WATER PRODUCTIVITY ASSESSMENT:
Measuring and Mapping Methodologies

Basin Focal Project
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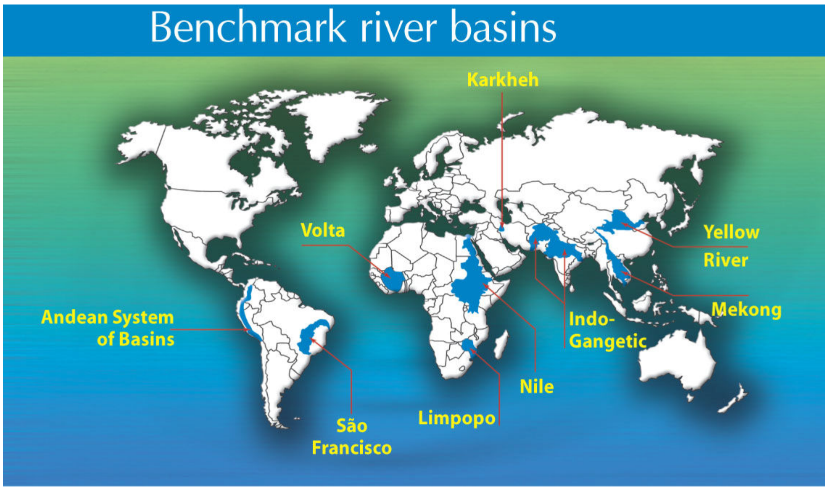
CGIAR Challenge Program on
WATER & FOOD

**WORKING WITH PARTNERS TO ENHANCE
AGRICULTURAL WATER PRODUCTIVITY SUSTAINABLY
IN BENCHMARK RIVER BASIN**



DISCLAIMER

This is an advance edition of the *Water Productivity Assessment: Measuring and Mapping Methodology*, and is a **draft version** of a working paper to be published formally by the Challenge Program on Water and Food. This report contains less than fully polished material. Some of the works may not be properly referenced. The purpose is to disseminate the findings quickly so as to invigorate debate.

The findings, interpretations, and conclusions expressed here are those of the author(s) and do not necessarily reflect the views of the Challenge Program.

Comments and additional inputs that could contribute to improving the quality of this work are highly welcomed.

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1 INTRODUCTION

There are two main concerns in the Challenge Program on Water and Food (CPWF):

1) to improve the livelihoods of the poor whose livelihoods are impaired by lack of access to sufficient clean water and
2) to improve the overall productivity of water at basin scale ("water productivity).

Access to clean water is considered a basic human right; lack of it is often itself an indicator of poverty. However, in rural areas, the role of water in human well-being is more complex than access to drinking water (van Koppen 2002). Water is used in a variety of productive and consumptive activities. Food production, income generation via fishing or agro-processing, and health can all depend directly on the quantity and quality of available water. Where water is not piped, the time that households must devote to collecting water is a major factor in livelihood options and outcomes.

One of the key features of a livelihoods approach to analysis is that it is dynamic and explicitly recognizes how opportunities and vulnerability affect well-being. Because of their lack of safety nets, the poor are often disproportionately affected by shocks such as droughts, heavy rains or floods. By the same token, mitigation of these shocks can be disproportionately beneficial. The ability of water assets to contribute to rural livelihoods is vulnerable to both natural and social forces, each of which can deal catastrophic blows or contribute to the slow erosion of the quality of, or access to, a resource. In both cases, uncertainty and insecurity affect the contribution of water assets to rural livelihoods, with implications for people's incentives regarding exploitation and/ or conservation. The ability to identify the pressure points—where water assets are critical and vulnerable—is crucial and is not always easy because many of the important driving forces are difficult to observe. Research can play a role in identifying these driving forces and developing ways to assess them empirically, and to mitigate their negative impacts.

The concept of water productivity (WP) is offered by Molden *et al.* (2003) as a robust measure of the ability of agricultural systems to convert water into food. While it has been used principally to evaluate the function of irrigation systems as the amount of 'crop per drop', it seems reasonable to extend the concept to include other types of livelihood support, such as mixed cropping, pasture, fisheries or forests.

Depending on the scale of analysis, the two objectives of improving WP and improving livelihood can appear either congruent or opposite. One of the subtler objectives of the CP is to both improve livelihoods and water productivity through the same interventions.

A role of the BFPs is to try to determine where the poor are within basins (poverty "mapping") and understand specifically in what way their livelihood strategies are limited by water or are vulnerable to water management. These issues are dealt with in more detail in an accompanying paper:

Livelihood support mechanisms	**Vulnerabilities**
Rainfed agriculture	Floods, droughts, landslides,
Irrigated Agriculture	Soil and water degradation
Fisheries	Lack of access to land, water, markets or capital
Pastoralism and livestock	Threats to domestic water supply and sanitation
Household (off-farm income)	Water related health issues
Industry	Degradation of biodiversity and natural productive ecosystems

The full range of benefits from agricultural production extend far beyond the simple measure of local production, to include indirect and broader impacts (Hussain, 2005). Multipliers of economy-wide farm / non-farm multipliers vary widely. Estimates in India suggest a multiplier as low as 1.2 for local schemes up to about 3 for the country as a whole. Multipliers tend to be larger in developed economies, estimated as high as 6 for Australia[1].

Non-economic benefits complicate assessment further. Environmental benefits can include direct product (including fish) or environmental flows (Smakthin, 2004[2]).

The purpose of WP is to enable rapid comparisons between water use systems in space and time: a WP of 1.5 kg/m^3 may be considered 'good' whereas one of 0.5 kg/m^3 'bad'. For this purpose, it may be preferable to restrict the concept to *parts* of a system that are comparable elsewhere, rather than determine productivity for the entire system. For example it may be useful to know that the WP of upland rice in Laos is lower than in neighboring Thailand, even though rice in the Laotian context occupies only a small proportion of total production. The questions in this case is: would modification of allocations increase net livelihood support?

Through the BFPs, the range of users of WP assessments includes reesarch investors (donors), policy-makers, water managers and farmer advisers. Ultimately, we envisage the concept used not just by researchers but all stakeholders who have influence to change water use. The aim is to enable users to lift water productivity, either by reducing the volume of water used; or by increasing the benefit from a given volume. For example, farmers in dryland areas of Australia already use a similar concept as part of everyday management. It is not unusual for farmers to use the measure to compare one field with another: a 22 kg/mm $_{\text{(growing season rainfall)}}$ crop is regarded as 'good', whereas an estimate of (say) 12 kg/mm indicative of cultivation or fertilizer problems.

The projects will identify interventions that target the "water-poor" and assess their potential impact on income, livelihood and water productivity. Water productivity indicators allow the comparison of outputs of physical (kg), financial (dollars) and profit (dollars gross margin) of different enterprises per unit of water depleted (actual evapotranspiration) or diverted (Rainfall + Irrigation (Surface and ground waters) + run-on + contribution from high water tables).

2 WP: A SIMPLE MEASURE TO ENABLE COMPARISON

Use of WP originated in irrigated systems, broadly out of a frustration with the ambiguity of concepts of irrigation efficiency (Secker and Molden, 2003). A similar concept also seems useful to represent the comparative efficiency of rainfed systems (Rockstrom et al., 2003[3]).

WP seems most valuable for comparing the conversion effectiveness of a given agricultural system. However, the perceived value of water - hence the effort people will use to improve its productivity - depends on scarcity. Hence WP is more directly linked to overall ambitions in water-scarce or water-costly stituations than in systems which are supplied with plentiful, low value water. WP is most meaningful as an indicator as water resources become increasingly scarce.

Hussain *et al.* (2005) point out that the most meaningful measure is of marginal value, that is, the additional value that is created when water is added (or lost when water is not available). This paper also suggests that assessment with pro-poor intentions should also weight assessment to account for the increased value of benefits in low income groups. This argument is made on the basis that (a) income has dimishing marginal utility in purely

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1 Hill, H. and Tollefeson, L., 1996. Institutional questions and social challenge. In *Sustainability of Irrigated Agriculture.*

2 Smakthin, V., Revenga, C. and Doll, P., 2004. Taking Into Account Environmental Water Requirements In Global-Scale Water Resources Assessments. Comprehensive Assessment Research Report 2.

economic terms; (b) that if the intention is equitable income distribution, a dollar generated on behalf of a low income earner is worth more than one generated for a richer person and (c) that on a one-man, one-vote principle the per *person* benefit counts more than the per dollar benefit. On the basis of this, the relative value of protecting fisheries and forests is increased by their importance to the poor and marginalised.

The simplest way to compare water productivity across different enterprises is in dollar terms. However, since water is only one of many inputs, and its significance decreases as we move up the food chain, total value is somewhat misleading. We propose that **gross margin** (Product income less total variable costs) per unit of water delivered or depleted is a better way to compare across different types of production (agriculture, horticulture, livestock rearing, aquaculture etc).

Since there are feed-back effects of changing water use in the hydrologic pathway (typically upstream-downstream effects), it is necessary to look at the impacts of different interventions and the scale of adoption in a way that internalizes hydrologic feedback in terms of water quantity and water quality. The best way to do this is by integration of the production system, the hydrology and the economics within one modeling framework. This can vary from simple spreadsheets, to suites of hydrologic, allocation and production models to integrated hydrologic and economic models. The precise requirements and solutions will vary according to basin context and data availability.

3 MEASURING WATER PRODUCTIVITY

We are interested in measuring water productivity with respect to the amount of water directly consumed by the cropping system (evaporation and transpiration) as well as relative to the amount of water supplied from different sources. As we move upscale from field to farm to basin, we wish to know how much water has been **depleted** in agricultural production, which accounts for actual evapotranspiration (Et) by the crop, evapotranspiration losses from return or “unused” flows and losses to sinks, such as saline groundwater (see Molden, 1998). In measuring depleted water, we also account for flows not used by the crop and returned to the hydrologic system.

At field, farm and system scale, the denominator of water use is potentially made up as follows:

$$NetWater_{in} = Rain + SI + GWI + net\_capillary\_rise + runon - runoff - deep\_percolation \quad (1)$$

where:

SI = surface irrigation supply

GWI = groundwater irrigation supply

Some components may not be relevant depending on circumstances, for instance: no irrigation in rainfed farming, no run-on (incoming overland flows) or no capillary rise from high water table. Using both actual Et and net water supply as denominators can help us understand the context and options for management.

The problem of estimating WP becomes more complex for large, heterogeneous areas, containing complex mosaics of land uses. Discrepancy of meaning between WP of different users can obstruct comparison of different water users within a single area. To simplify this, the method of water accounting may help track different water depletion flowpaths (Molden, 1997[4]).

[4] Molden, D. 1997. Accounting for water use and productivity. SWIM Paper 1. System-Wide Initiative for Water Management. IWMI, Colombo.

3.1 WATER PRODUCTIVITY IN RAINFED AND PASTURE SYSTEMS

3.1.1 Water supplied and water consumed: The denominator

The main challenge we face in calculating rainfed water productivity lies in determining the denominator – how much water was consumed in order to produce a given output. First we have to account for the spatial variation in rainfall, and secondarily we may need to understand the contributions of residual soil-moisture, shallow groundwater and surface runoff from adjacent areas (run-on). Rockstrom *et al.* (2003) cite published data that estimates that for semi-arid rainfed environments between 70-85% of rain water can be 'lost' to the system as evaporation, runoff or drainage. Relatively small errors in water partitioning may lead to large discrepancies.

Better estimates of water supply in rainfed systems can be obtained by interpolation of rain gauge data against elevation and over space (Jones et al, 2000). Many authors have found that it is better to do this in two stages: 1) regression of rainfall against elevation followed by 2) spatial interpolation between stations using techniques such as kriging or thin plate splines. Co-kriging with elevation seems not to produce better results than elevation-adjusted splining.

Such data can be rasterised and combined with remote sensed estimates of actual evapotranspiration and of land use. Where met and rainfall stations are sparse, it is possible to use satellite based data (cold cloud cover duration, cloud temperature) to interpolate spatial rainfall patterns. There are three sources of data – Meteosat (now down to 4km (ref ITC Africa rainfall site)), GMS and TRMM (radar)[5].

Measuring actual water use is also not straightforward. In rainfed systems, there are periods of water stress where transpiration is less than potential, and evaporation losses from bare soil can be particularly significant in low density crop stands. It may be possible to improve estimates using coupled rainfall estimates with crop and water simulation models (Droogers and Kite, 2001 used SLURP and SWAP; Diaz *et al.* 2005 used MARKSIM-DSSAT).

The problem remains, however, of estimating T for low density crop stands. If we can measure actual evapo-transpiration (Et_a) directly, we have an unambiguous value for depleted water. In semi-arid and arid conditions, with low cloud cover, it is possible to integrate daily estimates of Et_a over a crop season and sometimes over a whole year. The SEBAL procedure allows Et_a to be calculated using satellite imagery that has a minimum of red, near infra red and thermal bands. Et_a can only be integrated seasonally at a pixel size of 1 km^2 (100 ha) at the moment. Spot measurements at finer resolutions (60m pixels) are possible using Landsat and Aster data, which is available with a minimum of 16 day repeat pass measurements.

If we can determine Et_a directly, we do not have to worry about the source of water (rainfall, run-on, shallow groundwater) since all are subsumed into the Et_a value. Where the ratio of Et_a to rainfall is higher than 1.0, we clearly have a situation where there is either groundwater contribution or run-on. However, run-on can occur when Et_a is significantly less than rainfall also.

Where it is not possible to apply the SEBAL procedure, the alternative is to revert to a soil-plant-water model such as SWAP or DSSAT which couple soil water balance with crop growth and water use. It is then possible to estimate actual Et on the basis of water balance and crop limiting soil moisture stress. Models such as SWAP have been "regionalized" for characteristic farm types (Droogers, 2001) and can be used in conjunction with GIS

5 See http://daac.gsfc.nasa.gov/precipitation/TRMM_README/TRMM_3A12_readme.shtml, http://disc.gsfc.nasa.gov/guides/GSFC/guide/arkin_gpcp_gpi_dataset.gd.shtml

characterization of rainfall and farming system. Higher spatial resolution estimation may be possible for variable soil characteristics (Pracilio *et al,* 2003).

Following the notion of hydronomic zonation (Molden *et al.* 2001), an alternative to exhaustive process simulation modelling is to use environmental correlation of daily climate, soils and terrain from 'known' sites to extrapolate over large areas. Global correlation of climate and soils is available using the method of Jones *et al.,* (2005)[6]. SRTM data for all basins is downloadable from the CSI website (URL http://srtm.csi.cgiar.org/).

It is possible to estimate effective rainfall factor if both input rainfall and Et_a are known over a season (Et_a/RF), but this will not show how the residual is partitioned between runoff and deep percolation. We have to assume that there is no other water supply than rainfall and that Et_a is effective rainfall.

3.1.2 Production – the numerator

In rainfed farming systems, grain is only one output of value to the farmer – the others are green fodder and dry fodder (straw and stubble). In pastoral systems, the value of green biomass is optimal at a certain stage of growth and it is common to convert green and dry biomass into digestible dry matter to account for this variability. Additionally, the value of product may vary according to its position within the farming system it is used, often in quite complex ways.

In the first instance, we can use secondary agricultural statistics to determine yields for different crops in different areas. These areas will normally be defined by administrative district and some GIS manipulation is required to make them spatially coherent with water use data (see above). IWMI South Africa have developed a good GIS based analysis of secondary production statistics to understand the water productivity of the Olifants Basin, but at the moment, the analysis is limited by the assumption that actual evapotranspiration equals the potential value calculated using the Penman-Monteith equation.

However, it is unlikely that much secondary data will exist on green fodder production and straw/haulm production and utilization. Some primary crop survey or crop cutting in targeted areas may therefore be required.

In the Karkheh river basin, wheat and barley are grown for fodder, which is grazed by sheep and goats. Fodder wheat and barley seem to be found on increasingly steep slopes and thin soils, substituting for degraded pasture. This needs to be differentiated from cereals grown for grain, and one way of doing this might be to use the SRTM 90m DEM to zone slope and aspect over the land use classification.

If secondary statistics are not available, or disagree markedly with research or sample survey data, then more comprehensive ground survey of yields will have to be conducted. Such survey will have to be stratified by farming system and location. We propose to include a research component to develop remote sensing-based techniques to estimate water productivity at a regional scale, using a variety of scales of imagery (Landsat at 28.5 m pixel to MODIS as 1km (thermal) and 500m (visible, near and medium infrared wavebands). Groundtruth, crop histories, classification, biomass development and yield will be required to understand the relationship between net primary productivity and yield and to better assess harvest index as a function of crop condition. Representative areas for survey can be selected from a preliminary analysis of satellite images, and local knowledge.

If we want to understand physical productivity of different farming systems, we need to consider the numerator as shown below:

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6 Jones, P.J., Diaz, W and J. Cock, 2005. Homologue: (beta version). CIAT.

$$WP_{kg} = \frac{KgDM_{grain} + KgDM_{greenfodder} + KgDM_{dryfodder}}{m^3} \qquad (2)$$

where:

KgDM = equivalent weight of product at a standardized moisture content (say 12% for grain, 86% for green fodder and 10% for straw (check this figure)

m^3 = water supply/use in terms of water delivered or transpired, as appropriate.

Unfortunately, the fodder value of straw and fresh biomass varies with species, variety and time of cutting or grazing. Conventionally, the value of different pastures and fodders is standardized by converting to digestible dry matter, where the digestibility values are often tabulated from experimental work in livestock rearing. It will be very difficult to do anything but assign an average value of digestibility to major fodders in Iran, and the data will have to be obtained from existing experimental data.

3.1.3 Estimating WP using the Sustainable Livelihoods concepts

Some other concepts that require thought:

1 Assessment of WP in complex livestock based farming systems, with exchange of 'white water' as animals are moved around the system (Peden, 2004).

2 Forest and agroforestry systems, that may have a special servicing function in catchments, and be of unsual importance culturally or because of biodiversity.

3 WP of fisheries and other aquatic systems, that maybe very difficult to quantify yet provide essential livelihood support to the poor.

Develop ideas of non-commercial values

Wes Wallender proposed an indicator of water wealth, as follows:

$$Water\_wealth = \frac{\$income}{m^3} . \frac{m^3}{person} = \frac{\$_{water}}{person} \qquad (3)$$

Taking this idea further, an approach may be to take account of the density of people supported by a given water resource. A case in point might be the Lakes region of Kenya and Uganda, which supports a large number of relatively poor people. Any assessment would need to take account of the sheer density of people. In the rainfed condition, a (very provisional) assessment might be:

$$Water\_livelihood = \frac{n\_people * basic\_needs\_met}{mm}$$

Basic needs met from agriculture might be estimated from existing livelihood survey data, where that exists.

3.1.4 Scale

As we move up scale from field to farm to basin, we need increasingly to compare water productivity in terms of the value of (different) products. If we convert physical output measures to farm-gate values (gross value of production) we can compare across different farming enterprises (wheat, barley, rice etc). IWMI's published output on Standardised Gross Value of Production (SGVP) has been questioned as the total value of production says nothing about costs, and therefore attributes average total benefit of all farming inputs to water.

If we wish to compare the productivity of different farming systems (including livestock and fisheries), we ideally should be able to determine the marginal productivity of a unit of water in each enterprise, and furthermore, we should be able to quantify the contribution water makes to total factor productivity. The former is almost impossible to do outside a research station, but it is possible to derive crop production functions that estimate the contribution of water to productivity in physical or monetary terms. Where feasible, production functions should be derived (as in IWMI's work in the Rechna Doab in Pakistan).

A simpler proxy for comparison across scales and enterprises is to look at the **gross margin of production** (**gm** = total value of product – total variable costs) per unit of water used or supplied. Although this still attributes the gross margin value entirely to water, it effectively accounts for the differential benefits and costs of the other inputs. This allows for a first step comparison of water productivity across different uses, including livestock and fisheries, and factors in the primary productivity of vegetation grown as feed with secondary factors of feed conversion efficiency. Of course, determining the gross margin requires a larger amount of field data on input types and costs, and this can only be derived from survey data. The greater the area scale, the more idealized a gross margin becomes for any enterprise, since the variability that explains individual farmer behaviour and management choices is averaged out.

Although there will often be a strong correlation between land productivity and water productivity (see Rechna Doab work, Ahmed et al. forthcoming), it is important to look at the comparable physical and economic measures of land productivity (yield, total income per ha and GM per ha). Many farmers are still more driven by land productivity than water productivity, and again a comparison of the indicators sheds light on farmer's perspectives, and also possibilities for interventions (for instance, where land productivity is high, but water productivity is low and visa versa).

3.1.5 Challenges in determining rainfed crop and pasture water productivity using remote sensing.

Although remote sensing offers us the chance to accurately represent land use and its spatial variation, to determine Et_a and possibly to infill rainfall data, there are a number of challenges to be addressed, as follows:

- Sub-pixel disaggregation of land use (between crops and between cropped and fallow land), when using 1km or 500m pixel (MODIS or AVHRR) data.
- Corresponding sub-pixel disaggregation and attribution of Et_a to each land use, or alternatively to land use defined by higher resolution imagery (Landsat at 28.5m).

The SEBAL procedure needs improved calibration for rainfed, pasture and forest land covers, and new research is probably required to do this, although a detailed literature review my unearth more recent research on this topic. Images for the upper and middle Karkheh basin require topographic correction to account for variations in reflectance due to the surface relief. Procedures have been developed by Tasumi and Allen to do this with Landsat data, and these can be adapted for use with MODUS data.

The water input story can be complicated by not being able to define contributions from high water table (although water table mapping will assist, if available) and not knowing the extent of run-on to rainfed lands, from surrounding catchment areas. It is also possible that there will be varying amounts of soil moisture carry over between seasons, depending on the year, the timing of rainfall: in general, we would expect all soil moisture in the root zone to be depleted every year in the Karkheh, with its strong pattern of winter rainfall and very high rates of potential Et in summer.

In some pastoral systems, such as in the Volta Basin, the value and availability of fodder is partly governed by knowing where livestock are….. where animals are "stall-fed", fodder use maybe localized due to the costs and difficulty of transport.

3.2 *WATER PRODUCTIVITY IN IRRIGATED AREAS*

The determination of the water productivity of irrigated crops is better understood at IWMI, since we have more experience in the field. The steps involved are as follows:

1. Map irrigated areas and crop types within the surface water / groundwater system
    a. Identify conjunctive use areas with the irrigation system
    b. Map high water table areas (secondary data)
    c. Obtain crop yield data through appropriate combinations of secondary (administrative or hydraulic district) data or from primary survey.
    d. Obtain data on straw and green fodder production and utilization from irrigated crops, usually from primary survey.
2. Overlay irrigation networks, and determine where there is flow data for primary, secondary and possibly tertiary canals.
    a. Select units for investigation, where sufficient water supply data exists
3. Estimate gross inflows
    a. Obtain and spatially interpolate rainfall data. Using secondary data, determine typical values of effective rainfall (that retained in the root zone or as surface storage in the case of rice)
    b. Obtain canal flow data and determine seasonal surface water supply. Where flow data is not generally available at lower levels of the distribution network, it is possible to develop and apply disaggregation techniques to estimate the net local supplies from canal head flows (see Ahmad and Bastiaansen, 2003)
    c. Survey groundwater pump locations, capacities and average operating hours to determine groundwater supplies.
    d. Where necessary, apply more advance procedures to estimate net groundwater contribution (see PhD thesis by Ahmad, 2002), using remote sensing and soil-plant-water models.
4. Estimate Et_a using SEBAL for each crop season, and disaggregate by cropping system.
5. Determine livestock holdings and fodder use (by survey)
6. Calculate land productivity (LP) in terms of GVP and gross margin.
7. Calculate water productivities (WP), with respect to total supply and Et_a:
    a. Physical production (kg)
    b. Gross value (SGVP)
    c. Gross margin
8. Identify innovative water use practices where WP is low but LP is high and vice versa.

9. Calculate water productivity at larger scales of irrigation system and basin, using the depleted and process fractions of water supply (Molden *et al*, 2001[7])
10. Determine system and basin average water productivity across all agricultural uses.

In irrigation systems, WP is measured as marginal yield per unit of water deplected by the system, ie: average crop product per unit of water consumed. Hussain (2005) suggests a broader range of possible indicators of productivity to account for value not accounted for in crop production. This paper also cites values derived from direct measurement –possible only in assessing WP of irrigated land.

Table 1: Indicators of productivity and value of water.

	Indicators
Water productivity-based indicators	Average product per unit of water
	Average gross value of product per unit of water
	Average gross margins per unit of water
	Average gross net value of product per unit of water
	Value of marginal productivity of water.
	Note: *Commonly used denominators for calculating water productivity based indicators are amount of water diverteted/supplied, water applied, gross inflow of water (rainfall plus irrigation), and crop evapotranspiration (ET).*

Source: Hussain, 2005.

4 IDENTIFYING INTERVENTIONS TO IMPROVE WATER PRODUCTIVITY AND TARGET POVERTY

Water productivity is an indicator of impact and improving it is a desired outcome of the development and adoption of interventions by the CPWF.

The CP intends to make an important contribution to the development of indicators that reflect the impact of technological, institutional and policy changes on the quantity, quality and productivity of water, access to and distribution of water, and ultimately on poverty. In fact, work is already underway in many of these areas. For example, better nonmarket methods are being developed to assess water productivity and value in alternative uses, including the development of “water and well-being indicators” (Vincent 2001). A growing number of empirical applications of the Sustainable Livelihoods framework for impact assessment are providing lessons about how we can directly and convincingly link agricultural and natural resources-management innovations with changes in the livelihoods of the poor (Adato and Meinzen-Dick 2002)

Bouman (2005) presents a systematic view of crop water productivity which offers 4 principles for improvement at plant, field and basin level:

- Improve consumptive water productivity, i.e. product per unit water transpired
- Increase water storage capacity
- Increase non-irrigation inflows to the production system
- Decrease non-productive outflows

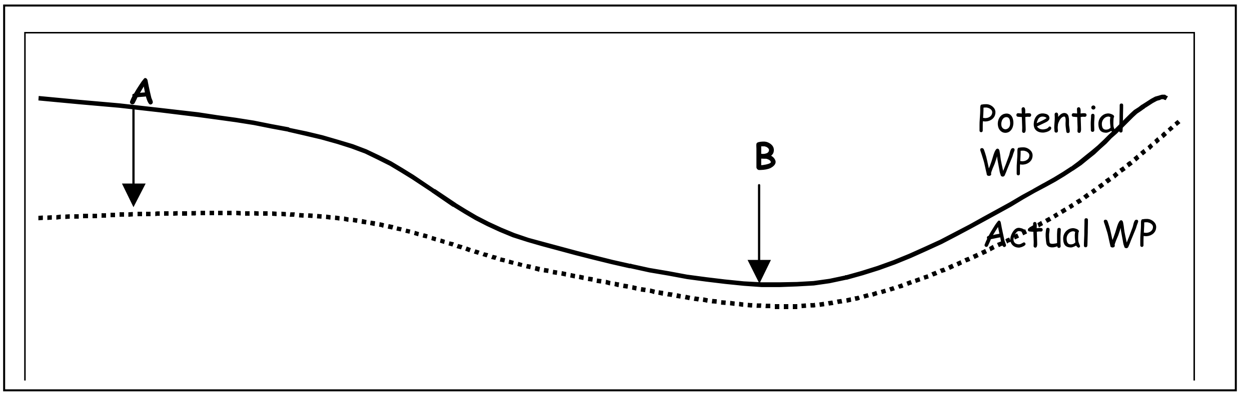
Each principle offers a range of contrasting opportunities at plant, field and basin scale.

[7] Molden, D., Sakthivadivel and Z. Habib, 2001. Basin-Level Use And Productivity Of Water: Examples from South Asia. IWMI Research Report 49.

4.1 RELATIVE WP

A site with low WP is not necessarily sub-optimal, any more than a site with high WP optimal. In this figure above, Site A presents greater opportunities for improvement than site B, even though this has lower WP. Characteristics of climate, soil and terrain will predispose a site to low 'manageability' or potential WP, that needs to be estimated in relation to the gain. For example, in the absence of irrigation, a site which experiences peaky rainfall, or onset of extreme vapour pressure deficits can present farmers with virtually non-manageable problems, for which the normal coping mechansim is risk reduction (Dercon, 2004) .

An option to assess relative WP would be to use 'calibration' sites of known favourable WP and extrapolate from these globally using th e Homologue tool for environmental correlation



(Jones *et al,* 2005).

4.2 EXAMPLES OF INTERVENTIONS

Interventions in production can be in improved crop varieties (shorter growing season with better harvest index, longer growing season with better drought tolerance, disease and cold resistance …etc), in conservation agriculture (capturing and utilizing more rainfall), in better input management (fertilizers, biocides etc.). Better technologies can be employed to improve production and productivity, for example supplemental irrigation or rain-water harvesting in rainfed systems, or improving distribution efficiency in irrigation systems in saline high water table areas. Intervention can also be in the policy sphere, such as changing water allocation, within irrigation systems or between irrigation development and rainfed area expansion. Sometimes policies will have to be evaluated that enable the replication and adoption of a physical intervention.

It is important to remember that, in certain circumstances (for example the Mekong Basin), water is unlikely to be a limiting factor at present, even though it could be in the future. The marginal value of water (locally at least) is less than in already water-stressed basins such as the Limpopo. In such situations, it makes more sense to look at interventions that maximize poverty alleviation through mininmzing environmental externalities.

It is also worth noting that the interventions that have the most benefit for the poor may not be concerned with increased productivity per se. Other factors that reduce vulnerability, such as much improved inter-annual reliability (reduced rates of crop failure); risk protection or better nutritional content (protein and vitamins) may be more important. Since many of the poorest are landless, farming systems that generate employment opportunities may in fact be more effective vehicles for poverty alleviation than improvements in the productivity of individual enterprises. This has been true for irrigation in India, where significant employment opportunities were generated in Punjab and Haryana, resulting in significant migration from Bihar and eastern states in the Ganges basin.

The impact of interventions to improve water productivity can only really be evaluated in full-scale systems. This evaluation might take the form of extrapolation to 'target' areas, coupled with modeling which integrates the land-use and hydrology in an appropriate way that can account for feedback effects of changed water allocation, effects of water use on salinity, changes of land use on hydrology and stream flow and so on. Agronomic interventions need to be scaled up using scenarios of adoption that are realistic in terms of physical setting (soils, agro-climate, farming system, water availability/supply security) and economic fit (characteristics of adopters, actual adaptation rates).

If there is significant groundwater use, and salinity is an important factor, then the integrating model should be a groundwater model, incorporating a salt transport module (ie MODFLOW with MT3D). Creating groundwater models is a very time and data intensive exercise, and is usually limited to well defined areas. It is highly unlikely that groundwater models can be built and calibrated at whole basin scale.

Where the system has predominantly a surface water supply with more limited groundwater interaction, a simple node-link model like WEAP may be adequate. If the system is dominated by rainfed agriculture, then a model like SWAT, which integrated land use and hydrology may be preferred, although there may be problems in representing groundwater use and surface water diversions. More complex models exist (such as MIKE-SHE) which integrate all process, but present very serious challenges in calibration, due to extensive data requirements, often related to soil characteristics. There are intermediate solutions, such as IQQM, which is basically a node-link model with more advanced hydrology options for catchment yield, ungauged inflows and storage. However, the data requirements even at this level are daunting.

The recent IWMI publication on the Zayendeh Rud basin in Iran (Murray Rust et al, 2004) provides a good example of the integration of models at different scales using simple spreadsheets as links, although it is a little light on the integration of groundwater.

"Best practice" can be defined either from research or preferably on-farm trial data, or by household survey, selecting the top 10% of producers to determine attainable yields and associated good management practice.

Allocation scenarios can be simulated by changing the balance of land under rainfed and irrigated conditions, or by adjusting water supply inputs through:

- rainwater harvesting,
- soil moisture conservation practices,
- supplemental irrigation
- changing surface or groundwater allocations
- conjunctive use policy

The benefit expected from these changes can be determined using crop production functions, or spatially attributing average land and water productivities for each intervention, or by using soil-plant-water models in representative situations. The feedback effects of these changes can be estimated in the medium term (30 years say) using one of the modeling approaches outline above.

The choice of modeling solution will vary from basin to basin according to the land use and hydrologic situation and the best solution will only become apparent after proper description of the land use, topography and hydrology, and consideration of the types of interventions to be evaluated.

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