
- **Reduced negative impact on local freshwater quality**: reducing the water effluent from farm fields (the non consumed /recoverable fraction of water applied for irrigation) will positively affect the surface and groundwater quality properties, due to minimised introduction in downstream water systems of leaking pollutants derived from over fertilization and pesticide application typical of conventional irrigation systems (e.g..: flood irrigation)
- **Reduced energy consumption**: not only related to farmer cost cutting but also help introduction of policies to improve energy security for countries exposed/affected by power supply shortages for agriculture or being heavy energy importers (e.g.: India)

For a farmer it is a legitimate and high priority objective to choose the technology with the highest irrigation efficiency (output of crop per unit of water consumed) and thereby obtain shifts from E to T (as shown in Fig. 3b above) and maximises the biomass production and harvestable yield of its crops. This maximises the beneficial consumption of the irrigation water used and reduces the non-beneficial consumption to a minimum. Since T drives biomass production (provided nutrients are sufficiently available), and biomass production determines how much yield the farmer will have to sell (provided that water is not restricted during critical growth stages), **farmers will aim at maximising the beneficial consumption T and minimise all**

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other flows (non beneficial consumption E and flows of non consumed water to drains and groundwater). From a farmer's perspective such flows are lost.

In a large-scale study (Burt et al, 2002; Mutziger et al 2005) it was determined that - if accompanied with good management, equipment and well adjusted to the specific climate and crop - **the introduction of drip irrigation (DI) and subsurface drip irrigation (SDI) increases the T component of ET more than any other irrigation technology**. This has already extensively been discussed in the Technical Brief N.1 and for the purpose of this document we therefore only use the original table here after, which summarises the irrigation efficiencies of the different irrigation systems available.

However, it is important to stress that applying apparently promising technologies in a new setting is often associated with surprises as it is difficult to find the most appropriate combination of modernisation of field irrigation hardware and management for a specific location (see Burt and O'Neill, 2007).

Pressurised irrigation system application efficiencies, AE (%)		
Sprinkler irrigation systems		
System type	Range	Average
Lateral move	60-75	70
Center pivot (high pressure)	65-80	70
Center pivot (low pressure)	75-90	80
Stationary guns	50-60	55
Traveling guns	65-70	70
Drip irrigation systems		
Surface	85-95	90
Subsurface	85-95	90
Surface irrigation		
Flood & Furrow	25-80	50

As mentioned here few times, DI/SDI is the most "efficient" technology from an irrigation perspective allowing the farmer to cut all "lost" water flows. In areas with high atmospheric evaporative demand it is highly appreciable to minimise the non-beneficial consumption of the consumed fraction (shifting E to T as illustrated in Fig. 3b). However, often irrigation water accounting does not distinguish whether the non-consumed fraction of the "lost water" is recoverable or not. Often the water "lost" from an irrigation engineer perspective actually makes sense from a total hydrological cycle perspective, as other water uses might depend upon these water flows. **It is therefore very important to make basin wide water accounting analysis**

assessing upfront the impacts that a more water "efficient" irrigation technology may have on the other water users before implementing it.

SECTION 4: CONCLUSIONS

Hydrology and irrigation engineering are two distinct fields, which have both developed their own water accounting terminology leading to widespread confusion of terms. We have introduced here an available value neutral terminology applicable to multiple fields of water and at varying scales, dividing water accounting into a **consumed** (beneficial and non beneficial) and **non-consumed** (recoverable and non recoverable) **fraction**. Furthermore we have defined **water use efficiency as productivity term** – output of crop per unit of water and highlighted that the latter is often confused with irrigation efficiency (the proportion of water used that is consumed by the crop). Unfortunately most of the time when the latter term is used no adequate distinction is made between T and E of the consumed fraction.

From a farmer's perspective it is rational to chose the most efficient irrigation technique maximising beneficial consumption T, which is correlated to biomass production, and cutting all other flows including the non beneficial consumption E and the non consumed fraction which might be recovered for other uses. As already highlighted in previous technical briefs, **DI and SDI are the most efficient irrigation techniques (if they are well managed and adopted to the specific climate and crop), allowing to cut the non consumed fraction to a minimum and maximise within the consumed fraction T and minimise E**.

Many other reasons to recommend a farmer for adoption of DI/SDI technologies are described in the previous page.

However, current practices show that, after farmers have invested in a more efficient irrigation technology minimising all the non-consumed flows, they will be able to grow the same amount of crop with a fraction of the water they needed before, and use the rest of the allocated water volumes for their farm to expand irrigation in their nearby fields.

While this is a highly desirable outcome for the farmer who is able to increase yield and profit, **it is also very important to evaluate what these "efficiency gains" from an irrigation engineering perspective might have on other water uses in the shared basin. Such an upfront analysis is particularly important if the irrigation project is planned for implementation in a water stressed region**. Only if all the water that was not consumed before the introduction of the "more efficient" irrigation technology was non-recoverable (for example if it flew directly into the sea), the new technology has no negative impacts on other water uses. However, if before introducing a "more efficient" irrigation technology such as DI/SDI a fraction of the non-consumed water was recovered for other water uses (such as downstream farmers, municipal water supply or maintenance of aquatic ecosystem services), the improved irrigation system might have a negative side impacts on the other water uses that must be evaluated . Water flows that were considered losses from an irrigation efficiency perspective actually made sense from a total hydrological cycle perspective and other water users recovered the "losses".

An example of alternative farm strategy aimed at partly overcome this potential issue could imply maintaining the average crop production tonnage with reduced irrigation amount on smaller farm surfaces while devoting the residual farm land become available for non irrigated crops or other uses.

Finally, the content of this Technical Brief is aimed at hopefully clarifying certain conflicting aspects between irrigation engineering and water resources management at watershed level.

While upfront expert hydrological/hydro-geological analyses at watershed level are always recommended before implementing large scale introduction of modern irrigation technologies (e.g.: DI/SDI) in order to better understand local water contexts and evaluate current and future water supply/demand gaps for different users (agriculture, domestic, industrial), **drip irrigation solutions are identified as a main driver to improve water productivity, improve farmer's income and contribution towards food security.**

Section 5: References

Key source

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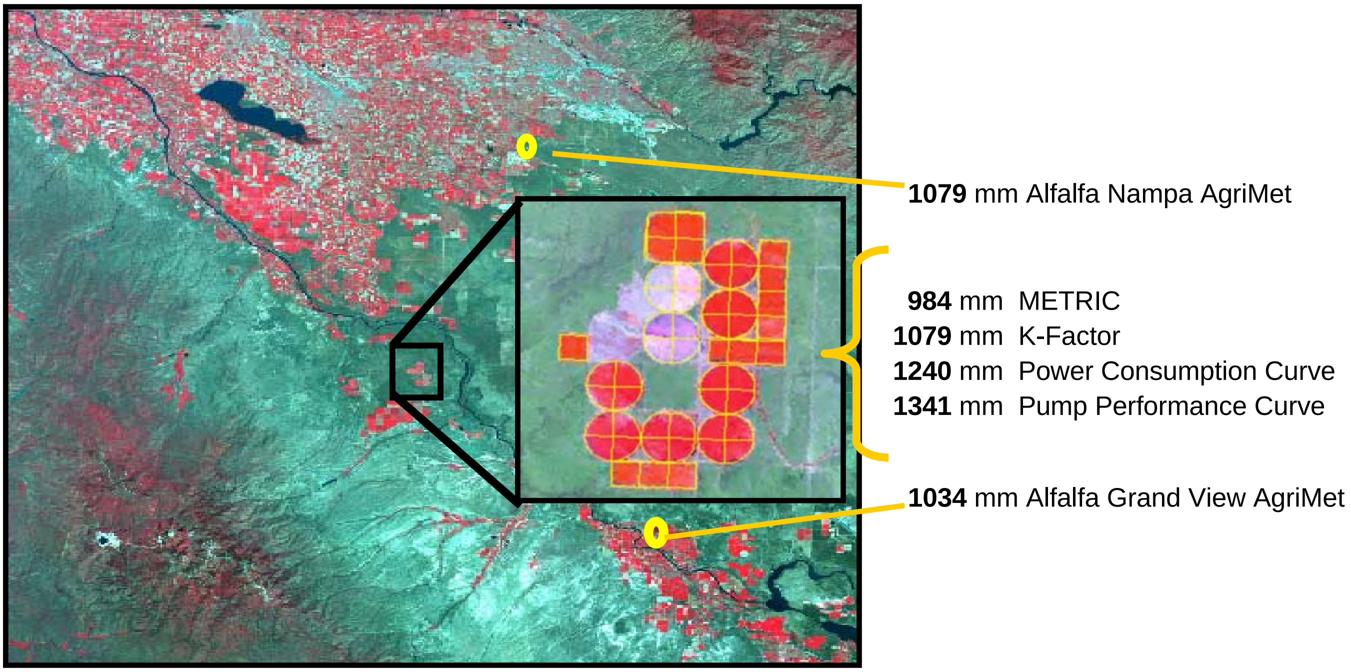
Water Rights Buy-Back

The Idaho Department of Water Resources and the U.S. Bureau of Reclamation have paid irrigators to leave water in the Snake River to support minimum flow levels. The Idaho Department of Water Resources used the METRIC model to evaluate irrigators' claims for water not diverted. In the example below, the irrigator used power consumption and pump performance curves for the year 2000 to calculate 7,574 acre-feet of water were diverted to irrigate 1,689 acres, which is 4.48 acre-feet per acre. The 4.48 feet correspond to 1,365 mm. The Idaho Department of Water Resources was willing to credit only the amount of water consumptively used, not the total diversion.

The Idaho Department of Water Resources used Landsat thermal data in the METRIC model to compute evapotranspiration. The Department compared the irrigator's claimed diversion with actual evapotranspiration output from the METRIC model and with 3 pump-related methods of computing diversion. All those numbers were compared to seasonal evapotranspiration for alfalfa, which is the crop with the largest water use, from nearby Bureau of Reclamation ArgiMet stations.



The Idaho Department of Water Resources concluded that the output from the METRIC evapotranspiration model value of 984 mm was the most realistic estimate of actual consumptive use because it was the only estimate that was less than alfalfa. The irrigator chose not to participate in the buy-back program. Landsat thermal data directly supported decisions about the wise use of public money.