WATER
– MORE NUTRITION PER DROP

Towards Sustainable Food Production and Consumption Patterns in a Rapidly Changing World

A report commissioned by the Swedish Government and produced by the Stockholm International Water Institute (SIWI) and the International Water Management Institute (IWMI) as input into the Commission on Sustainable Development (CSD) and its 2004–2005 focus on water and related issues.

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Note to Reader

"More Nutrition Per Drop" and the Side Event at CSD–12 were the result of an initiative by the Swedish Government. The topic addressed in this report is an issue identified as being of very high priority for the Swedish Government. The views put forward in this report, on the other hand, are expressed solely on behalf of the International Water Management Institute (IWMI) and the Stockholm International Water Institute (SIWI).

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The Stockholm International Water Institute (SIWI) is a policy think tank that contributes to international efforts to combat the world's escalating water crisis. SIWI advocates future-oriented, knowledge-integrated water views in decision making, nationally and internationally, that lead to sustainable use of the world's water resources and sustainable development of societies. www.siwi.org.

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Outlook

Production of food is a highly water-consuming activity. Huge volumes of water are transformed into vapour during the production process, both as plant transpiration and evaporation from the fields, canals, reservoirs and high water tables. With prevailing land and water management practices, a balanced diet represents a depleting water use per capita of 1,300 m^3/p yr, which is 70 times more than the 50 l/p day used to indicate the basic household needs of water.

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Despite laudable efforts and accomplishments in global food production, 840 million people remain undernourished [1]. The Millennium Development Goals agreed by the Millennium Assembly of the United Nations in 2000 seek to halve the number of undernourished people in the world by 2015. Moreover, the goals seek this target within an environmentally sustainable and socially acceptable framework.

The ambition to eradicate hunger and undernourishment and the obligation to ensure that there is enough food for future generations is equivalent to huge and basically non-negotiable additional amounts of depleting water use. At the same time, present production patterns are unsustainable: they involve large scale groundwater overexploitation, heavy appropriation of streamflow resulting in widespread river depletion and damage to aquatic ecosystems, fisheries and biodiversity. Environmental degradation and loss of production potential is caused by water pollution from agricultural chemicals and hormones, water logging and salinisation.

Therefore, water development and management must be addressed and changed if we are to reduce the number of undernourished people. Development and management becomes even more compelling due to the growing competition for water, which has created an increasing and conflicting global demand. Water scarcity is a harsh reality that affects billions of people in many parts of the world (Figure 1).

For several decades, the increase in food production has outpaced population growth. Now much of the world is simply running out of water for more production and the context for production is changing. Increasingly, consumer preferences and purchasing power tend to drive production patterns: if urban consumers like more variety, farmers will provide it. The trend towards a greater demand for water intensive food items, e.g. meat and dairy products, places greater stress on food production systems. A conscientious co-management of water for agriculture and ecosystems is a basic precondition for sustainability. The social dimension – ensuring better livelihoods in the face of rapid changes – is equally important.

Increasingly, consumer preferences and purchasing power drive production patterns.

Practical sustainable solutions require win-win-win situations – winning on environmental, economic and social fronts.

This paper highlights key facts, conditions and trends regarding water. Additionally, it explores its relation to sustainable food production and consumption patterns. It also highlights key water-food-nutrition-environment-livelihood trends, provides bona fide response options, and illustrates important policy directions for debate and discussion in coming months.

Despite laudable efforts and accomplishments in global food production, 840 million people remain undernourished.

Five Key Issues for Policy Debate

1. *Close the productivity gap between what can be and what is produced.* There is a potential for water productivity gains in both rain fed and irrigated areas. To close the gap will require a combination of agronomic, economic and social interventions.

2. *Facilitate the diffusion and use of new technologies for increasing water productivity.* In irrigation, production gains can be made with a shift in irrigation management practices. Reducing water to irrigation will require close attention to water flow paths – reducing unproductive evaporation and eliminating flows that encourage salinisation, high water tables or cause ecologic damage. In rain fed agriculture, deficient plant development is caused by dry spells, soil crusting, poor water holding capacity, nutrient deficiencies in soil, etc. Both high-tech technology (drip irrigation, precision irrigation, etc.), and low-tech measures (water harvesting, local tanks, treadle pumps, etc.) have to be encouraged and their application made socially acceptable and facilitated. The potential of crop breeding, including the genetically modified crops, needs to be scrutinised. A large part of the solution will be ensuring that producers have the incentives to adopt these practices.

3. *Identify and influence unsustainable consumption patterns*. Consumption patterns are the result of a complex mix of social forces. With a massive urbanisation and increasing wealth, food preferences will change. A significant increase in the demand for meat is expected but also other water intensive food items. It is vital that the "food basket" contains different food items to achieve food and nutritional security. What policy tools are available to stimulate preferences for food items which satisfy nutritional requirements and which are not depleting water resources?

4. *Identify minimum ecological service criteria for protection of aquatic ecosystems against water depletion*. In river basins representing 15% of the land area of the world, river depletion has already proceeded beyond the need for committed environmental flows to protect aquatic ecosystems. This situation implies an urgent need to identify minimum ecological service criteria that needs to be protected/maintained in all of the areas where we foresee that future depleting water use will further threaten aquatic ecosystems and the goods and services that they provide to humanity.

5. *Identify unsustainable agricultural subsidies and trade barriers*. In water scarce regions, food imports may ensure food and nutritional security regardless of the possibility to produce the food domestically. The ability to increase import is, however, limited by poverty and lack of foreign exchange. Agricultural subsidies and trade barriers are effectively reducing a desirable pattern of food trade and distort a sound resource utilisation. We need to identify unsustainable agricultural subsidies and trade barriers. To what degree can a liberalisation of trade help to solve food insecurity problems?

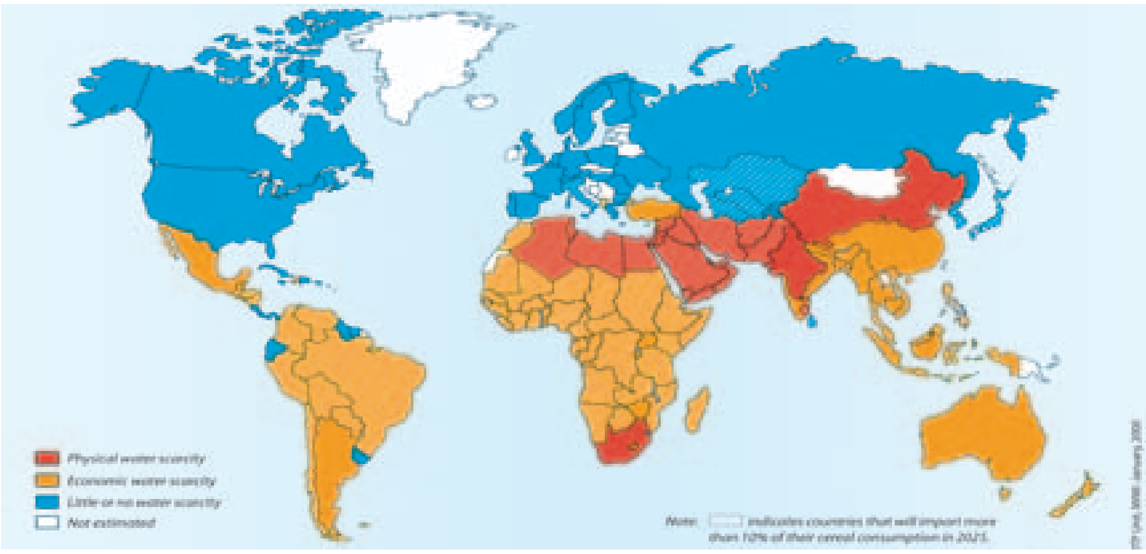

Figure 1: Projected blue water scarcity in 2025. Further water resources development is increasingly limited by rising difficulties to mobilise more water (red) or economic difficulties (yellow). Source: [2].

Executive Summary

Water's Web

Production, Nutrition, Ecology and Poverty

Huge volumes of water are transformed into vapour during the plant production process. This has far-reaching social and ecological consequences. Between 300 and 3,000 litres of water are required to produce one kilogram of grain.

Depending on diet, each person is responsible for the conversion of 2,000 to 5,000 litres of water to vapour each day. Drinking requirements of 2 to 5 litres, or "reasonable" household requirements of between 100 to 500 litres, seem insignificant when compared to the amount of water required to produce food [3]. Industry and service sectors typically require less water as compared to the agricultural sector.

The notion of a human right to food implies a water entitlement. Water availability is, however, constrained by hydroclimatic realities. This challenge forces the questions of how much additional water is needed to feed an expanding population and where and how this basic obligation can best be accomplished?

Projections to the future with current water productivity figures indicate that future food security will require huge additional water appropriation. The additional water requirements to alleviate hunger and undernurishment by 2025, would be equivalent to ALL water withdrawn to support all aspects of societal use today.

The results of past efforts to feed humanity have been impressive. Food production has outpaced population growth. Many areas of the world have, however, simply run out of water to grow more food. Other areas of the world, notably sub-Saharan Africa, have not put their water resources to work to produce enough food, and food insecurity and undernourishment prevail.

In view of the huge additional water requirements to feed the world, a most pertinent task, scrutinised in this report, is to produce more food with less water. This is a key aspect of "More Crop Per Drop." Without it, future sustainable food production is hardly conceivable.

Additionally, we must consider the achievement of "More Nutrition Per Drop," for the poor as well as for those who suffer from obesity. A balanced diet is important, especially as the human body must be able to assimilate the food nutrients.

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Additionally, we must consider the achievement of "More Nutrition per Drop." A balanced diet is important, especially as the human body must be able to assimilate the food nutrients.

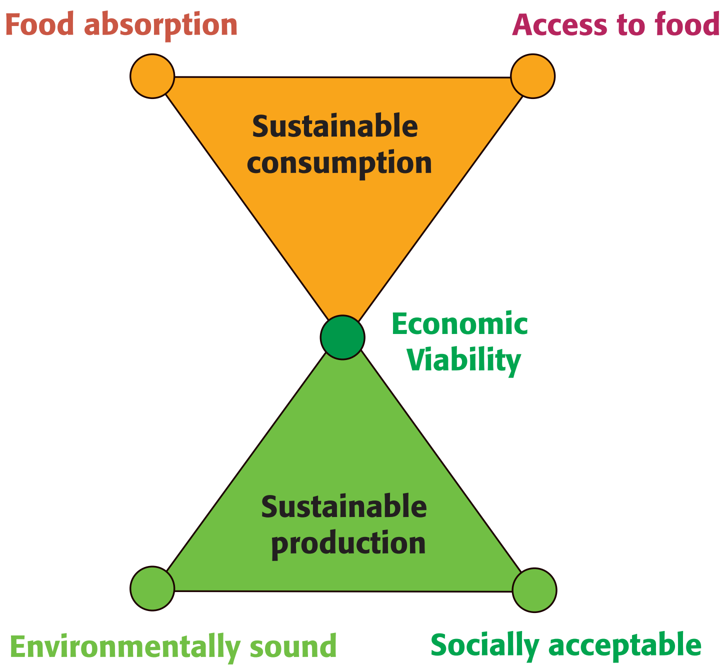


Figure 2. The Double Triple Win. The lower triangle refers to three components of sustainability. Food production must be economically viable, it must be environmentally sound and it must be organised in a manner which is socially acceptable. These three components must be considered in water policy and management, but also in land and resource policy in general. The upper triangle highlights another aspect of sustainability, namely consumption of food. One of the components coincides with sustainable production, i.e. economic viability. In addition, the growing number of people, who do not produce the food themselves, must have access to food, i.e. they must earn an income to be able to purchase the food they need and want. The component indicated in the upper left part of the triangle, refers to the composition of the diet and the ability of the body to absorb the nutritional value of the food consumed. Connections between production and consumption patterns will be discussed in Chapter 3.

Malnutrition and undernourishment still afflict nearly 15% of the world's population. The close links between trends in consumption patterns and preferences, and production changes must be identified. These links should be subject to modifications in incentives and public policy measures.

The gap between what *could* be produced and what *is* currently produced must be closed. In terms of sustainable consumption patterns and environmental sustainability, it is equally important to discuss what *should* be produced.

Photo by Mats Lannerstad for SIWI

Huge environmental problems undermine today's food production and will have to be actively mitigated and minimised: groundwater overexploitation, salinisation and water logging, water pollution, and deterioration of ecosystems and biodiversity.

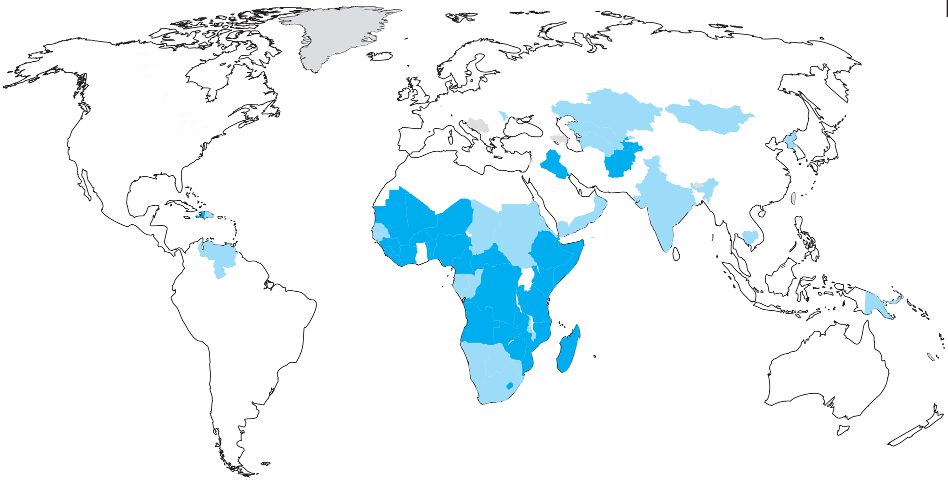
The Double Triple Win

Discovering Links Among Production Patterns, Consumption and Consumer Preferences

Practical sustainable solutions require win-win-win situations – winning on environmental, economic and social fronts. This presumes synergies between production and consumption; between food and environment; and between consumer preferences and production potential (Figure 2). The issue will, in other words, be to discover synergies that combine the more productive and more socially acceptable while depleting and degrading less.

Change the Fundamental Thinking About Water

The commonly used notion of "water use" must be specified to distinguish between depleting water uses in which water returns to the atmosphere and uses which allow re-use or re-circulation. Water use in food production and in the open landscape in general means that a certain fraction of the water will return to the atmosphere as evaporation and tran-



Top and high priority countries

No data

	Top priority countries	*High priority countries*
Sub-Saharan Africa	*25*	*13*
East Asia & the Pacific	*0*	*4*
South Asia	*1*	*1*
Arab States	*3*	*3*
Latin America & the Caribbean	*1*	*3*
Eastern Europe & the CIS	*1*	*4*

Figure 3: Priority countries for human development. Source: HUMAN DEVELOPMENT REPORT 2003 by United Nations Development Programme, Copyright 2003 by the United Nations Development Programme. Used by permission of Oxford University Press, Inc. [4]

spiration. Another fraction of the water supplied to a field will form drainage water and is potentially possible to re-use. In the case of paddy, it is commonly stated that the water requirement during a season is 1,200 mm. However, for most paddy varieties, with a season of around 100 days and a daily potential evapotranspiration of 5 mm, only about 550–600 mm are actually depleted (Box 2). The difference between what is supplied and what is depleted implies opportunities in terms of more productive use, including re-use by people for more crops and more fish and the environment to sustain wetland functions. Cascading reuse systems are prevalent globally, but not well understood.

Increase Water Productivity

Increasing agricultural output per drop of water depleted will allow more food to be grown with less water. There is tremendous potential for water productivity gains in rain fed and irrigated areas. This will require a combination of agronomic, economic and social interventions – including crop breeding, soil and fertility management, irrigation water management, and water rights and allocation of blue water supplies. In rain fed areas, mitigation of dry spells with on-farm water harvesting or supplemental irrigation can potentially triple water productivity in much of sub-Saharan Africa. Irrigation can be used successfully too. A 10-fold variation of water productivity in terms of value of output per water depleted has been observed – due largely to how water is managed.

Promote Water for Food, Nutrition and Livelihood Security

For the poor, the relation between access to water and food is a crucial link for nutrition and livelihood security. With a low and insecure income, the poor's access to food is constrained. Similarly, the capacity of the human body to absorb the food being consumed is dependent on human health, for which safe drinking water is a basic pre-requisite. Also, the intake of calories must be at an acceptable level, otherwise proteins and other vital substances for a "productive and healthy life" cannot be absorbed. Part of the food intake will be equivalent to wasting food. Similarly, a sick farmer will not be able to produce food.

Promote Consumption Patterns that Support Sustainable Production

Diets impact water depletion. More grain-fed meat means more water depletion in agriculture. Producers will naturally respond to consumer demands. Similarly, increasing water needs to urban uses will put increasing pressure to reallocate water from agricultural uses to city uses. Demand management practices in cities, together with more efficient and water saving technologies, e.g. low-flush toilets, low-flow showers and more efficient and cleaner technologies in industry, will relieve the pressures on scarce water resources. The disposed water from those urban centres must be more re-usable downstream and in the urban fringe areas.

The difference between what is supplied and what is depleted implies opportunities in terms of more productive use.

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Producers will naturally respond to consumer demands.

Water management is often dominated by managers whose primary goal is to meet farmers' needs.

Co-manage Water to Meet Agriculture and Ecosystem Demands

Because 70% of developed water resources is supplied to irrigated agriculture, water management is often dominated by managers whose primary goal is to meet farmers' needs. Shifting this slightly so that water could be managed to meet farmers' and ecologic needs could greatly reduce the ecological damage of prevailing agricultural water management practices. Aquatic ecosystems tend to be very sensitive to hydrologic peaks and low flows. Controlled releases of limited quantities of water to match natural hydrologic flows can yield environmental, social and economic benefits.

A better understanding of the relationship between "environmental flows" and ecosystem health must be achieved. Co-management presumes that an institutional mechanism incorporates these environmental flows into management regimes.

Focus on Poverty

The promotion of low-cost technologies and management approaches for access to, and productive use of, water must be undertaken. These innovations include low-cost drip kits, water harvesting, affordable pumps and water bags for storage that could provide more adequate food, nutrition and livelihood opportunities for millions of rural and urban poor. When new water is supplied, or supplies are reallocated, the poor must be considered. In many water-stressed basins, water is reallocated from rural agricultural settings to urban and industrial settings. Without institutional mechanisms for compensation, the losers will be those with the least power – the rural poor.

Box 1:

Water Trends

The Good, The Bad, The Double-Edged and The Sluggish

In seeking the paths towards sustainable synergies, four different sets of trends identified in this report have to be benefitted from or to which adequate attention should be paid.

Promising Trends

- Steady increase in the per capita consumption of food, from 145 kilograms of cereals per year in 1961 to 175 kg/year in 2000. Average global calorie intakes on a per capita basis have improved from 2,250 kcal in 1961 to 2,800 kcal in 2000 (cf. disturbing trends below).
- Steady increase in land and water productivity – with average yields increasing from 1.4 tonnes/ha to 2.8 tonnes/ha, and equivalent gains in water productivity from the 1960s to 2000. Closing the yield and water productivity gap offers an opportunity to feed the world.
- In global discourses, there is a shift in thought and emphasis from national food production, which dominated policies in the 1960s to individual or household food security as stated in the Millennium Development Goals. There are signs of a greater awareness of the significance of nutritional security.

Disturbing Trends

- Average calorie intake in South Asia (2,450 kcal) and sub-Saharan Africa (2,230 kcal) remain far below norms. Among the urban poor, the calorie intake is shown to be much lower as compared to what is required to "lead a healthy and productive life," while calorie intake in Western countries is above norms.
- An increasing number of rivers are reduced to polluted drains because of the combined effect of heavy depleting water use for crop production, urban expansion and pollution.
- Groundwater levels are declining rapidly due to overexploitation in densely populated areas of North China, India, Mexico and also in Western countries.
- Increasing land and water degradation from nutrient depletion, soil degradation, salinisation and seawater intrusion.

Double-edged Trends

- A growth in trade in food products and virtual water flows – the amount of water consumed in producing food – offers the possibility to relieve water stress. However, many countries hold a desire for national food self sufficiency. Resources to increase import of food are, however, limited due to poverty.
- Steadily increasing withdrawals for irrigation in developing countries are positive for economic growth and poverty alleviation, but negative for the environment.
- The use of Genetically Modified Organisms (GMOs) offers possibilities of increased production, but with unknown consequences for human health and the environment.
- Urban and industrial expansion offering possibilities of income and employment. In developing countries, cities are projected to use 150% more water in 2025 than they use today.
- Urban expansion will stimulate production of a variety of food items, which may stimulate improvements in water productivity and offer income opportunities for farmers.
- Increase in the number of people who consume but do not produce food. Modification in food preferences and diets will drive food production and influence water use.

Sluggish Trends

- Persistence of sectoral (domestic, environment, agriculture) and supply oriented (more water development and provision) and an inertia to implement integrated approaches.
- Persistence of agricultural subsidies in developed countries, giving a clear advantage to the rich over the poor in food production.
- Proper systems of incentives are not in place. There is a slow uptake of many promising solutions that increase water productivity, wealth and reverse environmental degradation.
- Subsidies on supply side management continue to dominate. These do not promote improvements in water productivity.

An increasing number of rivers are reduced to polluted drains because of the combined effect of heavy depleting water use for crop production, urban expansion and pollution.

Closing the yield and water productivity gap offers an opportunity to feed the world.

1. Water in Sustainable Food Production and Consumption Patterns

Behind every kilogram of food, 1000–3000 litres of freshwater are hidden.

Malin Falkenmark and Johan Rockström, 2004
Balancing Water for Man and Nature

With about 840 million people undernourished today and another 2 billion or more people expected to be seated at the table by 2025, feeding the world's growing population continues to be one of the most basic and sizeable challenges in the world.

Scope of Report

Discussions about sustainability generally refer to sectors of society. For example, analysis is rigidly categorised by industry, agriculture, forestry, fisheries and, quite often, water. Rarely is the topic dealt with concerning the interplay between what happens in these sectors and the situational dynamics at the household level – which is the most profound building block in sustainability.

The challenge to feed the world's population has been a lingering worry throughout history. This is so whether we seek to discuss farmers' obligations, consumers who must buy their food, or those who depend largely on food aid programs. With about 840 million people undernourished or lacking a secure food supply today and another 2 billion or more people expected to be seated at the table by 2025, feeding the world's growing population continues to be one of the most basic and sizeable challenges in the world. It is important to identify where and how the food will be produced and who will be providing it.

While national food self-sufficiency and stability, measured through output, have been considered good measures of food security, the current focus is more on chronic or even transient food insecurity at the household level.

In addition, what are the environmental consequences of intensified food production? As elaborated below, the basic question does not refer to water use in general, but the consumptive use, i.e. how much of the available or supplied water is actually depleted in connection with food production or how a "cascading re-use" of the remaining water can be possible. The latter aspect highlights the need to recognise quality and environmental aspects.

The feeding challenge has shifted in character over time. While national food self-sufficiency and stability, measured through output, have been considered good measures of food security, the current focus is more on chronic or even transient food insecurity at the household level.

According to projections by the Food and Agricultural Organization (FAO), the reduction of the number of undernourished by half by 2015, as set forth in the MDGs, is unlikely. FAO estimates that reducing the number of undernourished to 400 million will not be reached until 2030, 15 years behind the MDGs' target. If the MDG target is to be achieved, the number of undernourished would have to be reduced by some 25-30 million per year, which is significantly higher than the current rate of 2.1 million achieved so far. Naturally, above and beyond this, food security will also need to be achieved for the 70 million newborns each year. As far as we know, there is no valid projection about how to reach food security for all in the foreseeable future.

The 840 million undernourished people suffer not because of an insufficient gross production. However, the exact reasons behind these tragic figures are disputed. Poverty, which implies that the ability to purchase food is severely constrained, is certainly one important cause. Recent figures suggest that about 2.8 billion people earn a living on $2 or less per day. The level and orientation of production would be different if the level and distribution of income were different. Some analysts argue that changes in food preferences and the disposition of household income may be a contributing factor to a less healthy composition of diet. Among the wealthy, obesity is a huge and growing public health problem. The destitute, on the other hand, may spend part of their meagre resources on food items, which contribute to their undernourishment.

A shift in food preferences and a growth of demand in agricultural non-food products signals to farmers a need to modify cropping patterns. This, in turn, may have considerable consequences on water demand and food security. Hence, it is important to recognise that sustainability is closely linked to production, consumption, human preferences and perceptions, or development, as considered in a generic sense.

Finally, it is important to take the prevailing discussion one step further by emphasising that the possibility to lead a "healthy and productive life" requires proper absorption of the nutritional value of the food that is actually consumed. Food wastage during consumption, as a result of infections and diseases is considerable. Similarly, production is reduced if the farmer is sick [5].

The Three Dimensions of Sustainable Food Production and Consumption Patterns

The challenge ahead has three fundamental dimensions. First, the largest undernourishment and the most rapid population growth occur in the drought-vulnerable regions of Asia and Africa. Increases in overall production and in the yields are slow and beset with severe difficulties. The prevailing food production may be sustainable in terms of resource utilisation, but remains at such a low level that the national requirements cannot be satisfied through current levels of domestic production. To ensure food security and improve the nutritional standard, national production must increase. The alternative is to rely increasingly on imports, which could ensure sustainable food consumption. Many of these areas are, however, characterised by widespread poverty. Access to food, the second dimension, from imports is hampered by the lack of income earning opportunities for much of this population.

The third important dimension in efforts to achieve sustainable consumption refers to the ability of the human body to absorb the nutritional value of food consumed. If diseases like diarrhoea prevail, the nutritional value will not be absorbed.

Sustainable food production and consumption patterns, therefore, include three dimensions, each of them water-dependent in different ways (see Figure 2):

1. Food Production, which involves a consumptive water use much larger than the water needed in households or industries.
2. Food Access, which includes the ability to purchase or effectively avail food. Water allocations to industry, tourism, etc., could increase purchasing power of people to obtain the food they need. In water scarce areas such allocations will, most probably, reduce the amounts of water that are available for home food production.
3. Food Absorption, in which the human body must be able to use the food it is fed. One pre-condition for this is access to safe drinking water in order to avoid water-related diseases. A balanced diet is equally important [5,6].

Food production is, by far, the most water intensive activity in society. Water requirements in the household sector refer to a small fraction, while the requirements of industry and service sectors are 10–15%, on a global average.

Sustainable food production and consumption patterns include three dimensions: food production, food access and food absorption (the ability of the human body to use the food it is fed).

The largest undernourishment and the most rapid population growth occur in the drought-vulnerable regions of Asia and Africa.

Photo by Mats Lannerstad for SIWI

2. Variation in Water Productivity

Food and agriculture are by far the largest consumers of water.
They require one thousand times more than we use to drink
and one hundred times more than we use to meet basic personal needs.
World Water Development Report, 2003

Due to biological realities, a large amount of the water returns to the atmosphere in connection with the photosynthesis and plant growth as transpiration. Another large amount returns to atmosphere as evaporation. The former could be seen as the productive loss, while the latter constitutes non–productive losses.

Production Per Unit of Water Depleted

In contrast to most other sectors of society, food production is different in the sense that it involves a consumptive water use. Due to biological realities, a large amount of the water returns to the atmosphere in connection with the photosynthesis and plant growth as transpiration. Another large amount returns to the atmosphere as evaporation. The former could be seen as the productive loss, while the latter constitutes non–productive losses from the soil surface and landscape.

These two flows of water cannot be re-used or re-circulated. Since it is the climate which determines how much water returns to the atmosphere, geographical location and duration of the cropping season primarily determine how much of the available water is depleted in connection with food production (see Box 2). In terms of transpiration, there are no "economies of scale"; an increase in food production is associated with a corresponding increase in transpiration. This is the "non-negotiable" biological function of water, which, in principle, is scale neutral.

This does not mean that the production per unit of water available in the landscape is static. For instance, some of the water supplied to the fields will percolate down through the soil or seep from channels. This regeneration of streams or groundwater is, potentially, available for use in downstream areas. Better timing of cultivation in relation to water availability will reduce evaporation losses. This is an important possibility of increasing water productivity. Moreover, other options include technological changes, new seed varieties with shorter growth periods, and more careful and innovative management (Box 2). Food production, in terms of yields-per-hectare and productivity-per-water-unit, have steadily improved over several decades (see Chapter 5).

Box 2:

Crop Water Use and Water Depletion

Figures on how much water is used in connection with growing various crops are available in generaly accessible literature. In the comments to these figures a distinction is, unfortunately, seldom made between water use which refers to water that will return to the atmosphere as transpiration and evaporation, and the water that will remain in the landscape in terms of percolation, seepage and surface flows, which will regenerate aquifers and watercourses downstream.

Paddy cultivation could be used as an example. In books and reports, a common figure for water use in paddy cultivation is 1,200 mm.

This figure should be compared with the evaporative demand of the atmosphere, which is the determining factor for how much of the supplied water and the available rainwater that is not available for reuse *in situ*, or downstream. In a hot climate, the daily rate of potential evapotranspiration is around 5 mm and seldom exceeds 6 mm. The duration of the season for paddy cultivation is normally 90 to 100 days, depending upon, for instance, what varieties are grown, and if broadcasting or transplanting is practiced. The consumptive use of water, i.e. the amount of water that is depleted in connection with a season, is consequently about 550 to 600 mm, or about half of the 1,200. In other words, paddy cultivation has about the same consumptive use of water as, for instance, maize.

When referring to food production and agriculture in general, it is therefore important to specify what is meant by "water use". If water is supplied before land preparation and other cultivation activities start, gross water use will increase with each "extra day", but the productive use of water, i.e. the transpiration required for crop growth, will remain the same.

Yields and Variations in Water Depletion

At the beginning of the 1960s, when the Green Revolution began, the average crop yield in the world was about 1.4 tonnes/hectare. Thirty years later, in the mid-1990s, it had increased to about 2.8 tonnes/hectare, doubling the level (Figure 4). Yield improvements were particularly noticeable in cereals. In the mid 1960s, total global cereal production was about 0.94 million tonnes. In 1995, it was estimated to be in the order of 1.7 million tonnes, and projections by FAO and the International Food Policy Research Institute (IFPRI), suggest that production will increase substantially in the coming years so that total production may reach between 2.6 to 2.8 million tonnes in 2025. About 40% of this output is, however, used for animal feed, industrial purposes or is partly wasted during transport and storage. The increasing output component of the calorie intake for a majority of the world's population. More than 50% of calorie intake emanate from cereals [4]. In tropical regions, the cultivation of cereals is generally dependent on irrigation, i.e. paddy.

The figures just summarised hide substantial differences between countries and variations from one year to another. Average cereal yields per hectare vary, for instance, from 1.0 ton in Iraq to 6.9 tonnes in France (figures from 1995). Similarly, the amount of water depleted varies significantly, from 315 to 750 mm per season as a result of different evaporative demands from atmosphere, as illustrated in Table 1. Furthermore, the dependence on irrigation water is fundamental in some countries, notably in countries/regions with the largest concentrations of people, i.e. India, China, Pakistan, etc., while it is insignificant in other cases.

Beginning in the 1960s, when the Green Revolution began, the average crop yield in the world was about 1.4 tonnes/hectare. Thirty years later, in the mid-1990s, it had increased to about 2.8 tonnes/hectare.

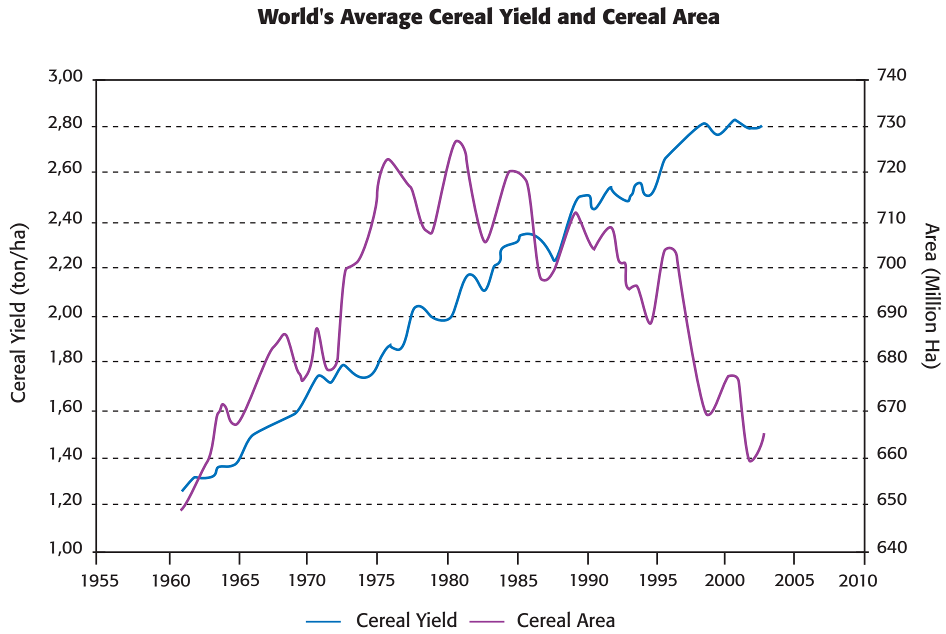

Figure 4. Trends in yields and acreage under cultivation in the world, 1965–2000. Source: Upali Amarasinghe, IWMI based on FAOSTAT data (2004) [7].

has resulted in considerable improvements in the average consumption of cereals, also in developing countries. Within one generation, during the last thirty years, the average per capita consumption in developing world has risen from 145 kg/year to about 175 kg/year.

The tremendous growth in cereals over several decades is now levelling off in some countries, while other agricultural products show a rapid increase, as mentioned in chapter 3. It is, however, still relevant to look at the production and consumption trends of cereals, since these are, by far, the most important

For Canada, which is a major cereal producer, the irrigation requirements are negligible, while in many countries in the tropics, the requirement is well over 500 mm during a season. In Egypt, a major food importer, nearly all crop water requirements are met by irrigation. Finally, it is relevant to mention that the effective utilisation of irrigation water varies from an estimated 75% in Israel to 45% in Iraq. For single irrigation schemes, a water use efficiency may be at about 15 to 20%, while the efficiency at the basin level could be very high since the water that is "wasted" in upstream reaches may be used in downstream areas.

Cereals are, by far, the most important component of the calorie intake for a majority of the world's population.

Selected exporters (1995)	Exports as % of world's total	Water productivity in kg/m3	% met by irrigation
USA	48%	1.26	15%
Canada	10%	0.88	4%
W Europe	10%	1.59	5%
Argentina	7%	0.49	5%
Australia	5%	0.54	28%
India	3%	0.34	41%
Exporters average*		0.81	26%
Selected importers (1995)	**Imports as % of world's total**	**Water productivity in kg/m3**	**% met by irrigation**
Japan	14%	0.73	73%
China	14%	0.75	46%
Egypt	4%	0.78	97%
Indonesia	5%	0.51	23%
Iraq	1%	0.21	89%
Sub Saharan Africa	<1%	0.19	2%
Importers average*		0.49	41%
World average*		0.60	34%
Average weighted by the countries' total production			

Table 1: Crop water productivity for selected importers and exporters of cereals. Source: [8].

Considerable improvements in water productivity are possible. But, is it likely, that trade in food item between areas of high and stable production potential and areas where these favourable conditions do not exist will play an increasing role in the future?

The wide range in the figures presented in Table 1 highlight the enormous differences in production potential and productivity between different climatic zones. They also imply that considerable improvements in water productivity are possible. One pertinent question in this regard is the following: is it likely that trade in food items between areas of high and stable production potential and areas where these favourable conditions do not exist will play an increasing role in the future? What would be the circumstances and consequences of an increase in such trade?

Food security is to a large extent also referring to sustainable fisheries and aquaculture. Fish is the primary source of protein for nearly one billion people, most of them in developing countries. As shown in Box 3, the catches have increased tremendously, but some of the stocks are under heavy pressure and the implications of aquaculture need proper attention.

Box 3:

The Blue Revolution Revisited: Can Aquaculture Become a Sustainable Solution for a Hungry Planet?

Capture fisheries and aquaculture play important roles for global food security, providing more than 15% of total animal protein supplies. Fish catches increased during the 20th century, but global per capita fish supply decreased from 14.6 kg in 1987 to 13.1 kg in 2000 because the human population has been growing faster than the total food fish supply. It has been estimated that nearly 70% of the world's fishing waters are already overfished and 90% of large predator fish have been cleared from the seas in the past 50 years or so. These are the species we most value, including tuna, swordfish, marlin, cod, halibut, skates and flounder. This development does not only imply an insecure future of these fish and the fishers that depend on them, it has also changed the whole dynamics of coastal marine ecosystems. Overfished marine systems have been shown to be more vulnerable (less resilient) to environmental change and disturbances like climate change, disease, invasive species and coastal pollution.

Global production of farmed fish and shellfish has more than doubled in weight and value during the past 20 years. This rapid expansion of commercial, intensive aquaculture of high-value carnivorous marine organisms (such as shrimp, salmon and cod) has often been called the "Blue Revolution." Today aquaculture supplies more than a quarter of all fish that humans eat, according to FAO statistics. However, many doubt that the growth in aquaculture will relieve the pressure on wild fish stocks and contribute to global food security. Current farming practices are on the whole not a sustainable solution for a hungry planet as each kilo of farmed fish consumes on average 1.36 kg of wild-caught fish (2001 data). However, in 1997, 1.9 kilograms of wild fish were required to produce every 1 kg of fish. This increase in efficiency is due in large part to the expanding freshwater aquaculture in China that farm carp or tilapia, which are vegetarians and do not consume any fish meal.

In addition to the impact on wild fish stocks, current intensive aquaculture practices cause a number of other environmental problems. These problems include destruction of mangrove forests and coastal wetlands for construction of aquaculture ponds, spread of fish diseases and the escape of non-native farmed fish species that compete with, or threaten the genetic integrity of, wild fish stocks.

However, there are alternatives. Less intensive aquaculture that uses multiple species can reduce costs and waste and increase productivity, according to an international team of scientists in a seminal article in the scientific journal Nature in 2000. Their recipe for how the aquaculture industry can become more sustainable included the following recommendations:

Less intensive aquaculture that uses multiple species can reduce costs and waste and increase productivity.

Photo by Lisa Borre. Courtesy Lakenet.

- Expand the farming of organisms further down the food webs, for example carp, mussels and algae.
- Reduce the use of fishmeal and fish oil as feed within aquaculture.
- Develop "integrated" farming systems that use multiple species to reduce costs and wastes while increasing productivity (e.g. farming algae and mussels near fish farms that take up the surplus nutrients).
- Increased governmental support for environmentally sound aquaculture systems and a stop on subsidies allocated to environmentally damaging aquaculture.
- Increase awareness within the aquaculture industry about its dependence on natural ecosystems and the shortcomings of today's methods.

Expand the farming of organisms further down the food webs, for example carp, mussels and algae.

Virtual water, the transfer of food from regions where production is comparatively easy to countries facing water stress, seems to be a rational strategy.

At the turn of the century, "global water savings" were about 175 km^3 per year as compared to a situation where all cereals would have been produced domestically. This is equivalent to about 3 times Egypt's annual Nile river supply.

Egypt, for instance, imported 8.6 million tonnes of grain (1995), thereby "saving" some 11.0 km^3 of water that would have been required if this food should have been produced domestically.

Agricultural Products Trade – the Role of Virtual Water

Countries characterised by heavy water depletion per unit of food produced or with low water productivity also tend to be water short and exposed to significant fluctuations in water availability due to climatic variations. The combination of water stress (i.e. large number of people per flow unit of water), hot climate and rapid population growth poses severe challenges for many countries in the Middle East, South and Southeast Asia and Africa. Poverty compounds the problem in these regions.

Under these circumstances, a transfer of food from regions where production is comparatively easy to countries facing water stress seems to be a rational strategy. It would facilitate food security and even sustainable food consumption, regardless of the conditions for production in places where people live.

Ordinary trade and food aid, which is about 20% of global food transfers, is referred to as trade in virtual water [9,10,11]. The concept captures the essence in food trade, namely that exporting and importing food is equivalent to the transfer of huge shadow volumes of water from the exporting to the importing country (Figure 7).

The significance of virtual water trade can be calculated in various ways. It can be measured in terms of total crop water depletion or in irrigation water depletion. A distinction should also be made between the amount of water that is actually used by the exporter and the amounts that the importer would have used in domestic production. If the exporter is more productive per unit of water than the importer, trade will reduce global water use, then there is a global water saving. For some countries, the domestic water resources are so limited that food self-sufficiency is practically impossible and importing food is a necessity. Egypt, for instance, imported 8.6 million tonnes of grain (1995), thereby "saving" some 11.0 km^3 of water that would have been required if this food should have been produced domestically.

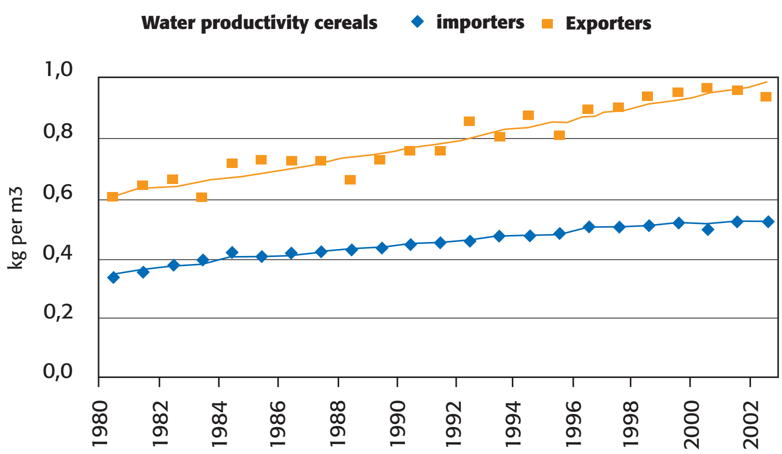

Figure 5: Crop productivity of cereals: 1980–2000. Source: [8].

Of the 1.7 million tonnes of cereals produced in 1995, about 12% were traded with the USA, Europe, Argentina and Australia as the major exporters. Water productivity in these countries is generally well above that of importing countries. It is also important to note that productivity has improved in exporting countries at a larger rate than in the importing countries, thus widening the productivity gap between importers and exporters (Figure 5). At the turn of the century, "global water savings" were about 175 km^3 per year as compared to a situation where all cereals would have been produced domestically. This is equivalent to about 3 times Egypt's annual Nile River supply. Globally, it takes about 1.62 m^3 of water to produce 1 kg of cereal. For some of the importing countries, the water depletion is much higher (an average 2.1 m^3 per kilo), while for exporters it is on average about 1.2 m^3 per kilo.

The importance of virtual water trade may seem obvious. However, there are several reasons to interpret the figures cautiously. A large share of the trade in food items is not dictated by water scarcity conditions, but rather by other economic reasons. Japan and South Korea are large virtual water importers, but not because they are water scarce.

Some export is going from countries with a lower water productivity to countries where the imported food could have been produced with comparatively less water. This is, for instance, the case with food exports from India to Indonesia and Saudi Arabia. Perhaps more significant, countries in sub-Saharan Africa with a low agricultural productivity and with poor nutritional status among the people do not feature as major importers, at least not of cereals. This is partly because they have tuber crops as staples and primarily because they lack the economic resources and the bargaining power to compete with other countries.

Even if water productivity is high in the exporting countries, it is also associated with environmental problems like stressed river systems (for instance the Colorado River), huge areas of monocropped culture which limit biodiversity, and groundwater declines (such as the Ogalalla Aquifer in the midwestern United States). It is made possible through heavy subsidies to producers. These subsidies stimulate production, while suppressing world food prices. Real world prices of rice, wheat, maize, fertilisers and urea are at a record low level (Figure 6). This benefits consumers, while those farmers who do not enjoy subsidies or receive fewer subsidies will find it difficult to compete. Since consumers are also tax payers, the low prices on subsidised goods are partly or fully paid for in another form. Incentives to invest are also reduced with the low prices that are paid for the product, that is, if farmers are not compensated through subsidies. The end result is that farmers in countries that cannot afford subsidies have great difficulties to compete and are not given the incentives to increase or improve production.

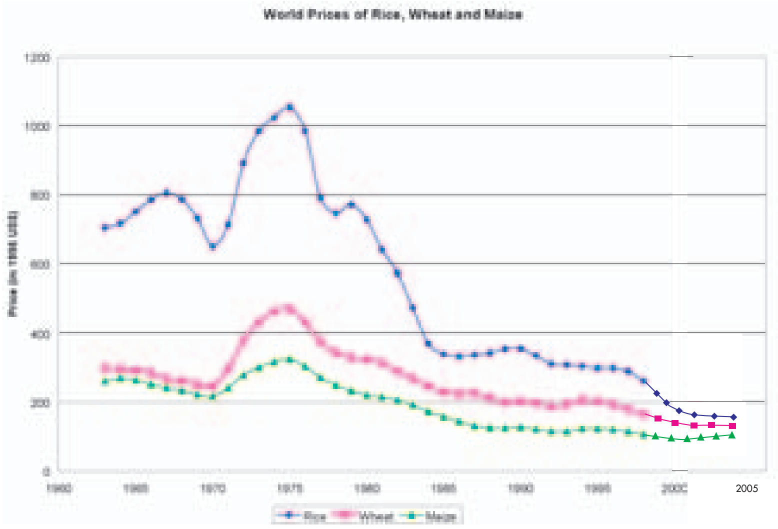

Figure 6: Real world prices of rice, wheat and maize. Source: IWMI based on FAOSTAT [12].

Nonetheless, the difficulties in achieving food security through domestic production for water-stressed countries are tremendous. Importing food is seemingly one possible solution for this dilemma. However, foreign currency is required to pay for imports, which in turn presumes economic development through industrial expansion, tourism or similar growth. This also presumes that some of the available water resources are diverted to these sectors. Pressure on the agricultural producers in countries attempting to move toward a greater reliance on virtual water trade will be significant. It is most important that farmers get the opportunity to invest in water productivity gains.

The political challenge to design an effective economic strategy toward greater reliance on food imports is considerable. Similarly, the social and cultural changes needed suggest that this transformation would be both difficult and slow. Improving productivity in countries suffering from food shortages is, however, also an important and demanding task. If increases in production and productivity had been easy, so many regions would not be facing this dilemma.

The political challenge to design an effective economic strategy toward greater reliance on food imports is considerable.

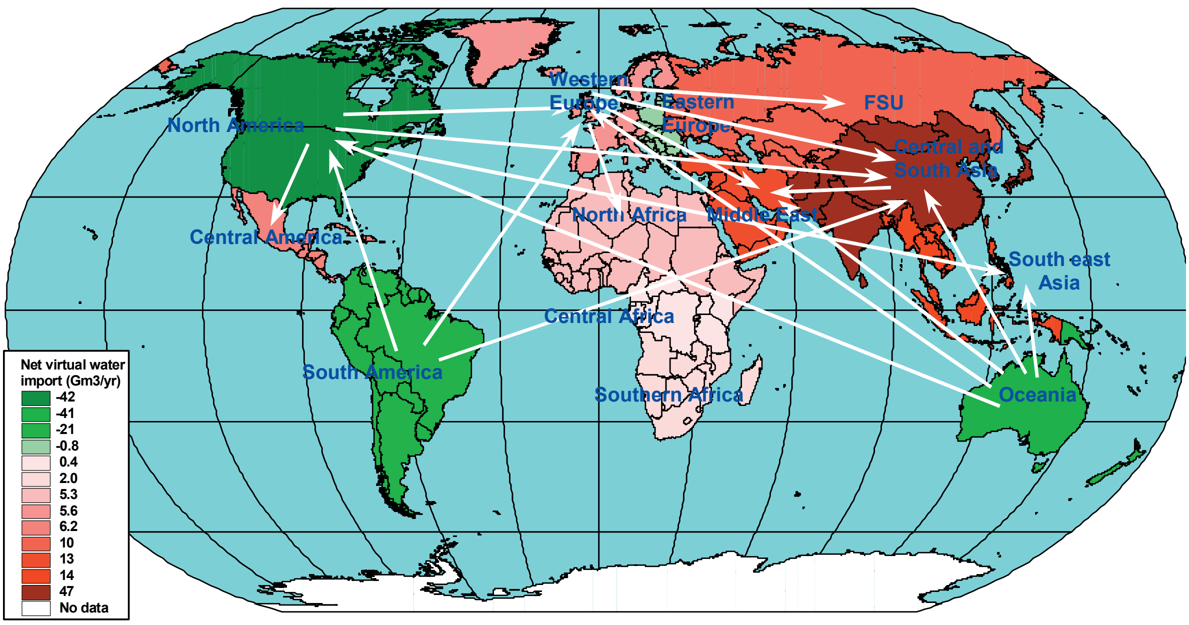

Figure 7: Virtual water trade balances in thirteen world regions (1995-1999). Source: [13].

Photo by Jack Dykinga. Courtesy USDA Agricultural Research Service.

3. Consumption Trend Implications on Water Depletion

In a sense then, poverty is the lock, productivity is the key, and food security is the prize

D.L. Winkelmann, 1998
Productivity, Poverty Alleviation and Food Security

Food Preferences and Diet Changes

Food is part of culture. As habits and preferences gradually modify, so will the pattern in diet composition change. Just as our individual preferences for different food items change with age, advertisements and education, so will the aggregate national and global food demand change over time. This is a fundamental circumstance since food production is, almost by definition, related to and organised in response to the real and perceived needs of people. Farming, as a way of life, may still characterise the situation in certain areas for some people. But there is a clear trend toward food and agricultural production organised and oriented to serve consumer preferences and market signals, not only in developed countries, but also in developing ones. In addition, it is adjusted in response to various regulations, subsidies and interests of the food industry.

Food is part of culture. Just as our individual preferences for different food items change with age, advertisements and education, so will the aggregate national and global food demand change over time.

For obvious reasons, farmers are reluctant to produce if their products are discarded. Nutritional value or low negative externalities of agriculture do not factor into such a scenario. These circumstances do not figure as prominently in the decision of the individual farmer as the desire to produce in response to demand. Moreover, the average consumer is presumably more sensitive to the price of the food and its perceived palatability than concerned about the product's water depletion, environmental implications or other related factors of its production, transport and storage. This is a plausible assumption since an increasing number of consumers are living far away from the sites where food is being produced. It may also be assumed that consumers' preferences for food items do not mirror the relative nutritional value of different food items. There is a difference concerning the amount of food that could and should be produced against that which is actually produced.

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The actual production, including the mix of crops, marketing and trends is thus determined through a complex mix of driving social forces. These forces are quite strong and as dynamic, if not more so, as the natural pre-conditions, like climate and soils. The central issue, therefore, is that production and consumption cannot be seen as two isolated phenomena – rather, as two sides of the same coin. But, like the coin, the two sides are rarely seen at the same time. It is reasonable to argue that since an increasing fraction of the food is not consumed by those producing it, it is the consumption preferences and purchasing power of the consumers that are the principle drivers of production (Box 4 and 5). In contrast, the Green Revolution increased and changed the composition of the food basket through changes at the supply side. So what are the typical food preferences and consumption patterns and what are the trends? Also, what are the implications from these trends for water depletion and sustainability? As mentioned in chapter 2, the production of cereals has increased significantly during recent decades. Even if staples like cereals, roots and tubers will remain important components in diets, the trends reveal an increased preference and demand of non-staples, while production and consumption of cereals are falling, even sharply in some countries. During the last three decades, the consumption of rice, for instance, fell by 50% in Japan and Taiwan. In India, it is shown that the buffer stocks of paddy are piling up. Since production has been declining while population numbers grow and exports increase, a reduction in consumption is a plausible explanation for the growth of the buffer stocks [14,5].

It is, however, quite important to know if the reduction is due to poverty in combination with increasing prices of food articles, e.g. a reduction in food access. It could also be due to shifts in preferences to other food items.

Box 4:

Urban Expansion – Increased Competition for Water and New Lifestyles

Rapid growth of urban centres is one of the most significant features of change today and in the foreseeable future. Within a generation, it is projected that some 2 billion people, or about 95% of the total population increase, will be added to the urban population, primarily in Asia and sub-Saharan Africa (Figure 9). This massive expansion is equivalent to the combined total national populations of China and India at the turn of the century [15]. The new demographic situation will have far-reaching consequences. For instance, the contribution to GDP and government revenues from urban sectors is generally quite high. In India, for instance, it is calculated that the contribution from urban sector to GDP increased from about 29% in 1951 to more than 50% in 2001, while the share of urban population was 17% and 29% respectively. Official sources claim that more than 90% of central government revenues emanate from the urban sector at the turn of the century. At the same time, the share of water allocated to the urban sector was around 17% in 2001 [15].

Water requirements in households, industry and service sectors will increase with city size. Even if requirements are comparatively small in the urban sector, growing demands still pose a significant problem in cases where all accessible water is allocated or committed. Already today, there are several examples in various parts of the world where some of the water that used to be delivered to the agriculture sector is now being diverted to urban areas [16]. Severe tensions and conflicts have resulted. Farmers, who have been accustomed to liberal supplies with virtually no fees have now to face reduced supplies and must often pay for water services.

Urban living implies that people are exposed to a wide range of goods, services, ideas, etc. Food supply in urban centres includes items that are only occasionally available in rural settings. Also, the mix of people, advertisements and other influences contribute to a modified lifestyle, including tastes and preferences for food [17, 18]. For the urban poor, the situation is critical. While general trends of calorie supply have shown an improvement (Figure 8), a very low calorie intake and absorption among the urban poor is obviously still a reality. In a comprehensive study on urban food insecurity in India, the poorest 10% have a calorie intake of between 1,580 to 2,200 kcal in the various states in 1999/2000 as compared to the international norm of 2,700 kcal (Figure 8) [19]. The combination of poverty and the lure of wide-ranging goods, means that purchasing power is extremely limited and that some of the households' meagre resources might be, or has to be, spent on items that are detrimental to a proper nutritional status.

Within a generation, some 2 billion people will be added to the urban population, primarily in Asia and sub-Saharan Africa.

Water requirements in households, industry and service sectors will increase with city size.

Global trends of increased demands for meat, dairy products and fruits and a reduced demand for cereals are presumably associated to urban expansion and the prevailing lifestyles within them.

A third possible alternative is that expenditure on non-food items takes a large share of the income at disposal. Unfortunately, there are very few studies on these questions. Apparently, urbanisation and globalisation constitute an important context for these changes (see Box 4).

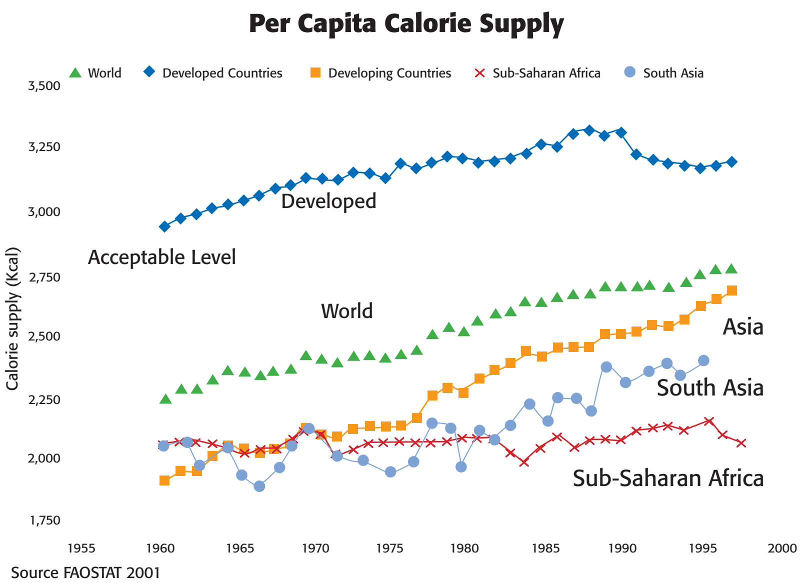
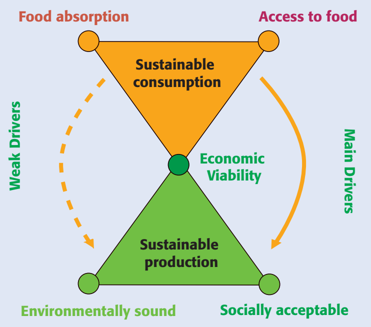


Figure 8: Per capita calorie supply. Source: IWMI based on FAOSTAT [20].

Box 5:

Production and Consumption of Food – Two Sides of the Same Coin



Water resources policy and management in relation to food security generally refer to production. Information about level of production or how efficient it is, is not sufficient to understand how nutritional security at household or individual level is achieved [5, 6). Although enough food is produced in the world today to feed everybody, about 15% of the world population are undernourished and an increasing number suffer from obesity. Access to food and food preferences are crucial variables in this connection.

If reduction in the consumption of cereals and other calorie-rich items occurs among the poor and already malnourished segments, the situation is most serious.

Answers to these complex issues have to be sought in the changes in demographic parameters and the associated modifications in socio-economic, political and cultural circumstances. As illuminated by Figure 9, the number of consumers is increasing, while the number of producers is not. The rural popluation in both developed and developing countries is likely to remain at about the same level during the coming one or two decades, whereas the urban population is increasing quite fast.

It is reasonable to argue that the food preferences of the consumers and their budget for food items increasingly drive production in terms of how much and what kinds of food items that are produced. If, for instance, the actual demand for meat and dairy products in LDCs would increase by about 100 million tonnes during the next one to two decades [17, 18], the implications on land and water utilisation will be significant. If such an increased demand would be directed to grain fed beef, the additional water requirements would be in the order of 1,500 km^3 (based on the assumption that each kilo of meat from grainfed cattle on average is associated with a water requirement of 15 tonnes, which is a low figure). If preferences were for other kinds of meat, the implication for water demand would be less drastic. Changes in consumers' food preferences will thus have significant consequences for resource utilisation. Anticipated and new preferences will be strong signals to the resource managers of how to allocate resources, where investments are warranted, where the risks and opportunities are, etc.

We do not know what the future preferences will be and how they can be met. Circumstances that determine consumer preferences and the relative position of food in the family's or individual's budget are complex and sensitive issues. As discussed in Box 4 and in the text, it seems that the food preferences among the urban population is much more dynamic and influenced by several factors as compared to the corresponding preferences among rural population, i.e. those who produce the food. A delicate question is the following: are consumer preferences for different kinds of food articles and the forces that determine these preferences, leading to the "best possible choice" in terms of nutritional security for the consumer? And do consumer preferences stimulate the production of such food articles that are environmentally most adequate?

One conclusion from the discussion above is that policy for food security should be directed both to producers and to consumers. Incentives and sanctions that can be designed for the producers should be supplemented with measures that influence consumers in terms of what food items are most desirable from a resource and environmmental point of view and also from a public health perspective.

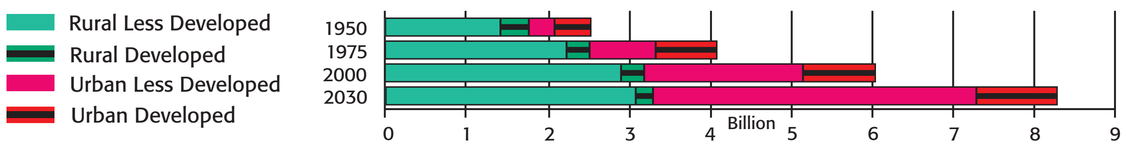


Figure 9: Demographic trends in rural and urban areas in developed and less developed countries 1950–2030. Source: [21].

This begs an important question: does reduction in the consumption of cereals occur in all population segments? If reduction occurs among the prosperous and those who eat more cereals and other calorie-rich items than are required, nutritionally speaking, there is no concern. Reduction occurring among the poor and malnourished, however, is most serious. Unfortunately, studies indicate that the poor – particularly urban poor – are the victims (see Box 4) [19]. A reduced intake of cereals and other calorie-rich foods is an important sign of non-sustainable food consumption.

Cereals, pulses and tubers (tubers and roots are staples in large parts of Africa) provide energy and are essential for the body to absorb and assimilate proteins and other nutritional value in food. A diet composed of various food items is therefore vital for a proper nutritional standard. Cereals, and also pulses and tubers, provide the primary source of the calorie intake, i.e. 2,700 kcal per person/day.

Production and access to food are therefore not sufficient enough to ensure food security at the consumer level; "the food basket" must be diverse. A policy implication is that programs promoting "food and nutritional security" are needed [6]. Education campaigns, re-organisation of subsidies and regulations that stimulate both consumption and production of essential components of the food basket should be contemplated.

Another pre-condition is that the human body can absorb the nutritional value of the food – disease-ravaged bodies cannot. Thus, the role of water is prominent; without access to safe water and proper sanitation, public health cannot be improved.

The Increasing Demand for Water-Intensive Crops

Parallel with a relative decrease in the demand for cereals, the demand for other crops and food items is increasing. The consumption of oil crops (palm oil, soya beans and sunflower) shows steady growth in developed and developing countries. It should be noted that food from the water-intensive livestock sector (beef, pork, poultry, egg, milk) is increasing between 3 to 6% annually, i.e. well above population growth [4]. A "livestock revolution" in LDCs is under way [17] (Table 2), with projected increases from about 200 million tonnes per year in the mid 1990s to 300 million per year by 2020. The increase will mostly be in developing countries. The increasing demand and consumption of food from the livestock sector mirrors an increase in purchasing power in some countries, but also mirrors urbanisation and globalisation. Most of Africa and hundreds of millions of poor in South and Southeast Asia, where the need for protein-rich diets is greatest, see no such change.

The products now in high demand are more water intensive. The animal protein (milk, meat) produced with grain-fed beef is several times more water consumptive than the production of most other foods. Ironically, diet preferences in the most populated and water stressed regions are moving towards more meat, not less. The environmental and livelihood consequences of raising beef, e.g. in the USA on irrigated maize and grains, however, are different than that of range fed cattle in Africa.

The emerging cropping pattern highlights a growing competition to use land and water resources. Investment resources and human capital are likely to be diverted away from the production of food which is essential for nutritional security and which require comparatively less water. Sustainability of food production is consequently part of the wider issue of sustainability of agriculture and sustainability of consumption.

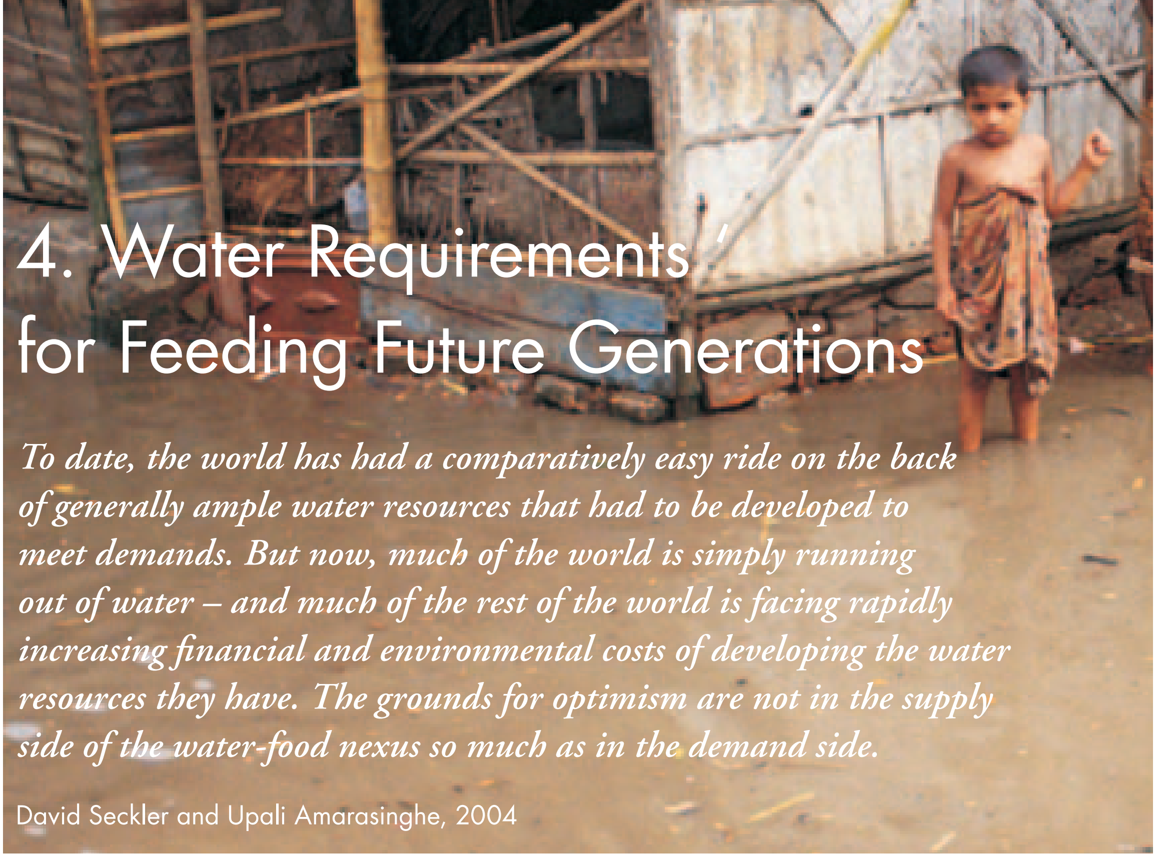
The emerging cropping pattern highlights a growing competition to use land and water resources

Diet preferences in the most populated and water stressed regions tend to be moving towards more meat, not less.

Cereals, pulses and tubers (tubers and roots are staples primarily in large parts of Africa) are necessary components in the diet because they provide energy and are essential for the body to absorb and assimilate the proteins and other nutritional value of the food.

Food item	Water requirement m^3/kg (avg.)	Trends in demand
Beef (grain fed)	15 or more	Increased by about 5% annually during last 20 years in LDCs, although not all countries. A continued rapid increase expected in LDCs
Lamb	10	
Poultry	6	Its share in meat consumption has more than doubled over the last three decades
Cereals	0.4–3	Current world output of 1.7 billion tonnes expected to increase to 2.6-2.8 billion tonnes in 2025
Citrus fruits	1	
Palm oil	2	Growth by 3% expected
Pulses, roots and tubers	11	

Table 2. Water requirements in m^3 to produce 1 kg of various food items and trends in demand.
Source: SIWI based on several sources.



4. Water Requirements for Feeding Future Generations

To date, the world has had a comparatively easy ride on the back of generally ample water resources that had to be developed to meet demands. But now, much of the world is simply running out of water – and much of the rest of the world is facing rapidly increasing financial and environmental costs of developing the water resources they have. The grounds for optimism are not in the supply side of the water-food nexus so much as in the demand side.

David Seckler and Upali Amarasinghe, 2004

Food Security for a Growing World Population

We saw in chapter 1 that huge amounts of water are being consumed in connection with food production. However, the amount available on the planet does not change. What are the implications for feeding the growing human population? What are the implications for global food security? What trade-offs must be considered to achieve these goals? Although much of the debate is focused on irrigated crop production, the world, in fact, depends for most of its food on rain-fed agriculture [22] (Figure 10). Moreover, predictions based on plausible assumptions of irrigation development and probable market responses leave a large hidden food gap in two geographical regions already plagued by large scale undernourishment: Sub-Saharan Africa and South Asia [23].

These regions have a low Human Development Index, and a mainly arid climate with large parts of savannah ecosystems lands [24]. In other words, they will have to cope with a nexus of poverty, increasing population, environmental problems and growing water scarcity. On the other hand, poverty eradication goes most naturally over agricultural development since the majority of the population

Although much of the debate is focused on irrigated crop production, the world, in fact, depends for most of its food on rain fed agriculture.

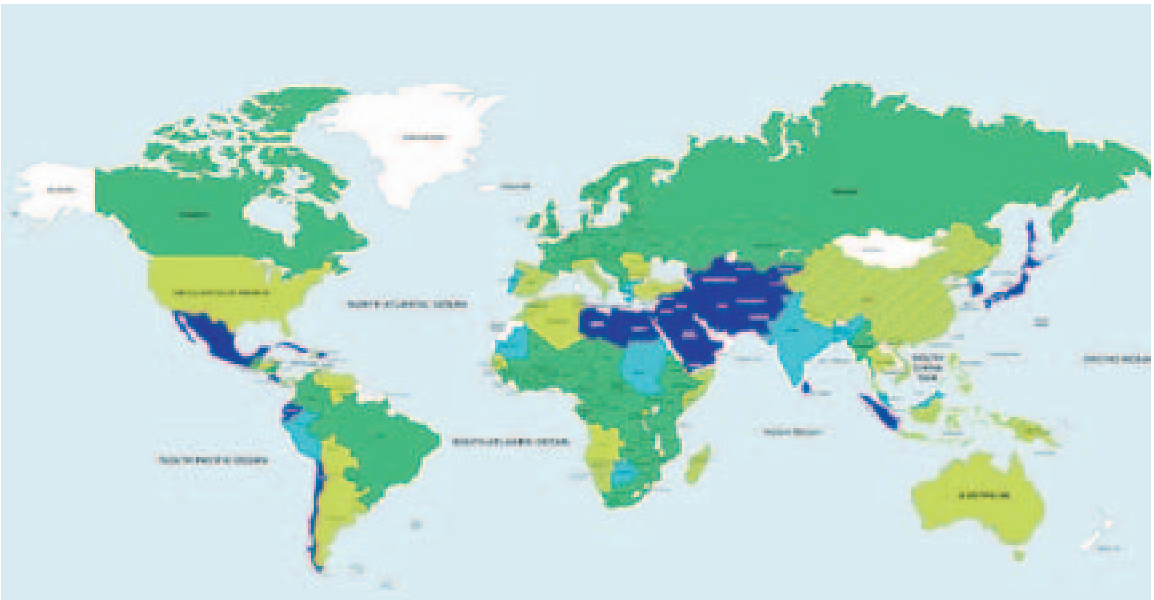


Figure 10: Green areas show countries depending for most of their food on rain fed crops. Blue areas only are mostly irrigation dependent (light colour more than 60%, darker colour more than 80%). Source: SIWI.

is rural. This makes water security for food production a crucial component of poverty eradication.

More Water Needed to Produce Adequate Food Supplies

The amount of water consumed in producing today's diets is on average 1,200 m^3/p yr but with large variations between different world regions, mainly due to differences in diets [25]. It varies from 600 m^3/p yr in the poorest regions up to 1,800 m^3/p yr in the richest regions with the most meat-based diets. It is also essential to mention that food production requires relatively much more water per kilo biomass in hot arid regions as compared to cool climate regions. The consumptive water use in hot arid regions is almost 3 m^3/kg cereal whereas in the temperate region, e.g. in parts of Europe, it is much less, or about 0.38 m^3/kg cereal (Table 1). Differences in yields are, however, also mirroring differences in management and the economic status of the countries. European farmers, for instance, put on a lot more fertilisers than farmers in the developing world. The net amount of water required for an acceptable nutritional level based on 80% vegetarian, 20% animal has been estimated as 1,300 m^3/p yr, whereas for a purely vegetarian diet it is about half of that [24].

In assessing tomorrow's water needs, we must also mention both what will be needed to eradicate undernourishment and to feed the additional population. With a water productivity at the current level, the additional consumptive water needs can be calculated to another 3,800 km^3/yr by 2025, growing to 5600 by 2050. The 3,800 km^3/yr is a huge amount and close to ALL the water withdrawals at present to support municipal, industrial and irrigation needs. The most important questions are how and where to find all this water, or, alternatively, how can the amount of water required be reduced. There are five basic possibilities:

- *Increased irrigation*. This alternative is strongly opposed by environmentalists who feel the need to conserve most of the remaining streamflow for the benefit of aquatic ecosystems.

- *Increased water productivity or crop-per-drop improvement*. Non-productive losses in current agricultural water use (Box 2) could be "converted" to productive use. Yields in both irrigated and rainfed agriculture could be enhanced with the same amount of water depleted, provided that improved land and water management are accepted and practised.

- *Horizontal expansion*. Water that is now being consumed by natural ecosystems in forests and grasslands could instead be used for production of crops.

- *Increasing production in areas with abundant water resources and other favourable conditions*. As shown in chapter 2, the transfer of food through trade or other means may reduce global water stress.

- *Improved crop varieties, especially drought and water-stress resistant types (Box 7)*. This will enable or enhance production in areas where food production is difficult or where yields are low with prevailing technologies.

Current developments indicate that increases in food production and efforts to achieve sustainability will require a combination of the above possibilities. In addition, it is essential to reiterate that the largest share of the world's food comes from rain fed system. An additional small increase in yields in this system would translate into a comparatively large absolute increase in the number of tonnes produced. To achieve a corresponding increase from irrigated agriculture would require a substantial relative increase in water supply.

The amount of water consumed in producing today's diets varies from 600m^3/p yr in the most undernourished regions up to 1,800 m^3/p yr in the richest regions with the most meat-based diets.

Window of Opportunity

Rain fed Agriculture in the Hunger Gap Region

If countries in the hunger gap regions, that is, in Sub-Saharan Africa are to achieve improved food self-sufficiency, i.e. to produce more food to feed them, the water requirements will increase. But there exists at the same time a huge window of opportunity. Since most of the farmers rely on rain fed agriculture, the challenge involves nothing less than a revolution in terms of upgrading rain fed agriculture in water-scarce tropical environments where present yield levels, due to frequent water stress and poor land management, oscillate in the regions of 0.5–1.5 tonnes/ha. Dry spell occurrence is a key constraint, and therefore an entry point for upgrading [24].

There is a potential for upgrading rain fed agriculture in tropical regions. By a combination of dry spell mitigation effects and nutrient supply, substantially higher yields could be achieved. Prospects for such an upgrading must be scrutinised and the mechanisms for a successful implementation identified and assessed. Management implications and social acceptance are obviously key conditions in this regard.

In assessing tomorrow's water needs, we must also mention both what will be needed to eradicate malnutrition and to feed the additional population. With a water productivity at the current level, the additional consumptive water needs can be calculated to another 3800 km^3/yr by 2025, growing to 5600 by 2050.

5. Pathways to Improving Water Productivity

We need a blue revolution in agriculture that focuses on increasing productivity per unit water – more crop per drop.

Kofi Annan, Secretary General of the United Nations, at the Millennium Assembly, 2000

In water-stressed areas, producing more food with less water may be the only option to ensure food security, and to restore systems so they can sustain long-term agricultural practices.

Improving agricultural water productivity requires an increase in the amount of output or value per unit of water delivered to or depleted by agricultural practices. Producing more food with the same amount of water is an alternative to increasing water supplies to an area. In water-stressed areas, producing more food with less water may be the only option to ensure food security, and to restore systems so they can sustain long-term agricultural practices (Box 6). For farmers with a limited supply of water, improving water productivity is a chance to improve incomes and livelihoods. In its broadest sense, improving water productivity means obtaining more value from each drop of water for agriculture, domestic, industrial and environmental uses.

How much scope is there for improving water productivity? In terms of the amount of kilograms produced per cubic meters of evapotranspiration in grains, observed values, according to some estimates, vary between 0.2 and 2.5. As noted above, yields of 0.5 to 1.0 ton per hectare are commonly observed in rain fed systems in sub-Saharan Africa, leading to extremely low water productivity. Within irrigation, a 10-fold difference has been found in the gross value of output per unit of water consumed by evapotranspiration when looking across 40 irrigation systems (Figure 11). Some of this difference is due to environment, or the price of grain versus high valued crops, but even in grain producing areas in similar environments the difference can be marked. Much of this difference is attributed to on-farm and irrigation system management.

What actions are needed? There are a variety of interconnected paths that can improve the productivity of water.

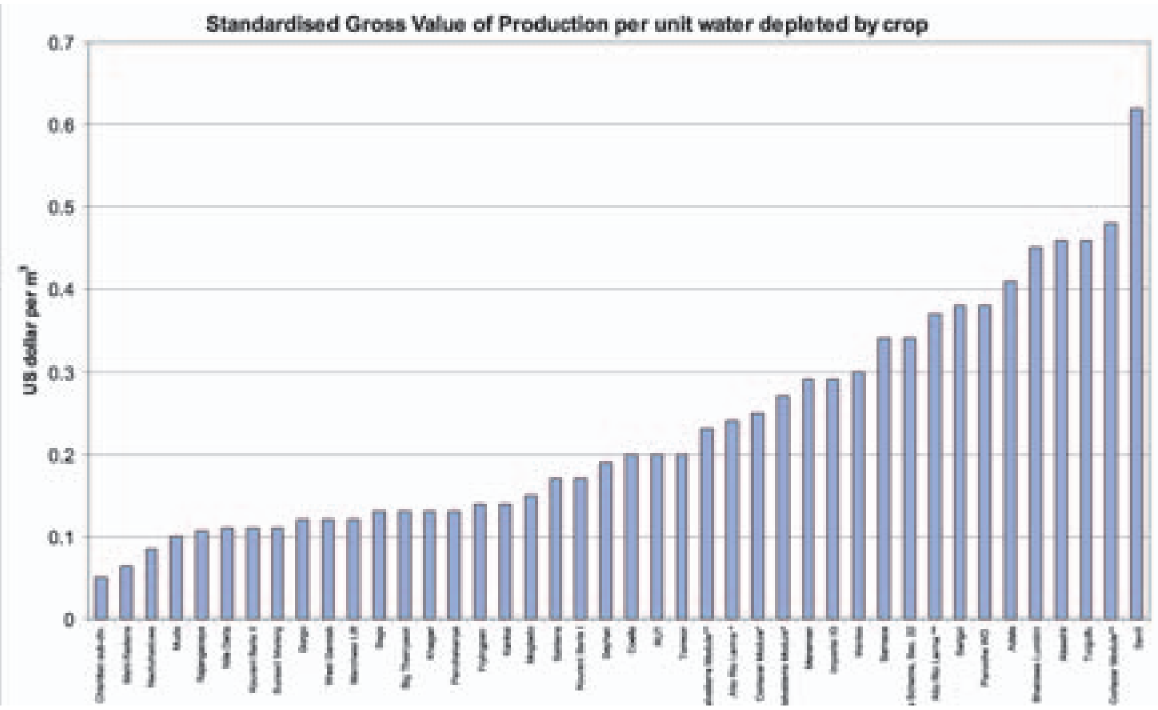


Figure 11: Productivity of water in 40 different irrigation systems. Source: [26].

Box 6:

Food, Water and Productivity Links

To illustrate the food, water and productivity links, consider water needs for India in 2025. In 1995, average grain yields were 2.7 tonnes per hectare. About 600 cubic kilometres of water were diverted for irrigation uses. Considering the growth in population and improvements in diet, diversion requirements in 2025 were calculated for different settings. If there is no increase in grain yield, India will have to double diversions for irrigation with the risk of environmental damage. On the other hand, if grain yields increase by 70%, no more increases in water diverted for irrigation will be required. While attractive, this water productivity strategy has food security risks, especially in times of drought. While people in India must strike a balance between the two approaches, providing means of improving the productivity of water provides more options to maintain the balance between food and environmental security.

Crop Breeding

The greatest gains in water productivity can be attributed to crop breeding efforts. Crop varieties that yield more produce with the same amount of water, or shorter duration varieties that consume less water, increase the productivity of water. Drought-resistant varieties help to stabilise yields, and help reduce risks in drought-prone rain fed areas. Exciting breakthroughs have been made in this area with traditional crop breeding. Genetically modified crops have shown the potential of raising yield and increasing crop productivity. But these are also the centres of a heated controversy (see Box 7).

Drought-resistant varieties help to stabilise yields, and help reduce risks in drought-prone rain fed areas. Exciting breakthroughs have been made in this area with traditional crop breeding. Genetically modified crops have shown the potential of raising yield and increasing crop productivity. But these are also the centres of a heated controversy.

Box 7:
The *Pros* and *Cons* of Biotechnologies

During the last eight years, a new dimension has been added to the debate and practice concerning food production and consumption through the genetically engineered crops, often referred to as Gomes (Genetically Modified Organisms) or GM crops. In 1996, the first GM crops became commercially available. It is estimated that the area under such crops was about 4.3 million hectares during the initial year. Since then the acreage brought under these has increased and is now (2003) estimated to be about 67 million hectares, with an increase from 2002 of 15%.

The debate about the pros and cons of GM crops is intense.

The impact of IPR and proprietary science on the further enlargement of the rich-poor divide must be scrutinised.

Use of GM crops is concentrated to a relatively small number of countries with six of them accounting for 99% of global usage: United States, Argentina, Canada, China and, as of 2002, Brazil and South Africa [27].

The acceptance and use of GM crops is quite limited in Europe, with only small acreages in Spain, Romania, Bulgaria and Germany. About two-thirds of the GM crops are grown in developed countries, but the share of the developing countries is growing. In terms of crops, soybeans are the most important with regard to acreage (more than half of total) and maize is on the increase.

The debate about the pros and cons of GM crops is intense. Proponents argue that they make it possible for farmers to control pests in a cost-effective manner while using fewer pesticides, thus reducing the detrimental environmental consequences associated with conventional agriculture. There is also a potential to develop seeds that are more drought- and salt-tolerant.

It is also argued that biotechnologies are scale-neutral, allowing GM crops to be grown in farms of varying sizes. So far, however, the big and resource farmers clearly dominate.

Through GM crops, it might be possible to grow crops in degraded areas, for instance, on lands affected by salinisation. In India, genes from mangroves have been inoculated into rice plants in an effort to boost yields in areas with high levels of salinity. Altogether, it is estimated that 6 million hectares of previously good agricultural land are subject to increasing salinity with the result that yield has been severely reduced and now rarely exceeds 3.7 tonnes per hectare. With the new GM seeds of paddy, it is shown in experimental plots that a yield level of about 11.1 tonnes per hectare can be restored. The new technology may thus give a boost to production of about 18 million tonnes and also improve livelihood for a large number of farmers in the salt affected areas [28].

The uncertainties with the long-term environmental and health consequences contribute to a widespread scepticism. Impact on the environment, particularly on biodiversity and the possibility of genetic contamination in centres of origin are not known. Possible health problems refer to allergenicity and antibiotic resistance. Many opponents also emphasise that the current food insecurity should not be interpreted in terms of insufficient overall production. It is rather an expression of poverty and lack of purchasing power, as emphasised in chapter 3. Another unresolved issue refers to the pertinent questions of who will control the GM seeds and the difficulties of social and public control of patents. The impact of IPR and proprietary science on the further enlargement of the rich-poor divide must be scrutinised.

Agronomic and Field Practices

Delivering water in the right amount and at the right time can reduce water stress and improve yields.

Good soil tillage, fertiliser practices, water application and soil-water management can raise the productivity of water. On-farm water harvesting practices, such as mulching or bundling in order to capture and store water effectively, convert non-productive evaporation to productive transpiration, thereby increasing biomass yield per unit of evapotranspiration. Within irrigation, precise practices – delivering water exactly in the right amount and at the right time – can reduce water stress and improve yields. The various forms of precision irrigation mainly sprinkler, drip irrigation systems and dead-level basins increase yields over good but ordinary irrigation systems by 20 to 70%, depending on the crop and other conditions. Additionally, they do so with much less water delivered to the field.

Low-cost Supplemental Irrigation Technologies for Rain fed Areas

There is considerable scope for increasing the productivity of rain fed agriculture by the application of supplemental irrigation at critical stages in the crop cycle. Such interventions will rely on the use of precision irrigation technologies combined with water harvesting or groundwater use. Providing a limited supply of water at the right time can save harvests and dramatically increase yields.

Low-cost versions of precision technologies, based on those used in commercial large-scale agriculture, provide an opportunity for fighting poverty while increasing productivity. In South Asia and Africa, low-cost bucket and drip sets are becoming increasingly popular with farmers. In areas where shallow groundwater is plentiful, thousands of poor farmers, like in Bangladesh, have used low-cost treadle pumps to supply water for crops for their own food security and additional income. However, we do not yet fully understand the potential, or the mechanisms, for the large-scale application of these technologies.

Improving Irrigation Management Practices

One basic principle of irrigation is the delivery of a reliable supply of water. Without such a supply of water, farmers do not know when the next irrigation will come, they do not know how much water will come, and they do not know if there will be enough water for their crops. In this uncertain environment, farmers will not invest in seed, fertiliser and land preparation. Consequently, yields and water productivity will suffer. A second basic principle concerns timing. At various times in a crop's growth cycle, water stress can be particularly damaging. Tube-well irrigation systems in India typically produce yields double that of canal irrigation systems. Tube well water is reliably available virtually on the farmer's demand, whereas in most Indian canal systems, farmers must wait for their turn which may not match crop needs. In China, canals feeding small tanks placed strategically close to farmers' fields allows them to store water effectively and apply it when needed.

Integrating, Recycling and Reusing: Basin and Irrigation Management

Increasing attention is being paid to reuse as an integral part of water management. For example, farmers in Egypt and other countries place small pumps in drainage ditches to recycle water and the irrigation agency blends drainage water with freshwater to increase the useable supplies. Millions of shallow tube wells have been developed in the Indo-Gangetic plains that are recycling water, effectively captur-

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Photo by Mats Lannerstad for SIWI

ing and using water before it flows out of the basin, and giving the ability to reliably and precisely apply the water to crops, thereby enhancing yields. Many farmers in peri-urban settings rely on wastewater from cities for their crops. Irrigating with low quality water is often the only option for many farmers. Inherent in these reuse strategies are pollution and health risks. The problem is that these are often individual or community initiatives frequently ignored by water management bodies, leading to sub-optimal situations for water quality degradation and water productivity.

An incorrect notion that has misguided thought and investment in irrigation is that because irrigation systems are 40% efficient, the remaining 60% is wasted.

Real Water Savings and Maintaining Environmental Integrity

An incorrect notion that has misguided thought and investment in irrigation is that because irrigation systems are 40% efficient, the remaining 60% is wasted, and that huge amounts of water could be saved by canal lining and conversion to more water efficient sprinkler and drip practice. In fact, because of recycling and reuse in many contexts, very little is really wasted, and the real problem is low output per unit of evapotranspiration and over-depletion leading to groundwater decline and dried up rivers. Real water saving implies that water can be freed up and transferred to another use without lowering existing agricultural production levels. Real water savings requires that we follow flow paths of water, and identify those paths that are not productive – for example evaporation from fallow land, or water flows into saline groundwater. These flow paths should be redirected into more productive or higher valued environmental, agricultural, urban or industrial use by an appropriate mix of technologies and incentives tailored to the situation.


Photo by Pete Mortimer. Courtesy USDA Agricultural Research Service.

Laws, regulations and organisations must be coordinated in order to conserve the basin-wide water resources.

Integrated Natural Resource Management within Basins

Within farms, irrigation systems and river basins, livestock, fish, and forests all have important water needs and implications. Integrating aquaculture into irrigation or examining the tradeoffs between crop water use and water for fisheries is a means of providing more food and nutrition per unit of water. Water for livestock, essential for the healthy lives of rural poor, is a primary water concern for many poor countries. In Ethiopia, for example, livestock watering has much higher priority than crop agriculture. Trees and livestock play an important role in land and water interactions. Denuded landscapes can hasten runoff and sedimentation, detrimental to both upstream and downstream uses. Integrating these production systems within a basin management framework can greatly improve the nutrition and value derived from water resource use, while lessening adverse side effects.

Policies, Institutions and Incentives

For any of these practices to work requires the right set of incentives for all involved parties. Theses are functions of people, policies and institutions. One difficulty that must be faced is that as competition for water becomes more intense, consideration must be given to how water used in one part of a basin impinges on how it is used elsewhere in the basin. This requires a set of laws, regulations and organisations that best coordinate and conserve the basin-wide water resources. Another area is that subsidies and pricing are often not conducive to increasing water productivity. Grain prices have fallen dramatically since the dam building era of the 1970s, removing incentives for farmers to invest in improved practices. This is a topic of immense importance and complexity. There are no ready-made solutions to change institutions for managing water in more productive ways. The search for such solutions should take precedence.

Increases in water productivity are necessary in order to solve many problems of the water crisis. However, they are not sufficient. It is imperative that these improvements be accompanied with a focus on helping the poor increase water productivity.

Attention toward the needs can be furthered by establishing and maintaining access to water, making affordable and available water productivity-enhancing technologies and providing a voice in local and global water decisions.

Whose responsibility is this? Increasing water productivity requires the coordinated set of actions, ranging from resource managers like farmers, fishermen, researchers and resource managers of agronomy and other natural resources, and, in fact, all of us who care about influencing local and global water policies.

Photo by Mats Lannerstad for SIWI

6. Sustainability Considerations

Groundwater overpumping may now be the single biggest threat to irrigated agriculture, exceeding even the buildup of salts in the soil.

Sandra Postel, 1999
Pillar of Sand

Undermining the Resource Base

Current food production is not environmentally sustainable for several reasons. It is undermining its own resource base and threatening the resilience of ecosystems (Box 8). There is a huge overdraft of groundwater to support irrigated agriculture [16]. Surface water irrigation systems are often extremely "wasteful," with surplus water percolating down to the underlying aquifer. This rise in the water table frequently generates salinisation of water and soil. There is a significant leaching of surplus fertilisers and pesticides polluting both rivers and aquifers.

Current food production is not environmentally sustainable and is undermining its own resource base and threatening the resilience of ecosystems.

Box 8:

Degrading Resilience of Ecosystems

A living system must be able to withstand shocks like floods and fire without collapsing. Ecosystems are complex living systems and therefore must be managed to ensure that they continue to provide "ecosystem goods" (like fish and crops) and "services" (like pest control, pollination and denitrification). This is important even under environmental changes like droughts, floods, fire and pollution. While threshold effects can cause the sudden loss of such capacity, ecosystem resilience is a measure of how much disturbance an ecosystem can handle without shifting into an inferior state. It refers to the ability of a system to withstand shocks and surprises, and then rebuild itself.

In a resilient system, disturbances provide potential for renewal and innovation. Without resilience, living systems become vulnerable to disturbances that could have been previously absorbed: clear lakes suddenly turn into turbid, oxygen free pools, grasslands into shrub-deserts, and coral reefs into algae-covered rubble. The new state may not only be biologically and economically impoverished, but also irreversible.

State shifts can occur when key structural variables like freshwater are altered. In terrestrial ecosystems the role of freshwater in the soil is crucial. These threshold effects due to alteration of soil water can be found around the world. They include dryland salinisation from vegetation change in Australia; water logging and salinisation in mismanaged irrigation systems; soil moisture deficit reducing crop production in degraded croplands; and shrub encroachment in rangelands.

Biodiversity plays a crucial role for ecosystem resilience. Each ecosystem has groups of species with similar functions: organisms that are pollinators, grazers, predators, seed dispersers, decomposers, nitrogen regulators or water flow moderators. In such functional groups, species can replace or compensate for one another in times of disturbance, and function as insurance against loss in ecosystem functions. If all species within such a functional group would be equally sensitive to a particular disturbance, the system would be very vulnerable. In a forest with many different species of trees, for instance, some species are probably more fire-tolerant than others, some might be less likely to fall during a storm, yet others might not be affected by an outbreak of a particular insect pest. They all respond in different ways to disturbances, hence providing insurance against the loss of all essential functions of the ecosystem.

A living system must be able to withstand shocks like floods and fire without collapsing.

Aquaculture adds even further pollution sources. The huge consumptive water use that occurs with crop production has reduced the streamflow in many rivers around the world, creating problems for downstream hydropower, navigation and coastal fisheries [29].

Experience has shown that easy access to water and continuous intensive agriculture practices may be detrimental to the sustainability of production. The long-term performance of high yielding agriculture, made possible through adequate water supplies and other inputs, is not evident. This is, for example, noted in the cases of Punjab and Haryana, two States in India which seem to be exploiting natural resources at a very fast pace. One of the key secrets of the Green Revolution was that crop yields were increased by a combined effect of fertilisers, water security and high-yielding varieties.

Overexploitation of Groundwater

Groundwater pumping is a useful way by which a farmer becomes self-sufficient in irrigation water. The farmer who can irrigate his crops whenever more water is required does not have to wait for an uncertain delivery of surface water from a shared irrigation scheme. Groundwater irrigation has been a significant mode in India and the North China plain, and has contributed to the rapid increase in food production on that subcontinent [30].

When too many farmers depend on the same aquifer, the effect may result in the lowering of the water table. This makes it more costly to pump up more water. Over time, the water quality tends to deteriorate and become increasingly corrosive as deeper and deeper layers are being emptied. Overdraft means that groundwater is being pumped at a higher rate than the natural recharge. This may cause the land to subside, and cause salt water to intrude from the sea in coastal areas, thus destroying the aquifer.

The total amount of overdraft has been estimated at some 160 km^3/yr. This is an amount equivalent to that which is needed to produce a vegetarian diet for almost 300 million people. Analysts have concluded that 25 percent of India's harvest may be at risk [30]. To phase out the global overdraft, the overall groundwater pumping must be reduced by a similar amount. Areas of particularly dramatic overpumping can be found in southern and western India, the North China plains and in the Rio Grande and Colorado river basins in the United States.

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Photo by Mats Lannerstad for SIWI

River Depletion

Long-term records on river flow show a marked reduction of annual stream flow in many rivers. This is of course an expected result, since crop production is a highly consumptive watering process [29]. This is the case even when there is little, if any, non-productive waste of water. The river depletion phenomenon is especially apparent in arid and semiarid regions where crop production depends on extra water being provided to complement infiltrated rainfall (Figure 12).

Globally, more than two-thirds of all water withdrawn for societal purposes goes to irrigation [31]. Only one third of the water withdrawn is drained back into the river systems. Extensive withdrawals have caused several rivers to dry up in the lower reaches, at least for part of the year. The effects of river depletion have lowered the annual flow considerably in

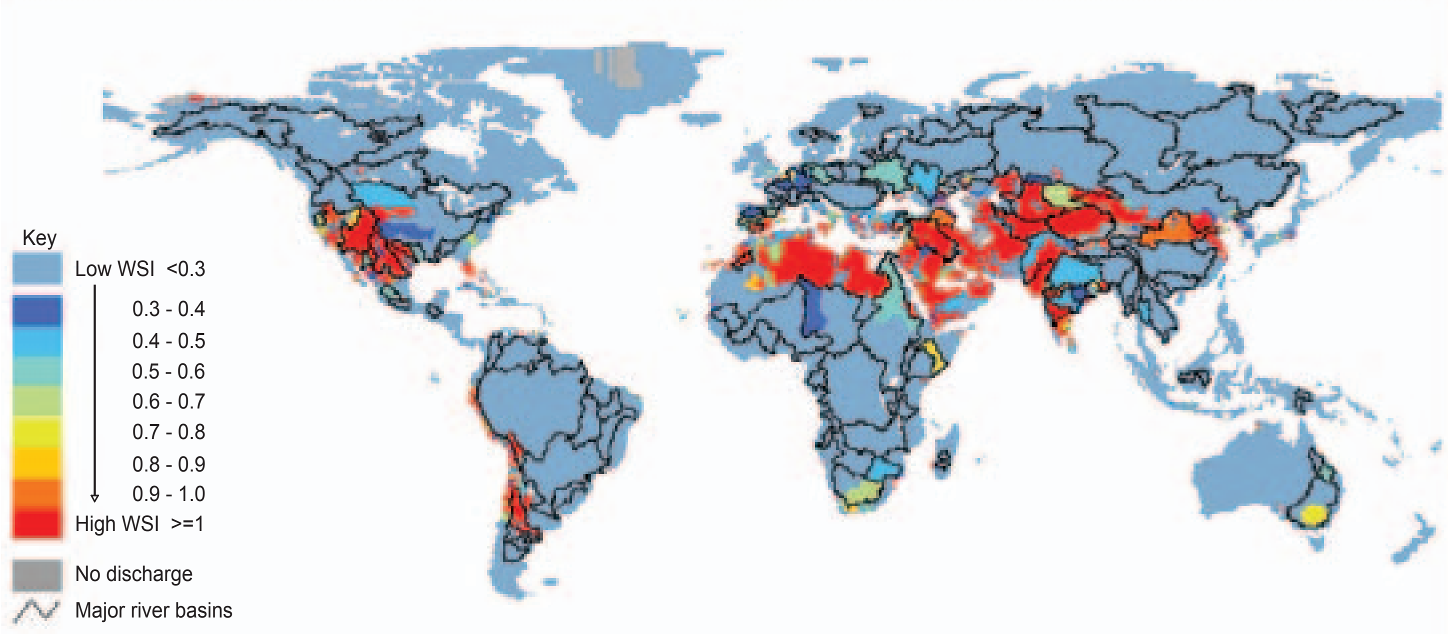

Figure 12: Water withdrawal in relation to blue water availability. Beyond a water withdrawal level of 0.7, the environmental flow has already been overappropriated (yellow and red areas). Source: [32].

rivers like the Ganges, the Indus, the Colorado and the Nile. The Yellow River, for instance, went dry seven months in 1997 and the neighbouring Huai River failed to reach the sea for 90 days that same year. The effects of river depletion are particularly evident in the Aral Sea basin, where tributaries end in a closed lake without an outlet. There is only one way for the lake to respond to an inflow that has been reduced to only 10 percent of what it was fifty years ago: by reducing the lake surface until the evaporation is in equilibrium with the reduced inflow. The depleting water used for food production and agricultural irrigation may exceed the water need for a natural reserve of ecological significance (Figure 12). If no precautions are taken, the result will be damaged riparian wetlands, lack of dilution water, escalating pollution levels and suffering aquatic ecosystems. The social and economic repercussions would be most severe for those depending on those ecosystems for their livelihoods (Box 9).

Salinity and Water Logging

Irrigation may cause water logging and salinisation of the soils. Regions with high potential evaporation and insufficient drainage face the highest risk for salinisation. The reason soils get salinised is that applied water through irrigation usually contains some salt. When water is evaporated, the salt is left in the ground, and will build up through time. Salts stored in the soil can rise to the surface by capillary forces. The build-up of salts in irrigated soils is leading to a decline in the productivity in irrigated areas.

Today, irrigated agriculture is practiced on less than 20% of the world's agricultural land. However, nearly 40% of the world's food production comes from irrigated lands. Roughly 20% of the world's irrigated areas are now being damaged by the buildup of salts [30]. Some sources argue that perhaps as much as 30% (20–30 million hectares) of irrigated land is affected by salinisation. The existing area under irrigation is reduced by 1–2% (0.25–0.5 million hectares) annually as a result of salinisation [33]. The problem is mainly restricted to about 100–110 million hectares of irrigated land, primarily located in semi-arid and arid zones.

Salinisation can also be caused by land cover change, as in Australia where the soils are naturally saline. Extensive clearing of native wooded vegetation has changed the water balance on the continent, causing water tables to rise. Higher water tables mobilise salts in the soil. Today 5.7 million hectares are subjected to dryland salinisation. This number is expected to rise to 17 million hectares by 2050 [34, 35].

Drainage and pumped well systems can prevent waterlogging and salinisation. However, salty drainage waters must be handled in an ecologically responsible way, since drainage effluent is often contaminated with salts, trace elements, sediments and small amounts of agricultural inputs. There is therefore a need to adopt more efficient technologies. Drip irrigation systems, such as those used by farmers in India, Israel, Jordan, Spain and the United States can cut water use by 30 to 70% [30]. Better scheduling of irrigation can also have an important effect.

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Water Quality Deterioration

Today's agriculture is non-sustainable because it adds pollution to both rivers and groundwater aquifers, caused by leaching of excess agricultural chemicals to water [36]. Fertilisers are a necessary component of modern agriculture to replace many soil nutrients consumed by earlier crops. Since farmers want to be prepared even for the plentiful rains, they often add surplus fertiliser, especially if it is subsidised. In less rainy seasons, nutrients remaining in the soil are easily leached out after seasonal rains.

In Central Europe, groundwater under the large agricultural plains has been polluted with nitrate levels beyond potability. In surface waters, increases of nitrate from fertilisers have been noted all over the world: in western Europe (Rhine, Seine, Po, Danube rivers), in North America (Mississippi River), in China (Yellow and Yangtze rivers). Nutrients entering water with agricultural runoff, such as phosphate and nitrate, can contribute greatly to the widespread problem of eutrophication, which has been increasing steadily since the 1950s.

With current level of water productivity, the additional amounts of water that would have to be appropriated to alleviate hunger by 2025 would be of the same order of magnitude as ALL water withdrawals today. Hence, improvements in water productivity are of significant importance.

Another type of agricultural chemicals that cause large problems in this area are pesticides, used to control weeds and insects. Contamination by pesticides has grown rapidly since the 1970s. When these substances are finally banned, they will have been in use for several decades, with plenty of time for entering into both rivers and aquifers. Generally, it takes several decades before a problem has been detected and monitored, providing decision support for such bans. Problems associated with Atrazin, for instance, a widely used herbicide, were first detected in the 1980s and is now present in many rivers with concentrations intermittently exceeding World Health Organization standards.

Seeking Win-Win-Win Approaches

If poverty prevails and if widespread undernourishment remains, the future will be full of dispair and frustration. The only viable strategy for sustainability is to strive for production and consumption patterns that are also socially acceptable (win-win-win).

Current agriculture practices are unsustainable in several ways. They are associated with highly wasteful water use and pollution patterns, many of them are environmentally degrading and they tend to favour resource-rich farmers.

However, it has also been shown in this report that there is ample scope to reduce the unproductive losses of water in agriculture and to increase water productivity. This is a vital obligation since the human population continues to grow. To produce the amounts of food needed at an acceptable nutritional level, presumes considerable amounts of additional water. This is true even if food preferences are moderated towards less water consuming diets. With current levels of water productivity, the additional amounts of water that would have to be appropriated to alleviate hunger by 2025 would be of the same order of magnitude as ALL water withdrawals today. Hence, improvements in water productivity are of significant importance.

Management in the past has primarily been oriented towards the goal of increasing production of food. Remarkable achievements have been made in this regard during recent decades as illuminated in this report. Today, good management is perceived in a wider context. It is part of "good governance" and proper resources stewardship. A new approach is called for, which includes due attention to environmental sustainability and which seeks to make sure that also small and resource poor farmers are provided with opportunities to contribute to the food security objective. A high level of production is hardly sustainable if it is associated with significant environmental impacts. Similarly, a socially unfair land and water tenancy situation and arbitrary and capricious rules and regulations, reduces the stability and long-term viability of the production system.

We must therefore find synergies that combine more productive actions that are also socially just and economically viable while less depleting and degrading. There are no guarantees for success. But the likelihood of achieving sustainable food production and consumption patterns increases if triple win situations can be created.

The Green Revolution aimed to reduce the threat of famines and recurrent food shortages through increases in production (a win situation). Today, a continuous increase in production is still considered necessary. It is, however, also realised that land and water use practices that undermine the very resource base on which production is based, cannot be sustained. Today's management strategies must therefore also be environmentally sustainable (win-win). But this is not enough. Both in terms of production and in terms of consumption, the final test of sustainability refers to the social dimension.

If poverty prevails and if widespread undernourishment remains, the future will be full of dispair and frustration. The only viable strategy for sustainability is to strive for production and consumption patterns that are also socially acceptable (win-win-win).

There is no one-for-all solution to this tremendously complex challenge. Some components, discussed in the text may, however, be reiterated:

- *Change the thinking about water use.* Distinguish depleting water use from through-flow-based water use, where a part of the water supplied to the field forms a return flow. This can potentially be reused by downstream water users.

- *Increase the food output per drop of water depleted.* Farmers must be given the incentives to invest in and benefit from the tremendous water productivity gains that can be accomplished in both irrigated and rain fed agriculture. These incentives must also be directed to the small and resource-poor farmers.

- *Promote water for food, nutrition and livelihood security.* Needless to say, a certain level of food production is necessary for food security, but it is not sufficient. For all those who do not produce any food themselves or who do not produce enough food, the access and the possibility to buy food is vital. The role of water in the

South Africa's National Water Act of 1998 underscores the need for a "Water Reserve," composed of two parts – the basic human needs reserve and the ecological reserve.

Box 9:

Co-managing Water for Ecological and Agricultural Purposes

Current Overappropriation of Streamflow

Ecological thresholds beyond which aquatic ecosystems suffer are being referred to by the concept "environmental flow reserve." This idea suggests that enough water remain in a river to ensure downstream environmental, social and economic benefits. On average, at least 30% of the natural stream flow must remain in the stream to maintain a fair condition of aquatic ecosystems [32].

A worldwide overview has shown that the environmental flow has already been overappropriated in a broad transcontinental zone from Mexico in the west to northern China in the east (Figure 12). Currently, at least 1.4 billion people live in regions where water use is already in conflict with environmental water requirements. This corresponds to 15 percent of the world's land surface.

When river flow depletion approaches this threshold, there is limited scope for any further increase of depleting water use – a situation known as a closed basin. In such situations, efforts must be concentrated on increasing the productivity, or value, of every drop of water evaporated from the catchments. Ecosystems are also vulnerable to changes in flow seasonality. This is the fluctuation between flood flow and dry season flow. With this understood, infrastructure and flow control in a river could therefore impact the ecosystem.

Seeking Sustainable Compromises

The problem of agricultural development and environmental sustainability requires broad-based solutions based on a quantification of ecosystem services that depend on the stream flow and its quality, and development of processes that strike the necessary balance between depleting water use, flow control and necessary ecological reserves. Innovative efforts in South Africa and Australia have shown that the process to establish them as part of an integrated river basin management system poses great challenges [37].

Australia has introduced the concept of "Working Rivers" to stress the need for a sustainable compromise agreed to by the water sources community. This approach considers the condition of the natural aquatic ecosystems and the level of human use. The more work a river's water does, in terms of hydropower production, water use in cities, industries and agriculture etc., the less natural it becomes. The resulting compromises between the level of work and the loss of naturalness may become different in different catchments, depending on the values the community places on the river.

South Africa has taken a partly different approach. It introduced an idea in its National Water Act of 1998. That law underscores the need for a "Water Reserve," composed of two parts – the basic human needs reserve and the ecological reserve. The latter relates to the water required to protect the aquatic ecosystems. The reserve will vary depending on the management class of the river, which is graded by the government as natural, good, fair, poor or severely modified. The resource quality objectives are then determined, seeking a balance between the need to protect and sustain water resources on the one hand, and the need to develop and use them on the other. Once the class and resource quality objectives have been determined, they are binding on all authorities and institutions when exercising power.

"income-generation-equation" is therefore a most relevant dimension in food security discussions. A third precondition refers to the capacity of the body to absorb the food being consumed.

- *Promote consumption patterns that drive sustainable production practices.* With an increasing share of the world population who are not producing the food they require, but who will influence the orientation of food production through their preferences, it is more and more important to stimulate such food preferences that are sustainable from a nutritional point of view and also with regard to production.

- *Co-manage water to meet both agriculture and ecosystem demands* in order to reduce the current overappropriation of water and the ecological damage of prevailing agricultural water management practices.

- *Develop a strong poverty focus by the promotion of low-cost technologies and management* approaches for access to and productive use of water, and by institutional mechanisms for compensation where water is being reallocated from rural agricultural settings to urban and industrial settings.

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Water – More Nutrition Per Drop

Towards Sustainable Food Production and Consumption Patterns in a Rapidly Changing World

Despite laudable efforts and accomplishments in global food production, 840 million people remain undernourished. The Millennium Development Goals agreed upon by the Millennium Assembly of the United Nations in 2000 seek i.a. to halve the number of undernourished people in the world by 2015. This, in itself, is a gigantic task of paramount importance to be addressed by the international community. Moreover, the goals seek this target within an environmentally sustainable and socially acceptable framework.

Food production consumes large amounts of water. Water scarcity is a harsh reality that affects billions of people in many parts of the world. Therefore, water development and management must be addressed and changed if we are to reduce the number of undernourished people. Development and management becomes even more compelling due to the growing competition for water, which has created an increasing and conflicting global demand.

This paper highlights key facts, conditions and trends regarding water aspects of food production and consumption. Additionally, it explores its relation to sustainable food production and consumption patterns. It also highlights key water-food-nutrition-environment-livelihood trends, provides bona fide response options and illustrates important policy directions for discussion in the near future, hopefully leading to wise decisions in CSD-13 in 2005 – a critical forum where different aspects of food production and consumption, protection of ecosystems and use of water will be discussed.

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