

## Scenarios on Water and Food in Asia

### 1. Drivers of agricultural water use

By far the most important driver in water use during the coming decades is the increase and change in food demand because of population growth and changes in diet. Though the growth rate is declining, in absolute numbers the Asian population is expected to increase by another 1.4 billion people before leveling off at around 5.3 billion people by 2050 (UN 2006). By then Asia will house nearly 60% of the global population.

By 2030 two third of the people will live in cities (Cohen 2005). Furthermore, average incomes, particularly among the growing middle class in fast growing economies such as India and China, are expected to grow rapidly. As incomes rise, food habits change toward more nutritious and more diversified diets (Pingali 2004). Rising incomes throughout much of Asia over the last three decades led not only to more consumption of staple cereals but also to a shift in consumption patterns among cereal crops, and away from cereals toward livestock products and high-value crops. In South East Asia meat consumption more than tripled, while dairy demand more than doubled from 1961 to 2003. Consumption of high-value crops, such as fruit, sugar, and edible oils also increased substantially (FAOSTAT 2007). The changes in diets exhibit a high correlation with incomes, in particular with livestock products: milk in South Asia and meat in East Asia (Figure 2).

Figure 2a: per capita meat supply versus income in India (pink), China (green) and USA (black) over the period 1961-2003

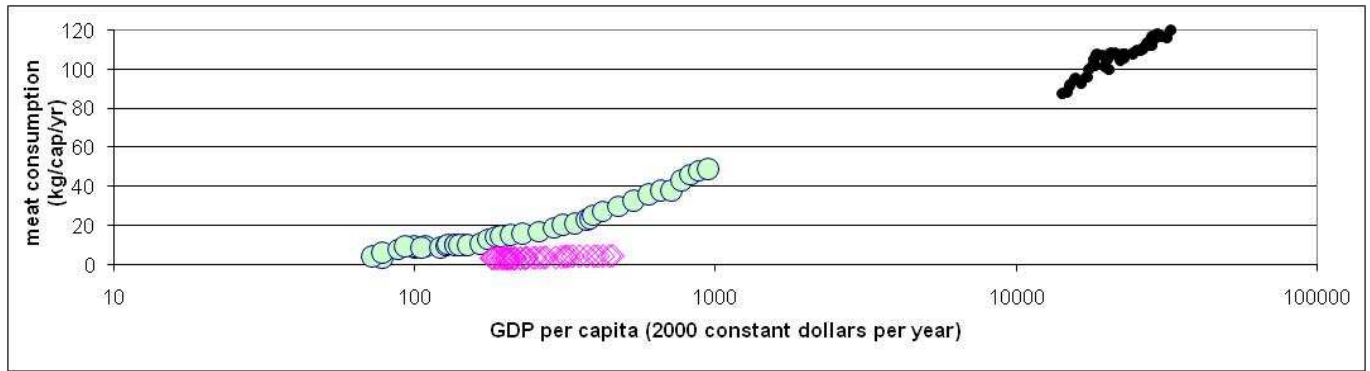
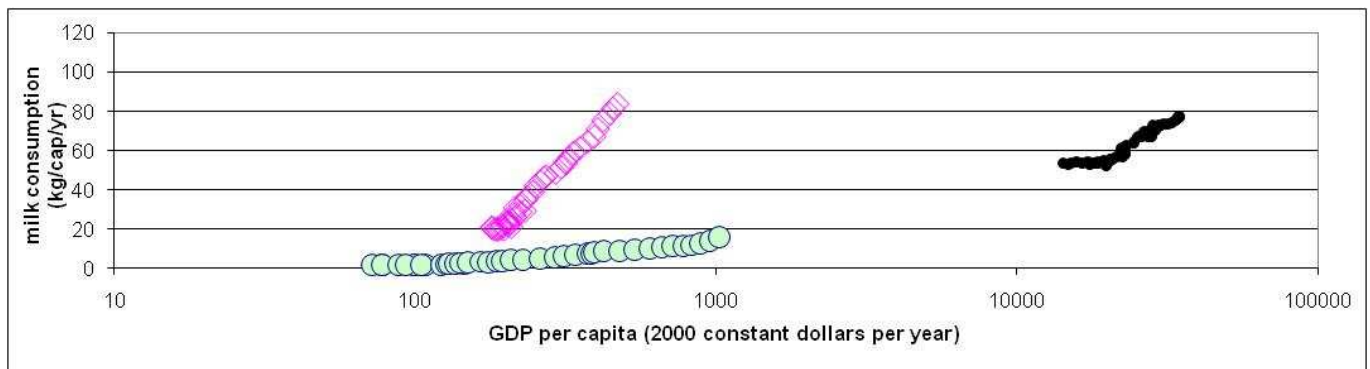


Figure 2b: per capita milk supply versus income in India (pink), China (green) and USA (black) over the period 1961-2003



In the years ahead, urbanization and income growth will continue to drive food demand toward higher per capita food intake and richer diets, particularly in low and middle income countries. Table 1 provides projection on future food demand for South and East Asia<sup>1</sup>. In East Asia the maize consumption is much higher than in South Asia because it is used for meat production. In India the meat consumption is low but the milk consumption is much higher. Such differences and changes in diet influence future agricultural water demand because diets based on livestock products, sugar, and oil typically require more water to produce than those based on cereals and roots and tubers.

<sup>1</sup> South Asia: India, Afghanistan, Bangladesh, Nepal Pakistan, Sri Lanka  
 East Asia: China, Indonesia, Malaysia, Myanmar, N & S Korea, Philippines, Cambodia, Laos, Viet Nam, Thailand

Table 1 food projections

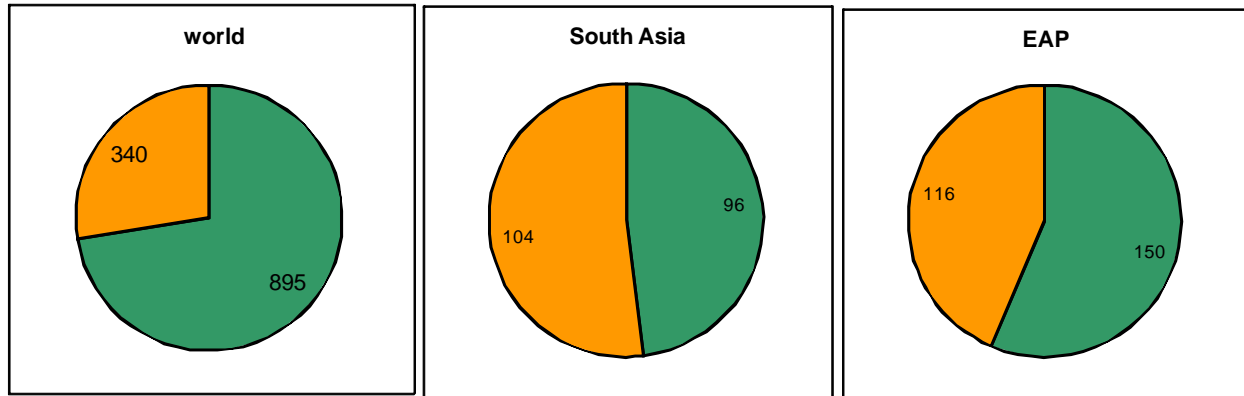
	South Asia			East Asia		
	2000	2050	% change	2000	2050	% change
Wheat	96	205	114%	121	193	60%
Maize	17	32	88%	184	341	85%
Rice	113	202	79%	219	287	31%
total cereals*	249	471	89%	529	935	77%
Meat	8	32	300%	75	190	153%
Milk	114	382	235%	19	60	216%

\* Include food and feed. Source Fraiture et al 2007

Food production requires large amounts of water. On average, one kilogram of grain requires 1,000 liters of water, but estimates vary from 400 to more than 5,000 liters per kilogram of grain. The amount of water required to produce crops varies by crop and region, depending on climate, mode of cultivation (rainfed versus irrigated; high-input versus low-input agriculture), crop variety and length of growing season, and crop yields. Global estimates of total crop consumption vary between 6,800 and 7,500 cubic kilometers annually (Rockstrom et al 1999; Postel 1998; Chapagain 2006, CA 2007), roughly equivalent to 3000 liters per person per day. Crops fed to cattle account for around 18% of the total crop water consumption. For South Asia and East Asia total crop water requirements amount to 1505 and 1692 km<sup>3</sup> respectively. A large portion, an estimated 78% globally, comes directly from rainfall that infiltrates the soil to generate soil moisture. The other 22% (or 1,570 cubic kilometers) is met by irrigation withdrawn from surface and groundwater sources and delivered to farm fields. In South Asia a relative large part of crop water requirements is met by irrigation (41%) for which 1100 km<sup>3</sup> is withdrawn from rivers, lakes and aquifers. In East Asia irrigation withdrawals amount to 520 km<sup>3</sup>. In South

Asia more than half of the harvested area is irrigated, in East Asia this is just less than half, compared to one quarter of world average (Figure 1).

Figure 1: Irrigated and rainfed harvested area in South Asia and East Asia compared with world totals (in million hectares)



Orange = irrigated; green = rainfed;

EAP = East Asia Pacific

Nonfood crops such as cotton only occupy very small part of the cultivated area but demand for cotton is expected to more than double by 2050. Crop production for energy also is increasing in several areas, with potentially substantial implications for land and water use in agriculture (Koplow 2006). At present less than 2% of the total cropped area is devoted to energy crops and only around 1% of the total water is evaporated by energy crops (Fraiture et al 2008). Potentially, the impact of bioenergy on agricultural water use is large. The water footprint of energy derived from biological sources is 40 to 70 times larger than that of fossil fuels (Gerbens-Leenes et al 2008). However, the future share of biofuels crops is highly uncertain because of the volatile energy prices, increases in food prices and environmental concerns. To produce one liter of biofuel crops evaporate between 2500-3500 liters (Fraiture et al 2008). Future water use for bioenergy varies by an order of magnitude from 1000 km<sup>3</sup> (lowest scenario in Berndes et al

2002) to 11,700 km<sup>3</sup> (highest scenario in Lunqvist et al 2007) of which a considerable part is met by non-crops (grasses, trees and waste). Because of the high degree of uncertainty we did not incorporate bioenergy in our scenarios.

Without improvements in land and water productivity or major shifts in production patterns the amount of crop water consumption in 2050 would increase by 70% to 90% globally depending on actual growth in population and income, and assumptions regarding the water requirements of livestock and fisheries. For South and East Asia this would mean that crop water requirements will reach to 2860 km<sup>3</sup> and 3215 km<sup>3</sup> for South and East Asia respectively. These estimates exclude the impact of likely improvements in water productivity (Molden et al 2007). However, even with improvements in water productivity, agriculture will continue to consume a large portion of the world's developed water supply.

A recently completed assessment on water management in agriculture (CA, 2007) concludes that there are sufficient land and water resources to feed the world but that today's food production and environmental trends, if continued, will lead to water crises in many parts of the world. Projections on future water foresee a worsening of water problems unless adequate policy measures are implemented (Seckler et al., 1998; Alcamo et al., 2005; Rosegrant et al., 2002; Vörösmarty et al., 2005, Lobell et al, 2008). Already there are signs of growing water scarcity, particularly in some important agricultural areas in Asia, such as declining water tables in North India, Pakistan, and North China, (Shah et al., 2007) while dried-up rivers, such as the Yellow river in China, the Krishna in India, Syr Darya in Central Asia no longer discharge to the sea for extended periods of time (Molle et al., 2007). Climatic change may aggravate water shortages in these areas.

## 2. Major pathways to meet future food demand

The policies and investment strategies chosen to increase food production will affect water use, the environment, and rural and urban poverty. Feeding 1.5 billion more Asian people by 2050 will require water development and management decisions that address tradeoffs between food and environmental security. Four broad strategies include (Fraiture et al 2007):

- a) Investments to increase production in **rainfed agriculture**- improving productivity through enhanced management of soil moisture and supplemental irrigation if small water storages are feasible; expanding cropped areas
- b) Investments in **irrigated agriculture**: increasing annual irrigation water supplies by innovations in system management, developing new surface water storage facilities, and increasing groundwater withdrawals and the use of waste water; and increasing water productivity in irrigated areas and value per unit of water by integrating multiple uses—including livestock, fisheries, and domestic use—in irrigated systems.
- c) **Agricultural trade** – by trading agricultural products from water rich and highly productive areas to water short areas.
- d) Reducing gross **food demand**—by influencing diets, and reducing post harvest losses including industrial and household wastes.

Each of these strategies will affect water use, the environment, and the poor in different ways.

Enhanced agricultural production from rain fed areas and higher water productivity on irrigated areas can offset the need for the development of additional water resources (Molden et al 2007; Rosegrant et al. 2002, Rockstrom et al. 2003). But the potential of rainfed agriculture and the scope to improve water productivity in irrigated areas is debated (Seckler et al 2000, Rosegrant

et al 2002, Kijne et al. 2003). Trade can help mitigate water scarcity if water-short countries import food from water abundant countries (Hoekstra and Hung 2005). But political and economic factors may limit its scope (Fraiture et al, 2004, Wichelns 2004). Investments in irrigated agriculture will help alleviate rural poverty (Castillo et al 2007, Faures et al 2007). But irrigated area expansion may have serious consequences for the environment (Falkenmark et al 2007). Reducing losses that occur in the food chain (i.e. from farmers' field to consumers' plate) will help reduce food demand and hence reduce water used in agriculture but because of the high number of actors involved improving the efficiency in the food chain may prove challenging (Lundqvist et al 2008).

Views on what future pathways are most appropriate diverge strongly.

### **3. Future pathways**

We use scenarios to illustrate and quantify tradeoffs in investment strategies using the WATERSIM model (Fraiture 2007). This numerical model consists of two fully integrated modules: a food production and demand module based on a partial equilibrium model, and a water supply and demand module based on a water balance and accounting framework. To adequately capture both hydrologic processes at basin scale and economic phenomena at country scale, the model uses 282 hybrid units intersecting 128 hydrological units with 115 socio-economic units (i.e. countries and country groups). The scope and feasibility of productivity enhancement and area expansion vary by region. Regional variation of opportunities and limitations are incorporated in the scenario analysis. For the purpose of this paper results are aggregated into South and East Asia.

Productivity growth is modeled as function of the exploitable yield gap, i.e. the difference between maximum attainable and the actually achieved yields. Under an optimistic scenario 80% of the yield gap is bridged; under a pessimistic scenario only 20%. In areas where the yield gap is large productivity growth rates are relatively high. In areas where yields are already close to the maximum obtainable level growth rates level off. The maximum obtainable yields are derived from the Global Agro Ecological Zones (GAEZ) methodology (Fischer et al. 2002; Bruinsma 2003). This methodology uses physical and crop management factors to establish maximum levels of productivity on a grid-cell basis. The maximum attainable yield assumes high input levels and best suitable varieties, depending on the quality of land. This approach provides realistic estimates based on known techniques, without assuming major breakthroughs. The potential of area expansion is determined by GAEZ land suitability classes. We assume that expansion is limited to lands in classes 'suitable' and 'very suitable' for agriculture.

Scenario analysis conducted as part of the Comprehensive Assessment indicates that growth in water diversions to agriculture varies anywhere between 10% to 57% by 2050 for South Asia and between 16% and 70% for East Asia depending on assumptions on trade, water use efficiency, area expansion and productivity growth in rainfed and irrigated agriculture (Fraiture et al., 2007). Increases in cropped area vary between 3% and 18% for South Asia and 10% and 34% for East Asia. Increases in crop water depletion between 13% and 36% for South Asia and 10% and 43% for East Asia (tables 2a and 2b and figures 3a and 3b). The background, rationale and results of the scenarios are described in the following paragraphs.

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Table 2a: Overview scenarios South Asia

	Baseline (2000)	Rainfed scenarios 2050		Irrigation scenarios 2050		Trade scenario (2050)	Optimistic scenario (2050)
		High yield	Low yield	Area expansion	Yield improvement		
Rationale		Emphasis on investments in rainfed areas: water harvesting and supplemental irrigation	Simulates the pessimistic case where upgrading rainfed is not successful	Emphasizes food self-sufficiency and stable food supply through expansion of irrigated areas	Emphasis on improving performance of existing irrigated areas: increase in yield and water productivity	Agricultural trade from water abundant countries to water scarce countries	An optimistic, but plausible, scenario that emphasizes optimal strategies that vary among regions
Irrigated area in million ha		104	104	135	115	104	118
% growth	104	zero	zero	30%	11%	zero	13%
Rainfed area (million ha)		111	126	100	110	109	90
% growth	98	13%	29%	2%	12%	11%	-8%
Irrigated cereal yield (metric tonnes per ha)		4.1	4.1	4.1	5.4	4.1	4.8
% growth	2.7	52%	52%	52%	100%	52%	78%
Rainfed cereal yield (metric tonnes per ha)		2.9	1.9	1.8	1.8	1.9	2.5
% growth	1.4	107%	36%	29%	29%	36%	79%
Crop water consumption directly from rainfall (km <sup>3</sup> )		1,042	1,182	1,079	1,018	1,008	930
% growth	886	18%	33%	22%	15%	14%	5%
Crop water consumption from irrigation deliveries (km <sup>3</sup> )		780	780	969	885	695	770
% growth	619	26%	0%	24%	-9%	-21%	11%
Withdrawals for irrigation (km <sup>3</sup> )		1,369	1,369	1,730	1,423	1,220	1,195
% growth	1,105	24%	24%	57%	29%	10%	8%
Cereal trade (% of domestic consumption)		7%	1%	-18%	2%	0%	2%

Table 2b: Overview scenarios East Asia

	Baseline (2000)	Rainfed scenarios		Irrigation scenarios		Trade scenario (2050)	Optimistic scenario (2050)
		2050		2050			
Rationale		High yield	Low yield	Area expansion	Yield improvement		
		Emphasis on investments in rainfed areas: water harvesting and supplemental irrigation	Simulates the pessimistic case where upgrading rainfed is not successful	Emphasizes food self-sufficiency and stable food supply through expansion of irrigated areas	Emphasis on improving performance of existing irrigated areas: increase in yield and water productivity	Agricultural trade from water abundant countries to water scarce countries	An optimistic, but plausible, scenario that emphasizes optimal strategies that vary among regions
Irrigated area in million ha		116	116	170	121	116	136
% growth	116	zero	zero	47%	4%	zero	17%
Rainfed area (million ha)		217	244	194	240	182	182
% growth	156	39%	56%	24%	54%	17%	17%
Irrigated cereal yield (metric tonnes per ha)		5.4	5.4	5.6	6.8	5.4	6.0
% growth	4.0	35%	35%	40%	70%	35%	50%
Rainfed cereal yield (metric tonnes per ha)		4.8	3.2	3.2	3.2	3.1	4.0
% growth	2.6	85%	23%	23%	23%	19%	54%
Crop water consumption directly from rainfall (km <sup>3</sup> )		1,904	2,165	1,839	1,926	1,487	1,565
% growth	1,346	41%	61%	37%	43%	10%	425%
Crop water consumption from irrigation deliveries (km <sup>3</sup> )		404	404	582	486	348	425
% growth	346	17%	17%	68%	40%	1%	23%
Withdrawals for irrigation (km <sup>3</sup> )		612	612	882	662	528	601
% growth	525	17%	17%	68%	26%	1%	14%
Cereal trade (% of domestic consumption)	-5%	-1%	-18%	-4%	-6%	-24%	-16%

Figure 3a: Scenarios in South Asia

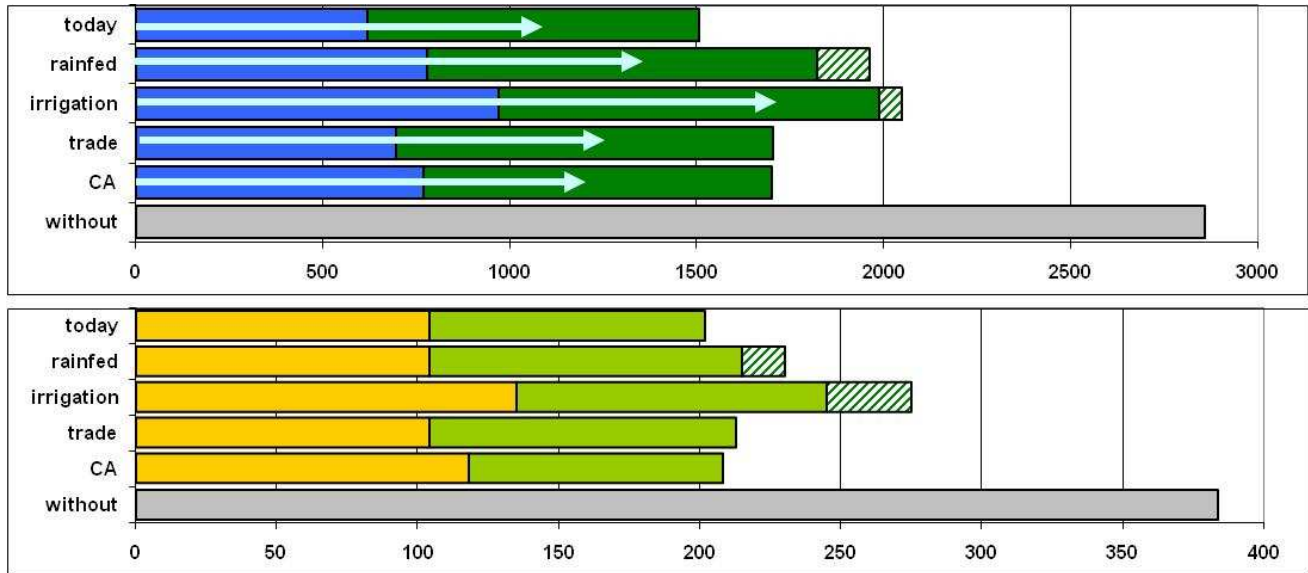
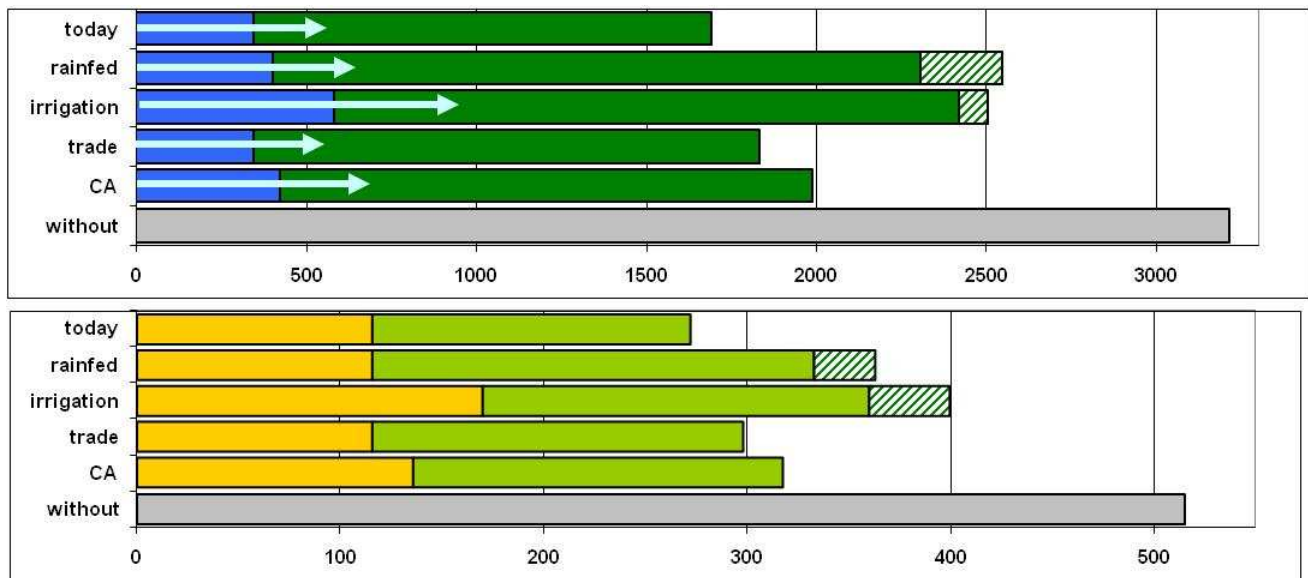


Figure 3b: scenarios in East Asia



### 3.1 The potential role of rainfed agriculture

Rainfed agriculture plays an important role in today's food supply of East Asia. Just over 50% of the gross value of East Asia's food is produced under rainfed conditions on 60% the harvested land. In South Asia less than one fourth of the gross value comes from rainfed areas consisting of

45% of the harvested area. The productivity gap between irrigated and rainfed areas in South Asia is much larger than in East Asia, pointing to a considerable scope for productivity improvements. However, the future food production that could and should come from rainfed or irrigated agriculture is the subject of debate.

There are several compelling reasons to invest in water management in rain fed agriculture (CA 2007). First, actual yields are low and there is an enormous –largely untapped– potential to increase productivity. Second, rural poor depend on rain fed agriculture rather than irrigated agriculture. Third, investment costs in rain fed areas tend to be lower than in irrigated agriculture. Fourth, irrigation development has high environmental and social costs (such as fragmentation of rivers and wetlands, water scarcity, water logging and salinization and displaced people in case of large reservoirs). Rockstrom *et al* (2003, 2007) argue that upgrading rainfed areas through soil and water conservation, water harvesting techniques and supplemental irrigation can double or even quadruple productivity in drought-prone tropical regions. Water management in rain fed areas, traditionally neglected, is key to raise productivity.

Nevertheless, the potential role of rainfed agriculture in contributing to Asia's food production is a subject of debate and forecasts regarding the relative roles of irrigated and rainfed agriculture vary considerably. Referring to mixed results of past efforts to enhance productivity in rainfed areas, Seckler et al. (2000) are less optimistic concerning the potential of rainfed areas. Relying on rain fed agriculture carries risks. Most water harvesting techniques are useful to bridge short dry spells but longer dry spells may lead to total crop failure. Further, while numerous studies document the benefits of upgrading rainfed agriculture, outscaling these isolated successes remains challenging. Water harvesting techniques have been known since long

but adoption rates have been low due to low profitability of agriculture, lack of markets, relatively high labor costs and high risks.

### An optimistic and pessimistic scenario

To contrast optimistic and pessimistic views on the potential of rainfed agriculture and assess risks, we develop two rainfed scenarios (Fraiture et al. 2007). A high yield scenario assumes that prices and incentives are right and physical and institutional arrangements are in place (markets, roads, extension services and credit facilities). Under this scenario 80% of the yield gap will be bridged. A low yield scenario assumes that adoption rates of water harvesting measures and supplemental irrigation are low. Under this scenario only 20% of the yield gap will be bridged. The scenario analysis shows that upgraded rainfed agriculture can produce the food required in future (table 3), but there are conditions that must be met.

Table 3: results of optimistic and pessimistic rainfed scenario

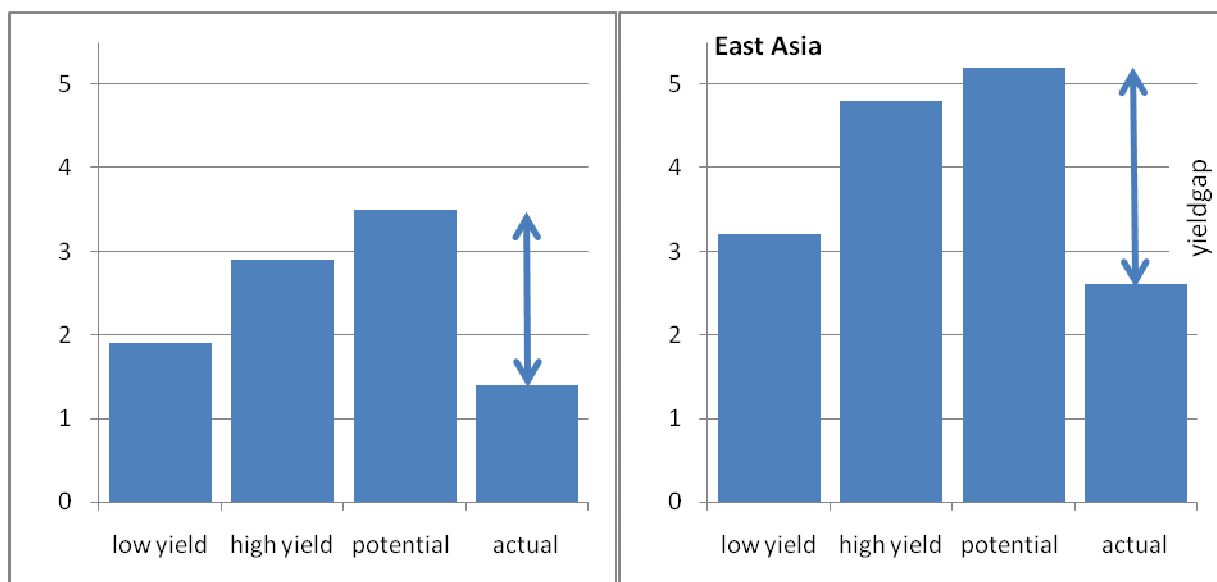
	South Asia					East Asia				
	2000	2050 opti- mistic	growth %	2050 pessi- mistic	growth %	2000	2050 opti- mistic	% growth	2050 pessi- mistic	% growth
<i>Rainfed cereal yield (t/ha)</i>	1.4	2.9	107%	1.9	107%	2.6	4.8	85%	3.2	23%
<i>Rainfed area (million ha)</i>	98	111	13%	126	29%	156	217	39%	244	56%
<i>Net cereal trade (% of demand)*</i>	7%	1%		-18%		-5%	-1%		-19%	

\* Negative numbers signify imports

In South Asia where actual yields are low the yield gap --and hence the potential for growth-- is higher than in East Asia. Under the optimistic scenario rainfed cereal yields more than double

from 1.4 tons/ha now to 2.9 tons/ha in 2050 in South Asia but in East Asia the growth is slightly more modest (in relative terms) from 2.6 to 4.8 ton/ha (figure 4). Under the optimistic scenario an increase of 13% of the rainfed area would be sufficient to meet all additional cereal demand in South Asia by 2050. In East Asia the area would have to increase by 39% because of the higher cereal demand for feed and slower yield growth.

Figure 4: rainfed cereal yields: optimistic and pessimistic scenario, in South and East Asia



Under the pessimistic scenario where rainfed cereal yields only grow by 23% and 39% in South and East Africa respectively, the shortfall in food supply will have to come from an expansion of the area. But where land suitable for agriculture is not available food imports are needed. In South Asia where 94% of the area suitable for agriculture is already is cultivated the scope for expansion is limited (FAO 2002) unless marginal lands are taken into production. Under the pessimistic scenario South and East Asia need to import nearly one fifth of its cereal demand. In South Asia the imports occur due to the limited scope of area expansion. In East Asia

the scope for area expansion is larger but yield growth is less while the increase in cereal demand is larger.

Experience indicates that the required productivity increases will not occur without substantial investments in water harvesting, agricultural research, supporting institutions and rural infrastructure. In addition, crop yields will vary with economic incentives and crop prices, as farmers will respond to those parameters when choosing key inputs. A high yield scenario will evolve only if generating high yields is profitable for farmers (Bruinsma 2003). The optimistic scenario assumes appropriate incentives are in place. By contrast, the pessimistic scenario shows that when these are missing more land will be needed. A large expansion of agricultural land may have a negative impact on biodiversity and ecosystem services. Where the scope of area expansion is limited large imports are needed. This may raise political and socio-economic issues.

### **3.2 The potential role of irrigated agriculture**

Irrigation plays a major role in food production, while also providing livelihoods to millions of poor farmers in developing countries. Irrigated agriculture currently provides 40% of the global cereal supply. In South and East Asia this is 64% and 68% respectively. East Asia produces close to 60% of the global rice supply, South Asia another 30%,. Total Asia produces 90% of global rice production, mostly under irrigated conditions. With growing food demand and climate change induced rainfall variability many expect that the contribution of irrigated agriculture to food production and rural development will increase in the coming decades (Bruinsma 2003, Seckler et al. 2000).

The perception on costs and benefits of irrigation changed markedly over the past 50 years (CA 2007, Faures et al 2007). After a decade of decline, the last few years have seen an increasing interest in public funding in water infrastructure for agriculture, particularly in Sub-Saharan Africa where irrigation development is limited and potential still large. Reasons for the renewed interest include concerns of climate change induced rainfall variability; maintaining the existing infrastructure; potential for poverty alleviation; the high potential to improve performance (Faures et al. 2007) and the recent surge in food prices. In India the groundwater boom, with millions of smallholders investing in private tubewells, continues despite environmental problems with groundwater overdraft and fossil groundwater mining (Shah et al 2007). Irrigation with wastewater is expanding in areas near major cities in developing countries (Qadir et al 2007). In India and Pakistan large investments are planned for rehabilitating and modernizing the Ganges and Indus River irrigation systems (Briscoe et al 2005).

We contrast two scenarios: one with emphasis on area expansion, the other focusing on yield improvements.

#### Area expansion scenario

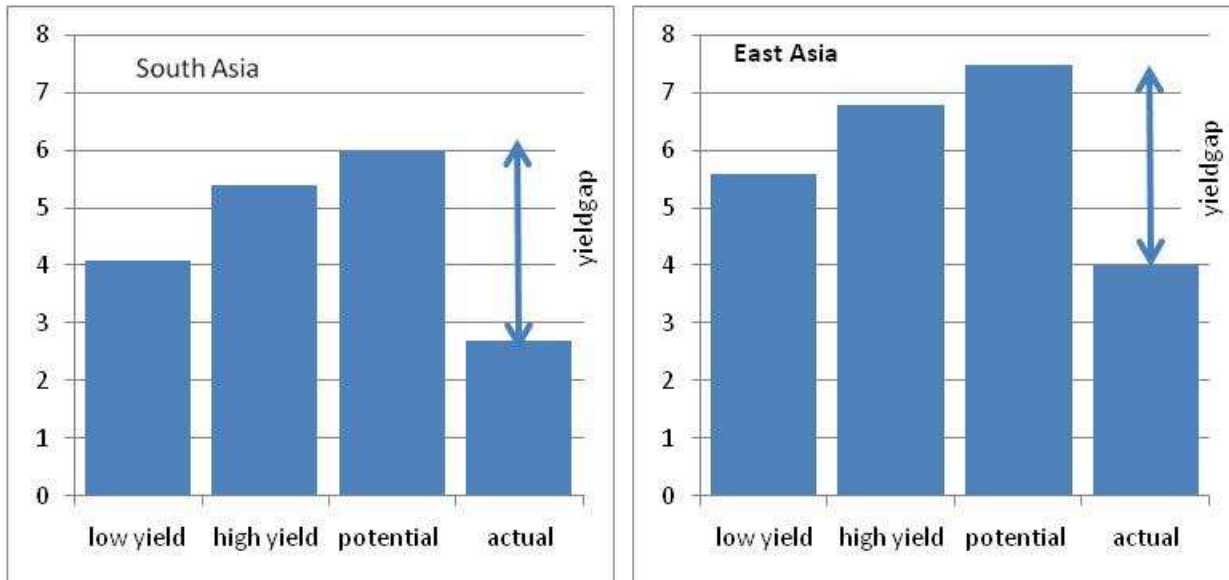
The area expansion scenario emphasizes food self-sufficiency and access to agricultural water to more people. Assuming a continuation of the groundwater boom, under this scenario the irrigated harvested area in South Asia grows by 30% over 50 years. In East Asia the harvested area under irrigation increases by 47%. Irrigated yields follow historical trends and grow by 40% and 51% in East and South Asia respectively. With this area expansion South and East Asia can be largely food self-sufficient in 2050. National food security and rural incomes are enhanced but it tends to come at a high financial and environmental cost, particularly in already water

scarce areas. In South Asia irrigation withdrawals increase from 1105 km<sup>3</sup> to 1730 km<sup>3</sup> (57%); in East Asia from 525 km<sup>3</sup> to 883 km<sup>3</sup> (68%). Important agricultural areas in South and East Asia are already affected by declining water tables and water scarcity. In South Asia possibilities to expand areas are limited or involve large infrastructure investments, such as the Linking of Rivers project in India. While in some areas in Asia irrigation expansion is still desirable and possible without adverse affects on water resources, by and large an agricultural strategy that heavily relies on irrigated area expansion will likely lead to additional pressure on water resources, aggravation of existing water scarcity and degradation of ecosystems. Most of the increase in production must come from productivity improvements.

#### Yield improvement scenario

Many irrigation schemes, particularly in South Asia, perform below potential and the scope for improving water and land is high (Molden et al 2007). This scenario explores the gains from enhancing the output per unit of water in irrigated areas. Under this scenario 80% of the gap between actual and obtainable irrigated cereal yield is bridged leading to a doubling in yield in South Asia (from 2.7 to 5.4 tons/ha) and a 70% increase in East Asia (from 4.0 to 6.8 tons/ha) (Figure 4).

Figure 4: Irrigated cereal yields under different irrigation scenarios



Water productivity also substantially improves under this scenario (water productivity of irrigated wheat increases by 41% and 30% respectively) but to a lesser degree than outputs per unit of land. This scenario foresees a 12% and 4% expansion of irrigated area in South and East Asia respectively, while irrigation diversions increase by 29% and 26%. To achieve the improvements in irrigated yields depicted in this scenario, water supplies must be increased in existing irrigated areas. In India, for example, farmers install additional tubewells in command areas to supplement unreliable surface water supply (Shah et al 2007). In some areas, yield improvements are achieved by augmenting water supplies in tailend areas, partly (but not entirely) at the expense of headend areas (see Hussain et al (2004) for a win-win case in Pakistan). Better timing of water deliveries also is helpful in improving crop yields. All of these measures lead to more water evaporated by crops, a precondition for increasing yields. As a result, water consumption and irrigation diversions increase substantially in this scenario.

Part of the increase in water consumption is offset by improvements in water use efficiency and water productivity. Improving productivity implies that more output is obtained

per unit of water consumed, perhaps by achieving a higher harvest index or reducing evaporation losses from soils. Improving efficiency implies that a larger portion of diverted water is used beneficially by crops, livestock, or other productive processes. This might be achieved, for example, by recycling drainage water or improving on-farm water management (Molden, Sakthivadivel, and Habib 2000 and Seckler et al 2000).

The scenario results show the enormous potential of improving performance in existing irrigated areas, particularly in South where more than 50% of the harvested area is irrigated and yields are low. Three quarters of the additional food supply by 2050 can be met by improving productivity of existing irrigated areas (table 5). In South-Asia all additional cereal demand can be met through irrigated yield improvements, though this would require additional water withdrawals.

Table 5: results of irrigated yield improvement and area expansion scenario

	South Asia					East Asia				
	2000	2050 yield scenario	growth %	2050 area scenario	growth %	2000	2050 yield scenario	% growth	2050 area scenario	% growth
<i>irrigated cereal yield (t/ha)</i>	2.7	5.4	100%	4.1	52%	4.0	6.8	70%	5.6	40%
<i>irrigated area (million ha)</i>	104	115	11%	135	30%	116	121	4%	170	47%
<i>Net cereal trade (% of demand)*</i>	7%	0%		2%		-5%	-6%		-4%	

\* Negative numbers signify imports

Improving irrigation performance and increasing water productivity is by no means easy (Molden, forthcoming). It requires that the right incentives and policies are in place to induce farmers to increase water productivity.

Arguably, the largest gains in water productivity in value per unit of water are achieved by diversification and by using water for many productive purposes—such as fisheries, livestock, home gardens, and other small enterprises (van Koppen, Moriarty, and Boelee 2006). This may require changes in irrigation design to incorporate small dams, fisheries, and flood protection.

### **3.3 The role of trade: virtual water, can it work in reality?**

Because the production of agricultural commodities requires large quantities of water, expanded international food trade can have significant impact on water demands at the national level. Allan (1998) coined the term ‘virtual water’ to denote the water used to produce crops that are traded internationally. By importing agricultural commodities, a nation ‘saves’ the amount of water it would have required to produce those commodities in country (Hoekstra and Hung 2005). At the global level, cereal trade has a moderating impact on irrigation water demand, as four of the five major grain exporters (USA, Canada, France, Australia and Argentina) produce grain in highly productive rainfed conditions. Major importers, such as Egypt, Mexico, Iran, Saudi Arabia, and Algeria, rely on irrigation to produce grains. In 1995 without cereal trade global irrigation water demand would have been higher by 11% (Fraiture et al 2004, Oki et al 2003).

International food trade could thus contribute to mitigating water scarcity problems. To assess the potential of trade as water saving mechanism we formulate the ‘ideal virtual trade’ scenario in which countries with abundant water resources and production capacities increase their agricultural production and export to water-short countries. North America, Latin America (mainly Brazil and Argentina), Northwest Europe, and Eastern Europe (Russia and Ukraine)

export to the Middle East and North Africa and to India, Pakistan, and China. In the importing countries, crop yields improve at a modest pace (25%) while irrigated and rainfed areas remain constant. Water-short areas in China, India, the Middle East and North Africa reduce their irrigated areas for cereals, shifting toward labor intensive, higher valued crops such as vegetables. In exporting countries rainfed yields of staple crops—such as cereals, soybeans (oil crops), and roots and tubers—improve by 60% on average. Rainfed areas in exporting countries increase by 260 million hectares, primarily in Latin America, where the scope for area expansion is still large.

The scenario analysis reveals that, in theory, world food demands can be satisfied through international trade, without worsening water scarcity or requiring additional irrigation infrastructure (de Fraiture et al 2007). But this would mean a considerable increase in food imports in both South and East Asia to around one fourth of the cereal demand by 2050 (table 6).

Table 6: trade scenario results

	Cereal demand 2000 (million metric tons)	Net cereal trade 2000* (million metric tons)	Net cereal trade 2050 (million metric tons)	Net trade as percentage of demand 2000 (%)	Net trade as percentage of demand 2050 (%)	Increase in Irrigation withdrawals
Global	1840	2880	145*	8%	17%	5%
South Asia	241	16	-119	-7%	-25%	10%
East Asia	505	-25	-191	-5%	-24%	1%

For many years, the Indian government has focused on achieving national food self-sufficiency in staples. With extensive investments in agriculture (mainly large scale public irrigation schemes and small scale private tubewells) India became food self-sufficient in main staples and has been a net exporter of food over the past few years. More recently, as the imminent danger of famines has decreased and non-agricultural sectors have expanded, the national perspective

regarding production and trade has changed. Food trade might become more important in future, particularly as the relative contribution of non-farm sectors increases in the Indian economy. (Dasgupta and Singh 2005; Rigg 2005).

But because of socio-economic and political reasons it seems unlikely that water concerns will be a main driver of increased trade volumes in the near term. Low income countries struggling with food security remain wary of depending on imports to satisfy basic food needs. Food imports must be paid for with foreign exchange which is earned by selling exports or obtained through grants and loans (Seckler et al. 2000). Many poor countries do not have sufficient exports to pay for imports, and recent hikes in food and energy prices further worsened the trade balance of many importers. Trade requires substantial amounts of energy for transporting goods, adding to the financial and environmental costs of trade. Fluctuating prices and dependence on one or few export commodities make poor countries particularly vulnerable. A degree of food self-sufficiency -and the development of water resources to achieve this- therefore still is an important policy goal. This was acutely illustrated in the first half of 2008 when rice, wheat and maize prices soared. Main exporters such as Viet Nam, Thailand and India responded by restricting rice exports over concerns of national food supply.

In order to make use of agricultural potential elsewhere without relying on trade some countries recently started buying or leasing large tracts of agricultural land, primarily in Sub-Saharan Africa. For example, the Korean company Daewoo is negotiating to lease one million hectares of agricultural land in Madagascar to ensure maize supply (in this case for ethanol production). To add more...

International trade provides water-short nations an option for responding to increasing water scarcity. The importance of this option in future will depend on many factors, including

the costs of engaging in trade, international trade agreements, and the nature of domestic economic objectives and political considerations (Wichelns 2004). The implication is that under the present global and national geopolitical situation, it is unlikely that trade alone will solve water scarcity.

### **3.4 Reducing gross food demand**

Diets based on meat from grain-fed cattle may take two times more water than pure vegetarian ones. A diet without meat requires an estimated 2000 liters per day to produce, while a diet high in grain-fed beef requires 5000 liters of water (Renault and Wallender 2000). Thus, the potential to reduce pressure on water resources by changes in food consumption patterns seems high. However, measures and policies to change diets are notoriously difficult to implement and sometimes controversial. Most of the discussion on how to reduce pressure on water resources has dealt with the producer rather than the consumer side of agricultural products (Lundqvist 2007).

A more promising pathway to reduce gross food –and therefore water- demand is minimizing losses that occur in the food chain. While estimates are sketchy and rather outdated, available evidence points to a considerable amount of agricultural produce lost in the steps between produced by farmers and eaten by consumers. Estimates vary between 40% to 50% (Lundqvist 2008). There are several stages in the food chain where substantial losses occur. Losses in the field (between planting and harvest) may be as high as 20% to 40% of the potential harvest in developing countries due to pest and pathogens (Kader 2005). Losses in processing, transport and storage are conservatively estimated between 10% and 15% in quantity terms, but

could amount to 25%-50% of the total economic value because of reduced quality (ibid). Lastly, substantial losses occur during retail and consumption, due to discarding excess perishable products, product deterioration and food not consumed. In the US around 25% of fresh fruit and vegetables are not consumed (by humans)<sup>2</sup> during retail and consumption (Kantor et al 1997). In developing countries this is estimated at around 10% (Kader 2005). **This section needs some examples from Asia.**

Despite the uncertainties in the estimates, the order of magnitude suggests considerable inefficiencies in the food chain and therefore large scope to reduce gross food demand and thus water. But this is by no means easy. There are many steps and many actors from field to fork, such as farmers, agricultural workers, truck drivers, shopkeepers, government officials and consumers. With urbanization the distance between farmers and consumers and hence the complexity of the food chain is growing. Where waste in individual steps is small costs and efforts to improve efficiency could outweigh benefits for the individual actor.

### **3.5 An optimistic scenario**

Optimal strategies differ by region (table 7). In South Asia land is becoming a constraint, and water scarcity problems are also on the rise. In South Asia **60%** of the harvested area is irrigated and the gap between obtainable and achieved yield is large. The scope to augment food supply and raise rural incomes by improving yields is high. By contrast in much of East Asia yields are already high imports are expected to rise. China has sufficient water in the South but not in the North where most agricultural areas are located.

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<sup>2</sup> Part of it ends up in compost or animal feed

We formulate an optimistic scenario combining positive elements from the scenarios above and accounting for the regional opportunities and constraints. The optimistic scenario does not include reductions in gross food demand because of the lack of reliable estimates and the high levels of uncertainty involved. Broadly speaking this scenario entails emphasis on irrigation performance improvements in South Asia, with modest area expansion. Where groundwater overdraft takes place areas are reduced. In East Asia both irrigated and rainfed yields are improved, but because of the relative limited scope and higher projected food demand East Asia net food imports will increase. Globally rainfed yields increase by 58% and irrigated yields by 55%. This scenario shows that even under optimistic assumptions related to productivity growth crop water consumption increases by 20% while withdrawals to agriculture increase by 13% by 2050. For South and East Asia irrigation withdrawals increase by 9% and 16% respectively (table 7).

Table 7: An optimistic scenario, results

	Irrigated water productivity cereals 2050 (kg/m <sup>3</sup> )	Cumu-lative change (%)	Rainfed water productivity cereals 2050 (kg/m <sup>3</sup> )	Cumu-lative change (%)	Crop water consumption 2050 (billion m <sup>3</sup> )	Cumu-lative change (%)	Irrigation withdrawals 2050 (billion m <sup>3</sup> )	Cumu-lative change (%)
South Asia	0.79	62	0.46	82	1700	15	1195	9
East Asia	1.06	45	0.57	36	1990	19	601	16
World	0.93	38	0.64	31	8515	20	2975	13

The scenario analysis makes clear that water use will increase as food demand rises. Even under optimistic assumptions this will likely lead to increases in crop water requirements and irrigation withdrawals.

## ***Conclusions and discussion (needs more Asia focus)***

Globally there are sufficient land and water resources to produce food for a growing population over the next 50 years. But it is probable that today's food production and environmental trends, if continued, will lead to crises in many parts of the world. Only if we act to improve water use in agriculture will we meet the acute freshwater challenge facing humankind over the coming 50 years. Challenges facing agricultural water management are different from those 50 years ago. The global population growth rate has slowed down but in absolute terms the global population continues growing before leveling off at around 9 billion by 2050 (50% higher than now). Urbanization and substantially higher incomes will result in a shift in food demand from cereals towards higher value commodities such as meat, milk, oil and sugar. These products typically require more water per calorie consumed. Agricultural markets are changing and new demands such as biofuels are emerging. At the same time water scarcity problems and/or groundwater overdraft are prevalent in an increasing number of river basins in agriculturally important basins in Asia (among others Syr Darya, Nile, Yellow River, and Indus). Maintaining or restoring ecosystem services, contributing to rural development and poverty alleviation and achieving production goals are challenging goals facing agricultural water management. Climate change adds another layer of uncertainty.

Water use increases in response to higher food demand. Different strategies to meet this demand have different implications to production goals, environment and poverty alleviation. In this paper we explore different scenarios emphasizing investment in rainfed and irrigated agriculture and the use of international food trade. Upgrading rainfed agriculture can meet agricultural demand but carries considerable risks. There is an enormous scope for improvements in productivity in both rainfed and irrigated agriculture.

We conclude with an optimistic scenario by combining positive elements of strategies in line with the regional strengths and constraints. The optimistic scenario shows that large part of the additional demand can be offset by productivity increases. But even under the optimistic scenario increases in water consumption and withdrawals to agriculture will increase. The challenge is to manage this increase in a way that minimizes adverse impacts on ecosystem services while providing the necessary gains in food production.

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