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Prospects for Irrigated Agriculture

Whether Irrigated Area and Irrigation Water Must Increase to Meet Food Needs in the Future

Validation of Global Irrigation-Water-Demand Projections by FAO, IFPRI, and IWMI

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Acronyms and Abbreviations

BCM	Billion cubic meter
ET	Evapotranspiration
FAO	Food and Agriculture Organization of the United Nations
FAOSTAT	FAO statistics
GAEZ	Global agro-ecological zoning
GDP	Gross domestic product
IFPRI	International Food Policy Research Institute
IMPACT	International model for policy analysis of agricultural commodities and trade
IWMI	International Water Management Institute
Km^3	Kilometer cubed
MDG	Millenium Development Goals
NET	Net evapotranspiration
PODIUM	Policy interactive dialogue model
PWS	Primary water supply
RDS	Rural development strategy
UNESCO	United Nations Education, Social and Cultural Organization
WB	World Bank
WFS	World Food Summit
WSM	Water simulation model
WSSD	World Summit on Sustainable Development (2002)
WUE	Water-use efficiency
WWC	World Water Council

Executive Summary

With the increased competition for scarce land and water resources, a major question raised regarding the promotion of food security is, how will the additional food be produced? Irrigated agriculture is one of the major contributors to the supply of food and fibers in the world. Forecasts of water supply and demand made by three different international agencies (IWMI, FAO, and IFPRI) provide a partial picture of food supply and demand and irrigation-water supply and demand by 2025 and 2030. Because the forecasted results have direct implications for decisions related to investment in water and in rural development, it is important to discover whether the irrigated area and irrigation-water must increase to meet future needs. Furthermore, it would be useful to assess how the pattern of future irrigation-water demand and supply develops, and whether or not it can be affected by various policy interventions.

The objective of the World Bank initiated "validation exercise," in cooperation with the three agencies, is to ensure that the models developed by these agencies consider a balanced range of assumptions and scenarios, introduce additional assumptions and scenarios, and replace, or fine-tune, some of them. More specifically, the objective is to introduce into the forecasts the possible impacts of additional policy interventions and to evaluate their likely effects on the global projections of agriculture-water supply and demand.

This document analyzes existing forecasts, expert opinions on the existing forecasts, and revised scenario results conducted by the three agencies as part of the validation exercise on the global projection of agriculture water supply and demand. Finally, some policy implications of the revised scenario results for the World Bank Rural Development Strategy (RDS) are outlined.

SUMMARY OF FINDINGS OF THE EXISTING FORECASTS

The first part of the validation exercise provides a brief review of the existing model structure and components, the assumptions made, the scenarios and scenario results, in order to look for answers to some of the emerging issues and challenges facing the agriculture water sector. The review of the existing models, assumptions, and scenarios developed by the three agencies provided different scenarios of the global water supply and demand by the year 2025 and 2030. The IWMI study indicated that the world's primary water supply would need to increase by 28%, from around 2,120 km^3 per year in 1995 to 2,718 km^3 per year in 2025. This amounts to an increase in surface and subsurface water storage sufficient to release roughly 600 km^3 of water over the 30-year period.

Considerations of irrigation potential, as addressed by the FAO study, indicate that agricultural-water demand should not exceed the available water resources. The FAO estimates of irrigation potential are based on renewable water resources, i.e., the resources replenished annually through the hydrological cycle. In those arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is usually larger than the irrigation potential. In terms of seasonal water needs, countries suffering from lack of precipitation, and therefore most in need of irrigation, are also those where water resources are naturally scarce. In addition, the water balance presented is expressed in yearly averages and cannot adequately reflect seasonal and interannual variations.

The various scenarios developed under assumptions relating to low investment in irrigation (e.g., low-investment, high intersectoral water demand, low groundwater pumping, etc.), as analyzed by IFPRI, indicated that the availability and reliability of water supply would be largely reduced by 2025 under these scenarios. The reduction in the amount of water available for irrigation is large under these water-stressed scenarios, with biggest reductions shown in the developing countries. This reduction in the availability of water for irrigation directly reduces the irrigated–harvested area and increases the year-to-year variability in irrigated area. For example, irrigated area in the world declines by 8 million ha on average between 2021–2025 under the low investment in irrigation scenario, and by 4 million ha under the high municipal and industrial water demand scenario, compared to the baseline scenario. In addition to reducing the irrigated area harvested, the more water-scarce scenarios also reduce the amount of water available per hectare in the remaining irrigated area.

Emerging issues, validation exercise, and expert opinions

The preliminary scenarios and findings, however, did not adequately address the emerging issues and challenges facing irrigated agriculture and agricultural development in general and necessitates a more realistic projection of global water demand and supply, involving several options (or assumptions) and scenarios. In an attempt to draw the attention of the three agencies involved in the modeling exercise, a group of experts was asked to provide general comments and specific suggestions. The group consulted during the validation exercise highlighted several emerging issues that need immediate attention. These are:

- To what extent would management of the existing systems and improvements in both field-level and basin-wide water-use efficiencies help to address the future water demand?
- To what extent would the use of a demand-based approach (e.g., full pricing of irrigation water, internalization of externalities, rewarding the producers for the public goods, etc.) help to close the gaps between water supply and water demand?
- How would intersectoral demand for water and the impacts of pricing policies on other sectors of water use affect the supply and demand of irrigation water?
- How would the development and management of transboundary water resources and the trading of water within and among the different uses and regions help resolve the national water requirements on a sustainable basis and in a cost-effective way?
- How much additional reservoir storage is needed to build up the large dams for augmenting freshwater to meet the growing water demand, and to what extent would it be financially, economically, socially, and environmentally feasible in the next 25 years? To what extent have the costs been estimated and the feasibility of solving the associated financing aspects studied?

The group of experts also provided specific comments and suggestions related to each of the models and to the need for revising several assumptions to address these emerging issues (see chapter 3 and appendix A-3.0).

Summary of findings of the validation exercise

The major findings and lessons drawn from the revised response to the experts' comments by the three agencies (IWMI, FAO, and IFPRI) are the following:

1. *Improved water-use efficiency (WUE)*[1] *would help in reducing the volume of total, global irrigation-water consumption significantly, and the national governments and international agencies should concentrate their efforts on improving the various facets of WUE.*

All three studies considered the potential for improvements in the various facets of WUE and the likely contribution toward meeting global water demand. Specifically, the findings of these studies indicate that the demand for improved WUE, and hence efforts towards improving irrigation efficiency, would mostly take place in water-scarce areas, such as in the Near East, North Africa, and southern Asia. Some countries in these regions are also increasingly facing food scarcity. Therefore, efforts toward solving food scarcity problems should be combined with applications of various means (economic, physical, and institutional) to improve WUE. Likewise, efforts toward improving WUE should also address basin-wide efficiency, as it can help in reducing the total level of water consumption, as shown by the IFPRI study. This has also been dealt in the IWMI study by introducing the concept of "multiplier effects" of water. National governments and development agencies should therefore focus on improving basin-wide efficiency as a part of the solution to the growing water-scarcity problem, rather than concentrating only on the improvements in field-application efficiency or investing in large storage projects.

2. *Scenarios run with higher water prices indicated a large reduction in water withdrawal, higher basin-efficiency, and full water reservation for the environment with modest impacts on food production, as price response is low in irrigated agriculture. This strengthens earlier conclusions that economic incentive measures will have a better impact when they are combined (and complement each other), and that the policy integration at the sectoral and economy-wide level should be the integral component of the rural development strategy aimed at promoting efficient use of scarce water and achieving the Millennium Development Goals (MDG) of meeting both the water and food security needs (Tiwari and Dinar 2002).*

As shown in the IFPRI revised scenario results (see appendix A-4.3), compared to the baseline conditions, all of the scenarios run with assumptions of high-price for irrigated agriculture resulted in large reductions of water withdrawal in a range of 730–900 km^3 in the world. Under the scenario with high prices, higher basin efficiency, and full water reservation for environment, water withdrawal is expected to decline by 900 km^3, while water depletion is likely to decline by 310 km^3. The ratio of water withdrawal to the total renewable water is also expected to decline by 8% compared to 10% under the business-as-usual scenario. The study results also indicated that even very large percentage changes in water prices would have relatively modest impacts on food production, primarily because price response is low in agriculture. On the contrary, water-price-induced efficiency gains in irrigation-water use would be significant. Also, in most of the water-scarce regions, relatively small impacts of higher water prices on the water demand is due to the fact that irrigation-water demand is constrained primarily by water availability, not by water prices. These all indicate that since pricing policy would have a significant impact on the improved water-use efficiency, as the price elasticity of demand is low in irrigation water, policy integration should focus on a range of economic incentive measures for improving the water-use efficiency in the irrigated agriculture and freeing up resources for achieving the Millennium Development Goals of meeting both the water and food security needs of millions of the poor.

3. *Technology would play an important role in the improved WUE, in raising water productivity, and in solving the future water scarcity problems. Considerations of water-scarcity problems and efforts to*

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[1] All three studies interpreted a different meaning to WUE: IWMI, application efficiency; IFPRI, basin efficiency; and FAO, application efficiency. See Appendix A-1.0 for further clarification.

solve them, especially in the arid and semi-arid areas, need to integrate research on, and adoption of, high-yielding drought-tolerant crop varieties.

The IWMI study results indicated that improvements in crop genetics in the drylands could significantly increase the amount of food produced with less water. It would also help in improving water productivity in irrigated areas, as well as the yields in rain-fed areas, thereby reducing pressure on the irrigated areas and scarce water resources. Further, as illustrated by the IFPRI case study, there is a need for a paradigm shift from addressing only land productivity (kg per ha) toward one addressing water productivity (kg per unit of water applied or per unit of ET), especially in the dry and semi-arid areas.[2] In this context, there is a need for coordinated efforts with the CGIAR Millennium Challenge Program on drought and desertification, which aims at carrying out focused research on the links between agriculture, land degradation in dry areas, and drought and examination of soil fertility, land, and water management strategies that mitigate drought and protect the natural-resource base.

4. *Considerations of the linkage between intersectoral water demand and the impacts of intersectoral pricing policies on future water availability for irrigation (e.g., scenarios developed with some restriction of future water supply for agriculture with increased intersectoral water demand) indicated that it would result in large food production deficits in most water-scarce regions.*

The IWMI forecasts considered water demand for domestic water supply and industrial-water use by 2025. The findings indicated that the domestic sector represents the smallest sector, at only 11% of diversions, but is the most rapidly growing sector with an increase of 84% over the period. Likewise, the industrial diversions would comprise 22% of the total 2025 diversions, growing at the rate of 60% over the period. The increased demand in both the domestic and industrial sector is expected to limit water availability for irrigation and hence in food production. But scenario analysis carried out by IFPRI considering the impact of pricing policies in each of the sectors also indicated that availability of irrigation-water might actually increase, because nonirrigation takes less water (the model assumes nonirrigation always takes the first priority for water supply) due to reforms in water-pricing policy. This indicates that although rising water demands in other sectors of the economy would have negative impacts on water availability for irrigation, policy reforms at the intersectoral level would help to minimize such impacts.

5. *Although none of the models consider the use of brackish water in arid and semi-arid areas and the recycling of sewage water in addressing the supply side of the global water projections, the incorporation of a multiplier effect of the reuse of drainage water—and especially, in consideration of the potential contribution of the water-harvesting techniques in rain-fed areas—provides interesting policy implications for solving the growing water crisis.*

As indicated by the IFPRI revised scenario results, improvements in rain-fed agriculture could offset the need for increased investment in conventional water augmentation (e.g., through building large dams, run-off-the-river diversion schemes, etc.). Improvements in effective rainfall through adoption of water-harvesting techniques combined with land- and water-management practices could significantly reduce the overdrafting of groundwater. In addition, it could also result in local and regional environmental bene-

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[2] The idea of a paradigm shift has been there for quite some time, and several people have noted this, including many from IWMI. For the record, the idea emerged many years ago, using the concept Shadow Value of Water, which was derived from farm-level and regional-level analyses. Economists such as Robert Dorfman (Harvard University), Earl Heady (Iowa State University), and Dan Yaron (Hebrew University of Jerusalem) observed from their empirical work in the 1950s and 1960s that the economic approach to maximizing returns from crop production is to optimize the use of the limiting input. In most cases, water is the limiting input, but in other cases it could be land or labor.

fits, thereby increasing in the stocks of public goods. The increased potential of rainwater-harvesting techniques in solving the water-scarcity problem also indicates the need for broadening the scope of irrigation-water investment programs from conventional options (e.g., large investments on building dams and reservoirs) in order to promote these techniques for the effective utilization of rainfall potential. The potential for improving water-harvesting techniques, rain-fed yield, and total production, however, could be held back by the lack of adequate statistics to predict the "effective rainfall" and optimal utilization of the potential. Likewise, research on crop genetics—particularly on high-yielding varieties suitable for rain-fed areas—remains a challenge.

6. *Considerations of environmental factors, though important, are limited by the lack of data at present, and efforts should be made to improve the environmental database.*

Considerations of the environmental aspects of water demand in the scenario analysis, as in the IWMI and IFPRI studies, indicate that limiting the freshwater availability for irrigation-water use or consideration of ecological limits of water use—whether ground or surface water—would further aggravate the scarcity of water for agriculture. Since the forecasts made in all the studies do not explicitly consider these factors, and the reliability of global climate-change models remains suspect, efforts should be made to make farmers aware of the adaptation process so they might cope with the risks associated with climate-change uncertainty and the potential negative impacts on water availability.

7. *Each of the models has several limitations in finding the answers to the issues linked to the institutional aspects. Complexity also arises because of the heterogeneity of institutional capacity, the tardy pace of capacity building, and the differences in irrigation-sector performance between the countries and regions.*

This further suggests that institutional dimensions such as water rights are important enough to consider as the nature of water rights greatly affects the process of selection and implementation of water-pricing policies and the trading of scarce water resources. Both the institutional reforms and economic instruments are important for improved WUE and reducing the total demand for irrigation water.

Major Departures from the Existing Forecasts and Implications for the World Bank Rural Development Strategy

The major importance attached to this exercise lies in finding to what extent these foci are relevant to the future demand of irrigation water and in addressing the physical, economic, and environmental constraints in matching the demand with the available supply of water. As for the question of the implications of the validation exercise for the Rural Development Strategy (RDS), a number of assumptions made, scenarios developed, and results available provide useful insights and linkages for shaping the priorities for Bank assistance.

The IWMI revised scenarios specifically attempted to address experts' comments on: i) improvements in crop genetics and water-use efficiency; ii) technological change and water use; iii) demand for irrigation lands; iv) demand for water from different perspectives; and v) demand for water for environmental purposes. Likewise, the IFPRI responded to the experts' comments and suggestions by adding some of the scenario results that address some of the concerns raised by the experts in regard to: i) water-use efficiency linked to the concept of water productivity; ii) impacts of crop genetics with assumptions on potential increase on crop yields both in the rain-fed and irrigated areas; iii) water crises associated with the lack of investments for irrigation development; iv) increasing water supply using water-harvesting techniques; v) water pricing and effects of intersectoral water demand, etc. Some of the revised scenario assumptions and results by IWMI and IFPRI indicate important departures from existing forecasts regarding the role of crop genetics, water-use efficiency, water productivity, and the contribution of rain-fed agriculture:

- The IWMI scenario results, corresponding to the assumptions of the potential impacts of likely improvements in crop genetics, showed a significant increase in net cereal-production surpluses for 100 developing countries equivalent to 6.4% of the total cereal consumption in 2025.
- Additional increases in irrigation efficiency assumed at 50% and reduction in noncrop evapotranspiration over the base case would reduce the growth in irrigation by 15% and the total primary water supply by 22%, which corresponds to the 3% and 2% reduction from the level of increase under the base case.
- Under the slower growth (of irrigated area) scenario and with no improvements in crop genetics and water-use efficiency, the primary water supply is expected to go up by 21%, which is 3% more than the base case result. The total primary water supply is expected to increase by 26%, a 4% increase over the base case. On the contrary, if primary water supply was limited to the base case, there would be a substantial food deficit in the developing countries.
- If the production deficit of all countries is to be reduced through additional growth in irrigated and rain-fed yield, the crop yield of all countries is required to increase by 39 and 26%, respectively, by 2025.
- The IFPRI revised scenarios indicate that some improvements in crop yields in rain-fed areas and water productivity in irrigated areas are possible, which would help to reduce the food deficit in developing countries. The IFPRI revised scenario with assumption of low-investment in irrigation development and water supply but a higher increase of rain-fed area and yield indicated that, compared to the baseline condition, rain-fed area is expected to increase by 6 million hectares and with an 11% increase in rain-fed yield with an additional 183 million tons increase in rain-fed production. This would result in a decline of 256 km^3 (18%) in the volume of total-global water consumption. The potential reduction in irrigated cereal production of 170 million tons would thus be completely offset by the increased investment in promoting water-harvesting techniques in rain-fed areas.
- One of the next scenarios with groundwater-overdraft phasing out, larger rain-fed agriculture development, and larger improvement of effective rainfall use carried out by IFPRI indicated a decline in groundwater pumping (by 169 km^3), a decline in total irrigation-water consumption (to 1394 km^3 from the baseline projection of 1480 km^3), and an increase in rain-fed area (by 4 million hectares over the base case) along with a decline in irrigated area (by 4.1 million hectares) with improvements in water productivity.

The validation exercise thus provides some clear insights into the implications of improvements in crop genetics, water-use efficiency, growth in irrigated area, and into making a shift in investments to the rain-fed areas. These scenario assumptions and results also provide useful policy implications for the RDS on several fronts. Some of the major implications that can be drawn from the existing forecasts and validation exercise for the RDS water-sector strategy are as follows:

- Productivity of agriculture as emphasized in the RDS paper would largely depend on improvements in WUE in irrigated areas and effective use of available rainfall in the rain-fed areas. All three studies considered the potential for improvements in the various facets of WUE and the likely contribution toward meeting the global water demand. These studies indicate the large potential for improved WUE for solving the growing water crisis and increasing agriculture productivity. The scope of policy intervention and investments in promoting WUE should consider basin-wide efficiency, as it would help to reduce the level of total water consumption, as shown by the IFPRI and IWMI studies.

- Investment strategies in irrigation and drainage infrastructures also need to be revisited. As shown by the IFPRI study, technology would play an important role in the improved WUE, in raising water productivity, and in solving future water-scarcity problems. Further, as illustrated by the IFPRI analysis, there is a need for a shift from addressing only productivity of land (kg per ha) toward water productivity (kg per unit of water applied), especially in the dry and semi-arid areas.

- The market-based instruments have been largely emphasized in promoting WUE and solving the water crisis. The revised forecasts considered linkage between intersectoral water demand and impacts of pricing policies on the future availability of water for irrigation (e.g., scenarios developed with some restriction of future water supply for agriculture with increased intersectoral water demand). Results indicated that while the demand for irrigation-water is expected to decline, availability of irrigation-water might increase because nonirrigation takes less water (the model assumes nonirrigation always takes the first priority in water supply) due to reforms in water-pricing policy.

- Likewise, as the scenario analysis carried out by the three agencies showed, although the domestic sector represents the smallest water user, it is the most rapidly growing sector, and the diversion of water to provide safe water to the majority of the rural poor as outlined in the RDS would have a significant impact on water availability for irrigation. The implications for the RDS is that the allocation of resources for augmenting additional freshwater in either sector should take place with examination of the possibility of generating additional employment and other direct benefits for the poor instead of maximization alone of a single objective of agriculture or industrial productions.

- The next important implication of the validation exercise bears upon the potential contribution of the water-harvesting techniques. The increased potential of rainwater-harvesting techniques in solving water-scarcity problems creates the need for the broadening of scope of irrigation-water investment programs to replace the conventional stress on large investments in building dams and reservoirs that can promote these techniques for effective utilization of rainfall potential.

- Achieving environmental sustainability is one of the changing priorities and criteria in the Bank's investment decision making. As is evident from the scenario results, the improvement in effective rainfall through the adoption of water-harvesting techniques combined with land- and water-management practices could significantly reduce the overdrafting of groundwater and generate local and regional environmental benefits, hence increasing the stocks of public goods. Thus, the Bank should focus on integrated land and water management programs in the rain-fed areas rather than focusing only on the large river basins.

The validation-exercise results also indicate that if the global communities have to reduce food deficit, the irrigated yield of all countries must be increased by an additional 27% over the base scenario. On the other hand, if the total production deficit is to be reduced through additional growth in rain-fed yield, the rain-fed yield is estimated to increase by an additional 22% over the base scenario. Increasing the potential for crop yields and closing the yield gaps is vital for solving water-scarcity problems and demands a coordinated effort between the CGIAR centers, FAO, and the World Bank.

THE WAY FORWARD

While the investigation so far has demonstrated that the various approaches used by FAO, IFPRI, and IWMI have identified important issues that affect the future of irrigated agriculture, it is clear that there are still issues that have to be investigated further. Such issues include the different concepts of WUE; the role of science and technology; the role of economic incentives; the issue of poverty; the impact on meeting the Millennium Development Goal of providing safe water to millions of the poor by 2015 and its impacts on intersectoral water demand; the interaction between irrigated agriculture and the environment;

the integration of irrigated agriculture in a global, institutional, and economic structure; and the social cost of the measures needed to bring about the change that will allow irrigated agriculture to continue its role as the fuel for the engine of rural growth.

To further distill our understanding of how future irrigated agriculture might meet the world's needs while sustaining the use of limited land and water resources, additional effort has to be made in both analytical work and dialogue among experts and policy makers. A first step could be that FAO, IFPRI, and IWMI join forces in improving the modeling capability. Indeed, IFPRI and IWMI have started to merge their two models, the IMPACT and the PODIUM, into one improved framework, recognizing the relative strengths and weaknesses in each. In this context, a few strategic collaborations with the partner agencies are suggested:

- First, the approaches and the results of the three analyses will be further shared via joint dialogues with more experts and developing-country policy makers in international forums (such as professional meetings, the Third World Water Forum, etc.). It is recognized that the present validation exercise is only the beginning of the long-term concerted effort that is needed in order to move the dialogue toward integrated irrigation and agricultural development that fall far beyond the aspects addressed in the work by FAO, IFPRI, and IWMI analyses.

- Second, it has been recognized that the potential measures that have been evaluated in the FAO, IFPRI, and IWMI analyses are only part of the equation. What is needed further is to provide a complete picture to the policy makers of the necessary investments. Therefore, quantification of the needed investment associated with each scenario of future development of the irrigated-agriculture sector is needed.

- Third, cooperation between the World Bank and the CGIAR centers should focus on the ongoing Millennium Challenge Program on Agriculture, Poverty and Combating Desertification in order to address both the water and food security needs as outlined in the Millennium Development Goals (MDG) and the WSSD Plan of Action.

- Finally, the forthcoming Water Sector Strategy of the World Bank should be fine-tuned to incorporate these major shifts and their implications in shaping the Bank's, and other development partners', investment decisions. The key strategic options based on the operational linkage between the RDS and outcomes of the validation exercise are suggested in section 6.

1. Introduction

1.1. Population, food, and water: present and future trends

1. Problems related to scarcity of water resources are increasing in many countries around the world. With increased population, the demand for food and fiber is expected to rise in the future. According to the United Nations' (midrange values) population projections, world population is likely to reach about 7.8 billion by 2025. The increased population pressure combined with per capita food consumption would obviously increase the demand for food and fiber, and thus, lead to more area under agriculture. The FAO study (FAO 2002) estimates that the world-average per capita food demand will exceed 3,000 kilo calorie by 2030 under the medium population variant scenario. Also by 2030, the total food demand and production of cereals is projected to be 2.8 billion tons. This increased demand for food would in turn push up the demand for irrigation water because irrigated agriculture is one of the major contributors to the supply of food and fibers in the world. With increased competition for scarce water and land resources, the concern is where the additional food will come from.

2. There are several projections of irrigation-water demand and supply by 2025 and 2030. The likely expansion of irrigated area and total water demand as projected by FAO study (FAO 2002) by the year 2015 and 2030 (from the base year 1997/99) suggests that the aggregate result for the group of developing countries shows that the area equipped for irrigation in this group of countries will expand by 40 million ha (0.6% per annum). This means that 20% of the land with irrigation potential not equipped at present will be brought under irrigation, and that 60% of all land with irrigation potential (402 million ha) would be in use by 2030. Likewise, the IFPRI study (Rosegrant, et al. 2000) projects the global potential irrigation-water demand to rise by 9.5% from 1758 BCM (billion cubic meter) in 1995 to 1924 BCM in 2021/25. This is similar to the projection made by IWMI (IWMI 2000). The IWMI study includes only 45 countries representing the major regions of the world and over 80% of its population. The results indicate that irrigation is, and will remain, the largest single user of water, accounting for about 68% of total diversions in 2025, although, compared with the other two sectors, the irrigation sector would be the slowest growing (by 17%) over that period.

1.2. Global projections of agriculture-water demand and matching the demand with the supply

3. These models have generated various scenarios that indicate future development in the water sector. The bottom line of the projections of the three models, however, is that in order to meet future food needs (in years 2025 and 2030), the irrigated agriculture area would need to expand by 15 to 20%, which necessitates the continuation of large investments for augmenting the water supply to meet the future irrigation-water demand. However, some of these studies also indicate that the future of irrigated agriculture is not so rosy and involves several physical and environmental constraints.

- *Constraints on availability of renewable water supply*: To meet the increased water needs, the world's primary water supply will need to increase by 22% in 2025 from the base year of 1995. Although agricultural water demand is not expected to exceed the available water resources, renewable water resources are being replenished annually through the hydrological cycle, and in the arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation would be larger than the irrigation potential. The existing storage volume, on the other hand, is being reduced by almost 1% per annum as a result of sedimentation, and the overdraft of groundwater is considered at 10% beyond the sustainable level. (IWMI 2000)

- *Land area constraints*: These likely reductions in the availability of water for irrigation combined with land resource constraints could directly reduce the irrigated harvested area and increase the year-to-year variability in irrigated area. In addition, the more water-scarce scenarios also indicate a likely reduction in the amount of water available per hectare in the remaining irrigated area. Likewise, there is a visible shift in the use of suitable land for irrigated agriculture to other uses due to urbanization and in a reduction in available land due to waterlogging and salinization and other forms of land degradation (FAO 2002).

- *Environmental impacts*: The net increase in the irrigated area in developing countries of some 40 million ha by 2030 will bring some environmental benefits because flat or well-terraced irrigated lands are not generally the cause of, or prone to, serious erosion. However, unless investments in larger water-use efficiency and drainage increase, the lowering of water tables, salinization, and waterlogging can further aggravate the situation. Overextraction of groundwater may push several million hectares of irrigated lands out of production (FAO 2002). Additional irrigation-induced environmental impacts include the loss of biodiversity and the deterioration of surface and groundwater quality and ecological services (some of which are important for food security like fisheries).

4. Knowledge of the future trends of irrigation-water demand and supply under different scenarios developed with basic assumptions of population growth and increased food demand. Some of the potential constraints, however, provides only partial information required for investment decision making and for managing the scarce water resources. In the past, large-scale investments in irrigation infrastructures were widely seen publicly as justified investments in the developing countries; however, with shrinking renewable water sources, increased cost of freshwater augmentation, limited public funding, etc., there is a need for a paradigm shift in the investment decision making process away from the conventional mode of financing the construction of large-scale dams and reservoirs in order to meet the future water demand. This further necessitates a more realistic projection of national and global water demand and supply, involving several options (or assumptions) related to some of these issues, which shape the development and management of scarce water resources in that changing context. Further, poverty reduction has been one of the changing paradigms of investment decision making in the rural areas. Past experience has shown that large public-sector investments in building dams and reservoirs have brought only limited benefits to the rural poor. How to make the public investment and international lending portfolios in the water-resources sector compatible to poverty-reduction efforts is another challenge. Thus, there is a need for a shift towards strategic investment decision-making which could deliver multiple benefits (e.g., food-security concerns, poverty alleviation, environmental public goods, etc.) in the rural areas.

1.3. Specific Objectives and Scope of the Validation Exercise Project

5. The Agriculture and Rural Development Department of the World Bank is in the process of issuing a rural development strategy aimed at directing future Bank activities in the rural sector. The irrigation subsector is a major player in the livelihood of people living in the rural areas. Because the results of the modeling efforts, or projections of irrigation-water demand and available supply, have direct implications for actions related to investment decision making and rural development, it is important to find whether the irrigated area and irrigation-water must increase to meet the needs of the future and to incorporate several of these issues to learn how the pattern of future irrigation-water demand and supply develops.

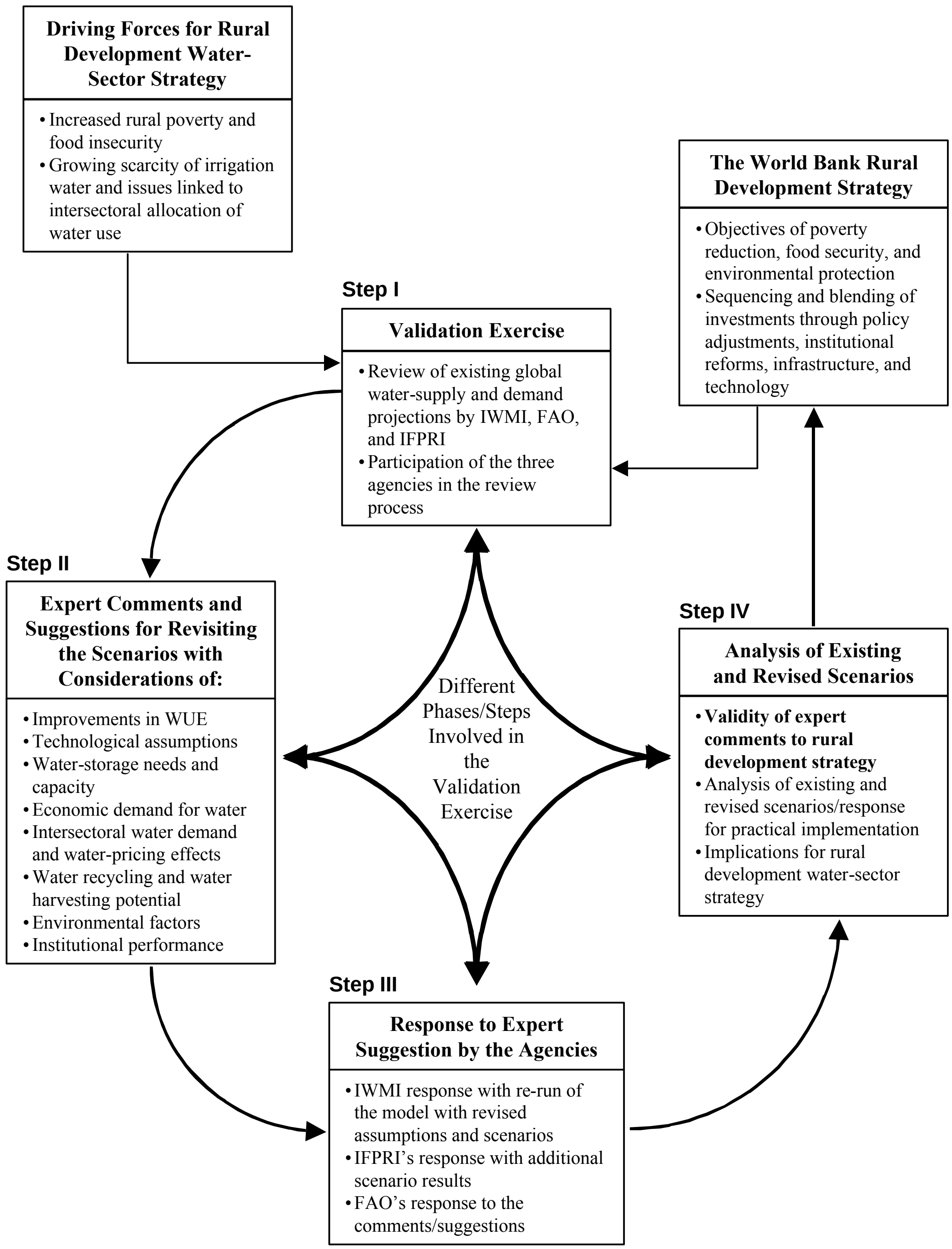
6. The specific objective of this validation exercise is to ensure that the models developed by IWMI, IFPRI, and FAO consider a balanced range of assumptions and scenarios; introduce additional assumptions and scenarios; and replace or fine-tune some of them. More specifically, the objective is to introduce into the forecasts the possible impacts of additional policy interventions and to evaluate their likely effects on the results. Figure 1.1 provides the conceptual framework of the process involved in this study.

7. A core team of experts (IWMI, IFPRI, and FAO modelers) was involved in the first phase of the validation exercise. Their input was further detailed and technically specified by a support team of technical experts. A menu of suggested modifications and their specifications was then shared with the agencies' modelers. Although all of the agencies principally agreed to participate and revisit the assumptions and alternative scenarios made, only some of the suggested scenarios were developed, and the exercise largely remains to be coordinated.

1.4. ORGANIZATION OF THE REPORT

8. The next chapter of this report summarizes the major assumptions made, scenarios developed, and results and analysis conducted by IWMI, FAO, and IFPRI. Chapter 2 presents a brief summary of each of these projections followed by a brief summary of the expert comments on these three exercises in chapter 3. Chapter 4 summarizes the model assumptions, scenarios, and results of the revised response from the three agencies as a part of the validation exercise. Chapter 5 discusses the various assumptions made and scenarios developed under different criteria and issues as raised by the group of experts. Chapter 6 attempts to summarize the findings and implications of this validation exercise for the World Bank and other partner organizations. Finally, conclusions of the validation exercise are provided in chapter 7. A more detailed review of the projections made by the three agencies, expert comments and suggestions, and summary of the revised response to expert comments and suggestions is presented in the various appendixes.

Figure 1.1 Conceptual framework: prospects of irrigated-agriculture validation exercise



2. IWMI, FAO, and IFPRI Projections of Future Irrigation-Water Demand and Supply

9. This chapter provides a brief summary of the major assumptions made, scenarios developed, analysis conducted and results found in the "Policy Interactive Dialogue Model" (PODIUM) developed by IWMI; the FAO projection study, "Agriculture: Towards 2015 and 2030," on the likely expansion in irrigated area and total water demand by 2015 and 2030; the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model for the projection and analysis of food supply and demand; and the Water Simulation Model (WSM) model for projections of water supply and demand by IFPRI. The detailed review and references to each of the exercises are provided in appendix A-2.0.

2.1. IWMI PROJECTIONS OF FUTURE WATER DEMAND AND SUPPLY BY 2025

Introduction to the model

10. The PODIUM consists of two versions: the country model and the global model. The version of the model reviewed in this brief summary is the global model that includes 45 countries that represent the major regions of the world and over 80% of the world's population, as well as a less detailed analysis of 80 countries that has been used in the preparation of a water-scarcity map (IWMI 2000). In this application of PODIUM, the model is used to test the three scenarios: i) base business-as-usual; ii) no growth in irrigated lands; and iii) growth in irrigated lands. In all of these scenarios, the year 1995 is taken as a base year to represent the actual situation, while the year 2025 stands for the future situation. The global-level model is presented in Excel Spreadsheet format, and the results obtained from the individual country model are grouped to provide a global scenario of water demand and supply by 2025.

Model components and basic assumptions

11. The model framework and the methodological process adopted for the projection of water demand and supply for irrigated agriculture include the following four major components: i) estimation of national food requirements based on assumptions concerning population growth, daily calorie intake, and the composition of diets, etc.; ii) projection of cereal production based on the expected yields and cultivated area under both irrigated and rain-fed conditions; iii) conversion of projected food production into water demand and comparison with the base year case; and iv) analysis of the results by grouping the countries by the degree of water scarcity, assuming several criteria for classification of water scarcity. The model makes explicit assumptions regarding population growth, diet composition, food production, global food trade, hydrological aspects, intersectoral water allocation/needs, environmental aspects, and policy, institutions, and technology.

Scenario results and implications

12. Overall results of the study for the 45 countries under the IWMI base scenario indicated that: i) by sector, irrigation is, and will remain, the largest single user of water, accounting for about 68% of both to-

tal diversions and primary water supply (PWS) in 2025; and ii) the domestic sector is the smallest sector, at only 11% of diversions, but is the most rapidly growing sector, with an increase of 84% over the period. The no-growth scenario showed less demand for irrigation-water and therefore less strain on water demand with substantial deficits in cereal production in south Asia, east Asia, and in sub-Saharan Africa. Major implications of these scenario results include: i) meeting increased water demand by 2025 needs—the world's PWS to increase by 22%; ii) consideration of factors like the continued reduction in water-storage capacity of the existing reservoirs (assumed at -1% per annum) as a result of sedimentation and the overdraft of groundwater (assumed at 10% beyond the sustainable level), which indicates that the total amount of additional water storage and conveyance required by 2025 would effectively reflect a 41% increase in PWS; and iii) though the linkage between irrigation-water withdrawal and water demand in other sectors of the economy was not addressed, consideration of intersectoral (domestic and industrial) water demand indicates the growing competition over water available for irrigation by 2025.

2.2. FAO PROJECTIONS OF FUTURE WATER DEMAND AND SUPPLY BY 2015 AND 2030

Introduction to the FAO exercise

13. The FAO study, "World Agriculture: Towards 2015 and 2030," projects the likely expansion in irrigated area and total water demand by 2015 and 2030. The projections made, however, do not correspond to the extrapolations of past trends, and in fact, deviate from them. The base year for the study is the three year average (1997/99) and the projections are made for the years 2015 and 2030. The year 2015 was chosen in order to assess the prospects for progress towards meeting the goal of the 1996 World Food Summit (WFS) of halving the number of chronically undernourished persons in developing countries by no later than 2015. The time horizon of 2030 is chosen to offer a sufficiently long period to analyze technical issues of agriculture and sustainability.

Model components

14. Irrigation potential in the FAO 2015 and 2030 study is considered as area of land suitable for irrigation development (including land already under irrigation). Methodologies used in assessing irrigation potential vary from one country to another. In most cases, it is computed on the basis of available land and water resources, but economic and environmental considerations are also taken into account to a degree. Except in a few cases, no consideration is given to the possible double counting of water resources shared by several countries, and this may lead to an overestimate of irrigation potential at the regional level. The model includes three components: i) projection of commodity demand-supply balances (Supply Utilization Accounts); ii) development of Global Agro-Ecological Zone (GAEZ) database on agro-ecological classes and identification of potential suitable areas for rain-fed and irrigated agriculture; iii) generation of land use balances in great detail (by agro-ecological classes and with distinctions between harvested and arable land); iv) computation of actual crop area, yield, cropping intensity, etc., for the base year (average of 1997–99 database) and projections for the years 2015 and 2030 by agro-ecological zones for the 93 developing countries; and v) computation of water balance and water withdrawals by 2015 and 2030 and calibration of the water balance results by comparing calculated values for water resources per country. The basic assumptions and preliminary computations are made in areas of: i) socioeconomic aspects (population); ii) the GDP growth rates; iii) land area, crop yields, and crop production by agro-ecological zones and countries; iv) rainfall, surface runoff, and crop water requirements and water-use efficiency; and v) food security concerns.

Scenario results and implications

15. The water balance for each country and year is defined and computed without accounting for water withdrawals for other needs (industry, household, and environment). The projection consists of only one scenario—i.e., the base-case scenario. The results of the projection exercise, in general, indicated: i) that for the group of developing countries, the area equipped for irrigation will expand by 40 million ha (or 20%) over the projection period; ii) that the harvested–irrigated area will expand by 84 million ha, which accounts for almost half of the increase in all harvested land; iii) that the projected net increase in arable irrigated land of 40 million ha is less than half of the increase over the preceding 36 years (99 million ha); iv) that the share of irrigated agriculture to total cereal production is expected to increase from 59% in 1997/99 to 64% in 2030; and v) that for the 93 countries, irrigation-water withdrawal is expected to grow by about 14% (from the current 2128 km^3/yr to 2420 km^3/yr in 2030). This increase is much lower compared to the increase projected in the harvested–irrigated area, from 257 million ha in 1997/99 to 341 million ha in 2030. Most of this difference is explained by the expected improvement in irrigation management.

16. The study has several important policy implications. For example, the assessment of irrigation potential already takes into account water limitations, and the global water projections for 2030 assume that agricultural water demand will not exceed available water resources. In those arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is likely to be larger than the irrigation potential. In terms of water scarcity, those countries suffering from a lack of precipitation, and therefore most in need of irrigation, are also those where water resources are naturally scarce. Finally, the net increase in the irrigated area in developing countries of some 40 million ha by 2030 will have environmental benefits because flat or well-terraced irrigated lands are not generally the cause of, or prone to, serious erosion. However, unless there is increased investment in greater water-use efficiency and drainage, there could be growing problems from the lowering of water tables, salinization and waterlogging. In addition, overextraction of groundwater could result in several million ha of irrigated lands falling out of production.

2.3. IFPRI PROJECTIONS OF IRRIGATION-WATER SUPPLY AND DEMAND BY 2025

Introduction to the IFPRI model

17. The IFPRI study (Rosegrant 2001) attempts to project and analyze how water availability and demand would evolve over the next three decades (from base year 1995), taking into account the availability and variability in water resources, the water-supply infrastructure, irrigation and nonagricultural water demands, and the impact of alternative water policies and investments on water supply and demand. The study uses the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model for the projection and analysis of food supply and demand and the Water Simulation Model (WSM) for projections of water supply and demand. Both the water supply and demand and food production is assessed at the river-basin scale. Crop production is summed to the national level, to which food demand and trade are modeled. The study also attempts to project irrigation-water demand under several alternative scenarios and consider changes in irrigated area and cropping patterns, change in water-use efficiency, change in rainfall-harvest technology, and change in water allocation among sectors, as the main drivers of policy shifts. Although global climate change could also significantly affect future irrigation-water supply and demand, this aspect is not directly incorporated into the current modeling framework.

Model components and basic assumptions

18. The model consists of three components: i) the projection of food demand and supply using the IMPACT model; ii) the development and use of the Water Simulation Model (WSM) for the estimation of water supply and demand (water balance at the river-basin level) and analysis of alternative scenarios; and iii) the integration of the IMPACT and WSM models for analyzing impacts of water-supply constraints on the food production, trade, and food-security concerns. The baseline assumptions and computations are made regarding: i) food production, demand, and trade year-to-year over the next 30 years; ii) hydrological aspects (effective rainfall, renewable water resources, and total water availability); iii) limits to water withdrawal or water supply for agriculture; and iv) technology (e.g., water harvesting and tillage practices).[3] The alternative scenarios include: i) low infrastructure investment (LINV) scenario; ii) high-M&I water demand (HMI); iii) the sustainability scenario: low groundwater pumping (LGW); and iv) low irrigated area and low water withdrawal (LIA-LWW) scenario.

Scenario results and implications

19. The results under the alternative scenarios (LINV, HMI, and LGW) indicated the reductions in the availability and reliability of water supply. The reduction in the amount of water available for irrigation is large under these more water-stressed scenarios, with the biggest reductions shown in the developing countries. Second, the reduction in availability of water for irrigation directly reduces the irrigated harvested area and increases the year-to-year variability in irrigated area. For example, irrigated area in the world declines by 8 million ha on average between 2021–2025 under the low-investment in irrigation scenario and by 4 million ha under the HMI. In addition to reducing the irrigated area harvested, the water-scarce scenarios reduce the amount of water available per hectare in the remaining irrigated area. Finally, there could be a significant drop in irrigation-water supply (or effective demand) for alternative scenarios compared to the baseline in 2025. The LGW scenario contains smaller impacts on these large regional averages, because the impacts are concentrated in the basins that have an overdrafting of groundwater.

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[3] For a comprehensive report of these and additional scenarios see Rosegrant, M. W., Cai, X., and S.A. Cline (2002).

3. Expert Comments on the Past Modeling Exercise, Assumptions, and Scenarios

20. This section briefly outlines the major issues raised and suggestions provided by the group of experts as part of the validation exercise. A summary of expert comments general to all of the studies, and specific to each of the studies by IWMI, FAO, and IFPRI, is provided in appendix A-3.0.

3.1. The Potential for Improving Water-Use Efficiency and the Validity of the Assumptions Made

21. In regard to assumptions related to Water-use efficiency (WUE), experts noted that none of the models have adequately taken into account the improvement in water-use efficiency (crop productivity per unit of evapotranspiration) that can be anticipated in the next 30 years in both rain-fed and irrigated areas.[4] These improvements will result from improvements in crop genetics, cultivation technologies (tilling, mulching, fertilizing), on-farm irrigation (soil-moisture management), and deficit irrigation in water-short areas. There are huge tracts of waterlogged/salinized land with low or zero yields that are presently producing vast amounts of unbeneficial evapotranspiration. Improvements in drainage conditions, the lowering of water-table and salt-leaching activities could result in a great increase in production with little increase in actual water consumption. The three models assume that the performance of the existing infrastructure will be improved (through rehabilitation and policy reforms), and consequently, the water-use efficiency, the cropping intensity, and the crop yields will increase consistently. However, these assumptions have to be backed by some reasoning, and the risk of failure has to be incorporated in the analysis through use of sensitivity analysis in both directions.

3.2. Taking into Account Technological Changes in Water Use and Improved Water-Use Efficiency

22. The experts also noted that there is a need to account for the contribution of genetics and the adoption of new crop varieties, particularly the opportunity to enhance drought-tolerant crops. The low-adoption rates of new varieties of crops by farmers are the result of the low-reliability of the irrigation-distribution system. These two factors have to be re-evaluated and incorporated into the models. Although some of the models (IFPRI's, for example) take into account some technological changes, one could expect assumptions regarding improvements related to in-situ water delivery (as in drip for vegetables or fruit trees), increased efficiency of plants in water use, increased plant tolerance to low-quality water (high-salinity, etc.) and increased plant tolerance to stress (low water availability), to cite a few of the perhaps most important ones to be included in the models. Equally, the social dimension (water users' associations and related) has been of critical importance to the success or failure of projects—and the multilateral and regional development banks have a lot of experience with this. Inclusion of such contributions in the mod-

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[4] See appendix A for the definition of water-use efficiency.

els would be positive, as they would better reflect possible rates of success/failure of the new technologies.

3.3. The need to consider institutional aspects of irrigation project performance

23. The major assumptions (or the scenarios) made in the global projection exercises should also attempt to clarify their "implementability." For example, the operation and maintenance performance by both irrigation agencies and irrigators on government-operated, gravity-fed irrigation schemes in developing countries in Asia (the largest irrigated areas of the world) is generally dismal. Likewise, little has been achieved in the restructuring of irrigation agencies and private-sector participation within a sector of broader national reforms. In addition, assumptions should include the impacts of efficient water charge combined with management schemes for appropriate fee collection and good management for ensuring water-service delivery. In any event, considerable investment combined with institutional changes would be needed to achieve the assumptions made in the various scenarios used in the three models.

3.4. Consideration of water demand for environmental purposes

24. Expert opinion also reflected the growing perception of the environmental community that water withdrawal for irrigation should be reduced, not increased, and this has to be well-reflected in the modeling exercise. Although this aspect has been dealt with in the IWMI and IFPRI exercises, other aspects of environmental demand, such as the decrease in irrigated area due to increased salinization and projections of water demand with consideration of the impacts of global climate change (e.g., likely droughts, increase in water demand due to increased evapotranspiration, CO_2 fertilization effects, farmers adaptation practices, etc.) were not considered, and efforts need to be made in this direction.

3.5. Consideration of water-storage needs and capacity

25. How much additional reservoir storage needs to be built, and to what extent would it be feasible? Experts note that these questions are of much importance when addressing the feasibility and "implementabilty" of water-storage needs and capacity. The adding of 621 km^3 of water over the next 25 years as projected by the IFPRI study also deserves further analysis, particularly in light of the latest report of the World Commission on Dams and the uproar that any new dam causes around the world. Experts also asked whether it is financially, economically, socially, and environmentally possible to build so many large dams in the next 25 years. To what extent have the costs been estimated and the feasibility of solving the associated financing aspects been studied?

3.6. The need to consider projections of economic demand for irrigated areas

26. Some of the experts noted that the studies are directed more toward determining irrigation "requirements" to meet projected demand for agricultural commodities than toward projections of the economic demand for irrigated area or for irrigation capacity. In their opinion, it looks as if the models are seeking to address the question, How much irrigation will be needed? But that is a technocratic, central-planning

approach and intrinsically not a very useful question. How much extra irrigation will become available in the next quarter century? is a much more useful question, but it leads immediately to, How much extra irrigation will be profitable in the next quarter century? That would lead to some really useful directions.[5]

3.7. Estimation of agriculture-water demand from different perspectives

27. The experts emphasized that the models adopted should discriminate between a wide range of concerns or linkages. These include: i) areas without irrigation and drainage systems; ii) rain-fed areas with drainage systems; iii) irrigated areas without drainage systems; and iv) irrigated areas with drainage systems. Likewise, the more appropriate question to be explored under different scenarios analyzed should be, What would be required in terms of changes in water-use efficiency, cropping intensity, yields, and prices (both for grains and water)? The question necessitates computation of the additional water agriculture that would be needed to feed an expected population at some future date (for example, 2025) with assumptions about improvements in water-use efficiency, irrigation intensity, and crop yields. The inevitable outcome is that more irrigated area is needed and agriculture will require more water to be able to feed the world. The estimates from the various models are in the range of 20–40% increases in irrigated area and increases of above 10% in water "needed." The obvious outcome is to underline the increased importance of irrigated agriculture for global food security.

3.8. Consideration of intersectoral water demand and water-pricing effects

28. Although two of the models by IFPRI and IWMI consider urban and industrial demand for water, the models' treatment of prices is incomplete: the product prices are endogenous only in the IFPRI model, and none have endogenous water prices.[6] The water aspect of each model is technical and mechanistic. There is no doubt that water will increasingly need to be priced in order to ration it, and thus, there is a need to explore consequences for water pricing.

3.9. Water recycling and harvesting aspects

29. The experts attempted to draw the attention of the modelers toward looking into alternative options for increased water supply. Especially in the arid and semi-arid areas, there is a need for considerations of additional sources of water other than the augmentation of freshwater resources, as there is a lot of available brackish water that can be used for certain crops or as a supplement to freshwater. In addition, other options, such as water availability through the recycling of sewage water, need to be considered as alternatives to the use of freshwater for irrigation. Likewise, systems based on the collection of runoff water

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[5] The IWMI and IFPRI studies should be differentiated on this question. IWMI does in fact use a normative approach to assess how much irrigation is needed to meet a specific food demand, but the IFPRI study estimates available and realized irrigated area based on projections of many underlying drivers and under a wide range of scenarios. Irrigated area is endogenous and a function of hydrological, investment, nonirrigation-water-demand growth, water prices, and other factors. The reviewer, however, is correct regarding the importance of the issue of profitability—or better put, the relative cost-effectiveness of irrigation expansion compared to other investments, including water-efficiency enhancement and agricultural research.

[6] IFPRI added water prices to the model—in part in response to review comments. IFPRI's water-price scenario can now be utilized (Rosegrant, et al. 2002).

are viable approaches to afforestation in arid and semi-arid zones. Many deserts are characterized by winter rainfall with rare runoff pulses. The time interval between runoff events is of the order of one year, with an extremely hot and dry period in between, and it is therefore advantageous to store the largest volumes of water during a runoff event. Water will deeply percolate into the soil, increasing soil-moisture availability, which in turn will allow trees, annual crops, or a combination of both to grow.

30. In addition to these general comments on all of the exercises, the group of experts provided comments and suggestions specific to each of the studies. The additional details on the experts' comments and suggestions are provided in appendix A-3.0.

4. Revised Response: Scenario Assumptions and Results

4.1. IWMI'S REVISED ASSUMPTIONS, SCENARIOS, AND RESULTS

Introduction to the IWMI validation exercise and scenario results

31. Most of the comments on IWMI's exercise were linked to the assumptions of growth of irrigated and rain-fed yield, growth in irrigated area and intensity, irrigation efficiency, and changes in NET and non-crop evaporation, etc. IWMI specifically tried to revise the scenarios relating to: i) improved WUE; ii) the impact of technological change on water use; iii) the demand for irrigation lands; iv) the demand for water in other sectors; and v) the demand for water for environmental purposes. The IWMI responded by re-running the PODIUM model assuming higher or lower growth rates for appropriate parameters from the levels that were assumed for the base scenario. They analyzed five alternative scenarios. Table 4.1 provides the summary of IWMI scenario assumptions and results. The detailed, revised response is presented in appendix A-4.1.

4.2. IMPLICATIONS OF IWMI REVISED RESPONSE

32. In addition to the IWMI original exercise, the revised response with seven alternative scenarios provides several meaningful implications for matching water demand with supply. These are:

- The problem of water scarcity and of matching the demand with supply needs a holistic approach rather than the conventional one of augmenting freshwater to meet the increased demand. It is equally important to improve crop genetics and water-use efficiency, which in combination would significantly reduce pressure on land and water and also help meet the future food demand.
- The lack of improvements in crop genetics and crop yields in both the irrigated and rain-fed areas coupled with irrigation intensity would result in an increase in the primary water supply and in substantial production deficits in most of the developing countries.
- A reduced growth rate in net irrigated area combined with partial improvements in water-use efficiency would prove disasterous to the goal of achieving food security; while PWS would increase, food production would sharply decrease.

33. Likewise, a slight growth in cereal-growing area and a partial increase in irrigation intensity would not prove to be an effective way to meet the world demand for food by 2025, and with decreasing cereal-growing area due to urbanization and land degradation, there is a need for a substantial increase in irrigation-water intensity. If the global community is to reduce the food deficit, the irrigated yield of all countries must be increased by an additional 27% over the base scenario. On the other hand, if the total production deficit is to be reduced through additional growth in rain-fed yield, the rain-fed yield would need to increase by an additional 22% over the base scenario. The scenario would be worse if intersectoral water demand is taken into consideration. Thus, increasing crop yields in both the rain-fed and irrigated areas is a challenge, and solving water scarcity problems requires a holistic approach combining different disciplines.

Table 4.1 Revised IWMI assumptions and scenario results

Revised Scenarios	***Assumptions***	***Scenario results***
AS11	▪ This scenario assumes that improvements in crop genetics and adoption of new varieties (especially drought-tolerant crops), cultivation technologies, on-farm irrigation management, and in drainage will results in higher yields in both irrigated and rain-fed yields and higher growth of irrigation efficiency. In addition, the scenario assumptions include lower non-crop evaporation rates. ▪ This scenario attempts to address experts' concerns regarding improvements in crop genetics, water-use efficiency and technological changes in water use.	▪ Likely improvements in crop genetics, while resulting in a significant increase in net cereal-production surplus (e.g, 165 M MT for 100 developing countries) in 2025, would also reduce the growth in irrigated area (by 15%) and PWS by 22% when the improvements in crop genetics are linked to the improvements in irrigation efficiency (assumed to increase by 50%).
AS12	▪ In addition to the assumptions made under the scenario AS11, this scenario assumes that improved crop genetics and the adoption of new technologies would also result in lower net evapotranspiration.	▪ Under this scenario, the growth in irrigation PWS would be reduced by 6% compared to scenario AS11 and by 8% from the base case. The growth of total PWS for all countries is 18%, a reduction of 4% from the AS11 scenario and a reduction of 6% from the base case.
AS13	▪ Required growth in area parameters under scenarios AS12 would have zero production surplus/benefit at the world level.	▪ An assumption of less growth in net irrigated area, combined with high growth in irrigation intensity, would result in an increase in PWS for all countries (by 7%, a reduction of 10% from the base scenario). The growth in total PWS is thus expected to increase only 16% under this scenario compared to 24% in the base case.
AS21	▪ The risks of failures of the assumptions in the base scenario are addressed in this scenario. It assumes lower growth in both irrigated and rain-fed yield and lower growth in irrigation-application efficiency compared with the base-case scenario. ▪ This scenario attempts to address experts' concerns regarding improved WUE and the demand for irrigation water.	▪ The lack of improvements in crop genetics or crop yields in both the irrigated and rain-fed areas coupled with irrigation intensity would result in substantial production deficits in most regions (e.g., total production deficit at the world level to 180 M MT). The PWS is also expected to go up by 21%, which is 3% more compared to the base case as a result of a decrease in WUE.
AS22	▪ In addition to the assumptions in AS21, reduced growth in area parameters is also assumed. It assumes lower growth in total cereal-growing area, net irrigated area, and irrigation intensity.	▪ Assumptions with reduced growth rate in net irrigated area and an only 50% increase in irrigation intensity would result in reduction in PWS (only by 13%, which is 4% lower than in the base case). The production deficits, however, would go up to 247 M MT, which is equivalent to 10% of the total food consumption by 2025.

Table 4.1 Revised IWMI assumptions and scenario results

Revised Scenarios	***Assumptions***	***Scenario results***
AS31	▪ This scenario assumes no growth in irrigation, primary-water supply and attempts to address expert concerns about agricultural water demand from different perspectives.	▪ Less irrigation PWS is available in 2025 compared to 1995, and the growth of irrigation intensity of all countries under this scenario is 3% less than the base scenario. ▪ This scenario also results in substantial production deficits. The total production deficit (210 M MT) of all countries is equivalent to 9% of the total 2025 consumption. Next, if the total production deficit is to be reduced through additional growth in irrigated yield, the irrigated yield of all countries is estimated to increase by an additional 27% over the base scenario. The irrigated yield of all countries would increase from 3.32 MT/ha in 1995 to 4.65 MT/ha under the base scenario to 5.54 MT/ha under scenario AS31. On the other hand, if the total production deficit is to be reduced through added growth in rain-fed yield, the rain-fed yield is estimated to increase by an additional 22% over the base scenario.
AS41	▪ This scenario assumes no growth in total primary water supply and attempts to address experts' concerns regarding agricultural water demand (including for environmental purposes).	▪ The scenario analysis with consideration of intersectoral demand (assuming a reduction in PWS by 16% from the 1995 level to meet the demand of domestic and industrial sectors) would result in even higher production deficits compared to Scenario AS31. If the additional production deficit of all countries due to increased competition for water in other sectors is to be reduced through the growth of irrigated and rain-fed yield, the crop yield of all countries would be required to increase by an additional 39% and 26% in irrigated and rain-fed areas, respectively, by 2025 over the base case.

4.3. FAO'S RESPONSE TO EXPERT COMMENTS AND SUGGESTIONS

34. FAO responded to the experts' comments and suggestions with brief clarifications on each of the issues raised. It is noteworthy that the FAO exercise is largely based on expert judgments and has several restrictions when revisiting some of the assumptions and developments of the scenarios outlined by the experts. FAO's response as part of the validation exercise mainly addresses the issue of WUE, technological and environmental aspects, economic demand for irrigation water, estimation of water requirements for cotton crops, etc. In addition, FAO's response to the specific comments on their exercise includes the assumptions made on the estimation of actual evapotranspiration; use of traditional technical-efficiency of water use; assumption on area rehabilitation for irrigation; food supply and demand related to trade; etc. The FAO response does not include any revised scenario or results. The detailed response is provided in appendix A-4.2.

4.4. IFPRI'S RESPONSE TO EXPERT COMMENTS AND SUGGESTIONS

35. The IFPRI responded to the experts' comments and suggestions by revisiting some of the scenario results in regard to: i) linking water-use efficiency to the concept of water productivity; ii) the impacts of crop genetics (with assumptions on potential increase in crop yields in both the rain-fed and irrigated areas); iii) the impacts of water crises associated with the lack of investments in irrigation development; iv) the impacts of increasing water supply from water-harvesting techniques; and v) the impacts of water pricing and effects of intersectoral water demand. The IFPRI provided clarification of several issues raised by the experts. These included environmental considerations such as climate change, institutional performance, and other aspects. Finally, IFPRI responded to the specific issues raised by the experts on the assumptions made and scenario analysis. The detailed response is presented in appendix A-4.3.

Revised scenarios and assumptions

36. The IMPACT model considers both basin-wide WUE and potential contribution of water-harvesting techniques for supplemental irrigation-water demand in the rain-fed areas. The model assumes that water-harvesting techniques could be adopted more cautiously to provide farmers with improved water availability in some local and regional ecosystems. The following three of the revised scenarios analyzed considers the improvements in the effective use of rainfall (Rosegrant, et al. 2002):

Scenario 1: This scenario assumes no improvements in effective rainfall use (NIER). The baseline scenario assumes improvement in effective rainfall use by 3–5%.

Scenario 2: This scenario assumes low-investment in irrigation development and water supply but an increase in rain-fed area and yield (LIV-HRF).

Scenario 3: This scenario assumes low-investment in irrigated areas but with some investments in rain-fed areas. It assumes low-investment in irrigation development and water supply but an increase in effective rainfall use (LIV-HIER).

Scenario 4: This is a sustainability scenario with restrictions on groundwater pumping but with larger rain-fed agriculture development. This scenario assumes a groundwater-overdraft phasing-off, with larger rain-fed agriculture development, and a bigger improvement in effective rainfall use.

37. Other scenarios developed include considerations of intersectoral water demand, treatment of water prices, and subsidies. Regarding intersectoral water demand, the IFPRI model tries to solve problems of supply, demand, trade, and commodity prices but does not attempt to run scenarios incorporating self-sufficiency as a goal or policy. Some scenarios are developed with higher water prices relative to the baseline scenario, and results are currently being assessed. Water prices are differentiated by sectors and by the developing and developed world.[7]

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[7] We are indebted to Mark Rosegrant, who was easily convinced to incorporate prices into the IFPRI's model. This model was published in Rosegrant and Cai (2002) and in Rosegrant, Cai, and Cline (2002). Mark Rosegrant also allowed us to use the excerpt from the latter publication, which reads: "The results presented in this chapter show that water prices are a powerful tool for influencing water demand in domestic, industrial, and agricultural sectors—and therefore in determining the availability of water for the environment. Even though the water demand response to water prices is relatively small in agriculture, the total amount of water saved through water price increases is large because irrigation accounts for such a large share of water use. Conversely, although water consumption in domestic and industrial is relatively small, the price response is high, so these sectors also contrib-

Revised scenario results

38. The base scenario developed from the conditions used to estimate water productivity in irrigated and rain-fed areas. It was created by taking into account the impact of technology and management improvement and investment in water productivity and by searching for potential ways to improve food security through enhanced water productivity. Both the increase of crop yield and the improvement in basin efficiency were expected to contribute to the increase in water productivity, with a major contribution coming from the crop yield increase. The scenario results indicated that:

- Water productivity (crop yield per unit of ET) of rice ranges from 0.15 to 0.60 kg/m^3, while that of other cereals ranging from 0.2 to 2.4 kg/m^3 in 1995. Under the baseline scenario of the analysis, from 1995 to 2025, water productivity will increase—the global average of water productivity of rice will increase from 0.39 to 0.52 kg/m^3, and the global average of water productivity of other cereals will increase from 0.67 to 1.01 kg/m^3.

- The results indicated that water productivity of irrigated crops is higher than that of rain-fed crops in developing countries but lower in developed countries. This shows that in developing countries, irrigated agriculture is more efficient in resource utilization and food production than rain-fed agriculture. However, the results also point to the untapped potential for increased water productivity of rain-fed crops through research and infrastructure investment.

- With the low-investment in irrigation development and water supply but high increase in rain-fed area and yield (LIV-HRF), rain-fed area is expected to increase significantly (by 6 million hectares and an 11% increase in rain-fed yield with an additional 183 million tons increase in rain-fed production). This would result in a 256 km^3 decline in water consumption (an 18% decline in comparison to the base case). The potential reduction in irrigated cereal production of 170 million tons would thus be completely offset by the increased investment in promoting water-harvesting techniques in rain-fed areas.

- Even with low-investment in irrigation development and water supply and a higher increase of effective rainfall use, the total water consumption and irrigated area is similar to that of the LIV-HRF scenario. This scenario had 1215 km^3 in irrigation-water consumption; although the projected improvements in effective use of rainfall water would not fully compensate for the decline in production due to low-investment in irrigation development.

- The gradual replacement of groundwater overdraft with larger rain-fed agriculture development, coupled with an improvement in effective rainfall use is expected to cause a decline in groundwater pumping (by 169 km^3); total irrigation-water consumption (from 1480 km^{3}to 1394 km^3); and an in-

ute substantially to water savings. Even under the worst-case scenario where water prices have no impact on basin efficiency [BE], the large percentage changes in water prices have relatively modest impacts on food production. These modest impacts occur because the water price response is low in agriculture, the declines in irrigated production cause increases in food prices that induce more rain-fed production (and partially mitigate the fall in irrigated production), and in a few water-scarce regions where water use is constrained by water availability rather than by water prices, a portion of the water released from nonagricultural provides additional water for irrigation. In the more likely case that there are at least moderate increases in *BE* in response to increases in agricultural water prices, beneficial water consumption for irrigation is maintained at nearly the [Business-as-Usual] (BAU) levels, even though total consumption declines when water prices increase. Even severely water-scarce river basins such as the Yellow and the Indus basins are able to compensate for water price increases and achieve water use efficiencies, irrigation reliability, and cereal production nearly equal to—and in some cases slightly higher than—BAU levels. The major beneficiary in the higher price scenarios is the environment. The dramatic reduction in the ratio of withdrawals to total water availability in response to price increases means a significant improvement in water quality as the reuse of water declines, and the reduction in water withdrawals provides a major increase in environmental flows."

crease in rain-fed area (by 4 million hectare over the base case) with a decline in irrigated area (by 4.1 million hectares).

Implications of revised scenario results

39. Although the IFPRI response still leaves several of the experts' comments and suggestions unanswered, the revised scenarios bear significant implications for investment decision making in solving the growing water crisis. These include:

- The impact of technology and investment on rain-fed areas has the potential to improve food security through enhancing water productivity. As the scenario results indicated, both the increase in crop yield and the improvement in basin efficiency were expected to contribute to an increase in water productivity (major contribution coming from the crop-yield increase).

- While the future demand for food production to achieve global food security would continue to largely depend on food production in irrigated areas, the rain-fed areas also could play a significant role. They could do this if investments are made to increase the potential of these areas through rain-water-harvesting techniques along with genetic crop improvements and soil-fertility improvements.

- With the future of growing competition for water and environmental externalities of water use, larger investments in rain-fed areas would help in reducing groundwater withdrawal, which has been unsustainably used in many developing countries.

5. Discussion on the Existing Forecasts and Revised Scenarios

5.1. Considerations of improvements in water-use efficiency

40. Water-use efficiency (WUE) is a function of both hydrological and socioeconomic variables. The definition of WUE assumed in the models varies and, therefore, so do the potential for improvements in WUE.[8] The IWMI's revised scenario uses the term "water-application efficiency" to define WUE and provides estimates of global water demand under two assumptions. The first is the increase in the total growth of irrigation efficiency by 50% over the base case (revised scenario AS11). The second is the total growth of irrigation efficiency of each country to only 50% of the growth rate of the base scenario.[9] The revised scenario (AS11) also assumes noncrop evaporation as a percentage of irrigation drainage to decrease by 5% from the base case. The model outputs corresponding to these two assumptions indicated some reductions in required primary-water supply (PWS) by 3% and 2%. The growth of total PWS is by only 15% and 22% by 2025 compared to the base case.

41. The IFPRI exercise considers higher basin efficiency (HBE) improvements globally in the next 25 years. The average basin efficiency for the base year 1995 is assessed at 0.56 globally (0.53 in developing countries and 0.64 in developed countries). The model output under these assumptions indicated a decline of 13% water withdrawal in developing countries and of 7% in the developed countries compared to the base case. The water consumption is expected to decline by 19% in the developing countries and 17% in developed countries.

42. The FAO study adopts the conventional concept of WUE. The irrigation efficiency is assumed to reach 44% from the base–year-level efficiency of 38%, a 4% point increase over 32 years. By region, the increase in irrigation efficiency would be more pronounced in water-scarce regions (e.g., a 13% increase in the Near East/North Africa region) than in regions with abundant water resources (between 0–4% in Latin America and sub-Saharan Africa). The projection scenario provides only the base case and is presented in appendix A-2.2.

Conclusions

- The improved WUE would help in reducing total global irrigation-water consumption significantly, and national governments and international agencies should concentrate their efforts on improving the different facets of WUE.
- The demand for improved WUE—and hence efforts toward improving irrigation efficiency—would mostly take place in water-scarce areas, such as in the Near East, North Africa and south Asia.[10]

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[8] See appendix A-1.0 for the definitions of WUE used by these agencies.

[9] See appendix A-4.1 for IWMI's revised assumptions and scenario results.

[10] One reviewer "doubt[s] if there is much gain to be made by increasing irrigation efficiency in the Near East and North Africa, because of already high basin efficiencies. There may be good reasons for increasing efficiency, like less pollution or better ser-

Some countries in these regions are also increasingly facing food production problems and efforts toward solving these problems should be combined with applications of various means (economic, physical, and institutional) to improve WUE.

- Efforts to improve WUE should address basin-wide efficiency, especially in the developing countries as it would help reduce the total water consumption, as shown by the IFPRI study. This, in fact, has been dealt with in the IWMI study, which introduced the concept of the "multiplier effects" of water. National governments and development agencies should therefore focus on improving basin-wide efficiency as a part of the solution to the growing water-scarcity problem, rather than concentrating only on the improvements in field-application efficiency.

5.2. CONSIDERATION OF TECHNOLOGICAL FACTORS FOR MATCHING WATER SUPPLY AND DEMAND

43. Technological change is key to improved WUE, matching water demand with supplies, and achieving global food security. The potential contribution of crop genetics and adoption of new varieties, particularly those with drought tolerance, improvements in *in-situ* water delivery (e.g., drip-irrigation technology for vegetables and fruit trees), increased efficiency of plants in water use, increased plant tolerance to low-quality water (high-salinity, etc.), and increased plant tolerance to stress (low water availability) are some of the technological options, to name just a few. The three studies have considered some of these technological options either explicitly or implicitly in their projections.

- The IFPRI-model projections of crop-yield growth are based on detailed estimates of potential contributions from public and private crop breeding and agricultural research investments. The revised scenario attempts to consider the impact of various forms of technological changes, such as improvement in water-use efficiency and the increase in rainfall harvest; improvements in land and water management; and increased investment in promoting water productivity. The scenario results indicated that the global average water productivity (crop yield per unit of evapotranspiration) of rice will increase from 0.39 kg/m^3 to 0.52 kg/m^3, and the global average of water productivity of other cereals from 0.67 to 1.01 kg/m^3.

- The IWMI's revised scenario (AS11) takes into account improvements in crop genetics and adoption of new varieties (such as drought-tolerant crops, cultivation technologies, on-farm irrigation management, etc). These considerations are implicitly incorporated in the revised scenario by assuming higher yields of crops in rain-fed and irrigated areas, improved WUE, and lower non-crop evaporation loss. The next scenario (AS12) attempts to project the water demand by assuming the potential improvements in crop genetics and adoption of new traits, which would result in lower net evapotranspiration (assumed at only 95% of the 1995 NET). The result (AS12) indicated that for all countries the required PWS in 2025 would be only 10%, a reduction of 12% from the base-case scenario.

- The FAO study does not take into account the technological aspects explicitly. It also assumes that future WUE will increase as a function of actual WUE and the available water resources (induced change). Technological options would play a significant role in promoting WUE.

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vice or increases in water productivity, but probably not so much on water savings. This is perhaps a subtle point, a little difficult to explain, but important."

Conclusions

- Considerations of water-scarcity problems and efforts to solve them, especially in the arid and semi-arid areas, need to integrate research on high-yielding drought-tolerant crop varieties. The IWMI-study results indicated that improvements in crop genetics in drylands could significantly increase food production using less water.
- It would also help in improving water productivity in irrigated areas and improve yields in rain-fed areas, thereby reducing pressure on irrigated land and scarce water resources. Further, as illustrated by the IFPRI case study, there is a need for a shift from addressing only the productivity of land (kg per ha) to addressing water productivity (kg per unit of water applied), especially in dry and semi-arid areas.

5.3. CONSIDERATION OF WATER-STORAGE NEEDS AND CAPACITY

44. The feasibility and "implementabilty" of adding water-storage capacity that is environmentally acceptable and economically feasible would largely shape the future of water availability to meet the growing need for irrigation water. In general, while the water-storage capacity of existing reservoirs in many parts of the world (particularly in China) is declining, the latest report of the World Commission on Dams and the uproar that any new dam would cause around the world limits the potential for increased augmentation of freshwater resources through construction of large dams. This raises the fundamental issue of the basis for the assumptions of increased water storage and the need for investment to increase the capacity to store more water.

45. The IFPRI report points out that globally available water-storage capacity is below the required storage capacity. The model estimates required improvements in total-global reservoir storage for irrigation and water supply at 3428 km^3 (for the base year 1995, which is an additional 47% of the total reservoir-water storage), and is projected to reach 4049 km^3 by 2025, which indicates a net increase of 621 km^3 compared to the base year.

46. The IWMI study indicates that in order to meet increased 2025 needs, the world's primary-water supply will have to increase by 22% (from around 2,120 km^3 per year in 1995 to 2718 km^3 per year in 2025). This amounts to an increase in surface and subsurface water storage sufficient to release roughly 600 km^3 of water over the 30-year period. A factor to consider is the continued reduction in the existing water storage capacity (assumed at 1% per annum) as a result of sedimentation and the overdraft of groundwater (assumed at 10% beyond the sustainable level). The total amount of additional water storage and conveyance required by 2025 is around 860 km^3 per year. This means a total requirement in 2025 of nearly 3,000 km^3, or effectively a 41% increase of PWS.

47. Both of these studies, however, do not extend the analysis to the estimation of investment needs and the implementability of the assumptions made regarding increased storage-capacity needs, and improved reservoir management.

Conclusions

- Although both the IFPRI and IWMI provide estimates of water-storage needs, neither study considers the constraints imposed on water storage due to the growing opposition to the construction of dams and reservoirs.

- The IWMI study incorporates the impacts of siltation problems on reduced reservoir capacity, but from the viewpoint of "implementability," there is a need to explore the potential for realizing these assumptions and estimating the investment needs.
- Estimates of water-storage needs in the IFPRI study, however, could provide a basis for extending the study to the analysis of the feasibility of increased water storage and the level of investment needed to meet the growing demand for irrigation water in different regions and countries.[11]

5.4. CONSIDERATION OF ECONOMIC DEMAND FOR IRRIGATED LANDS

48. All three studies have well incorporated the land-area limitations into their models in order to examine the impact on global water demand. But some basic questions need to be addressed: how much extra irrigation will become available in the next quarter century, and how much extra irrigation will be profitable enough by that time to draw more private-sector investments? These concerns are only partially addressed in the previous exercises.

49. The IWMI's revised scenario (AS22) takes explicit account of the land area limitations by making the following assumptions: i) lower growth in total cereal growing area; ii) lower growth in net irrigated area; and iii) lower irrigation intensity. The growth of the total cereal growing area of each country is assumed to be 2% less than the base period, which is equivalent to 25% of the total growth of all countries. The total growth of the net irrigated area of each country is considered to be 6% less than the base-scenario level. This is equivalent to 25% of the total growth of all countries of the base scenario. Likewise, the scenario considered the change in the total growth of irrigation intensity of each country at only half of the base-scenario growth.

50. In the IFPRI model, the potential irrigated area was estimated based on projected rates of completion of newly irrigated area. Actual irrigated area is then estimated as a function of the potential area, water availability for irrigation (determined by basin efficiency, climate and hydrology, and water demand in other sectors), and crop prices. The crop prices were created endogenously as a function of market-determined food supply and demand. Next, the IFPRI/IMPACT model assumes that the projected baseline increase of irrigation can be partially or fully "replaced" by the growth of rain-fed agriculture or more rapid rates of crop productivity or by higher rates of increase in basin efficiency.

51. The land area considered under irrigation potential in the FAO exercise includes land use in the existing rain-fed areas and land with untapped rain-fed production potential, The considerations are supposed to vary with the economic development as a result of the competition for domestic- and industrial-water use. One of the assumptions made is the expansion of irrigated area through growth in informal (community managed) irrigation, particularly in sub-Saharan Africa.The irrigated area is projected to expand by 45 million hectares in net terms by 2030. Likewise, FAO's exercise considers land-yield combinations based on the agro-ecological zones assessment and expert judgments on the potential increase in crop yield in each country. In addition, it is assumed that about 2.5% of the existing irrigation infrastructures must be rehabilitated or substituted by new irrigation each year. Under this assumption, about four-fifths of the 202 million hectares considered would have to be rehabilitated for net expansion. However, the FAO exercise does not explicitly take into account contractions of agriculture land, profitability of investments, etc.

[11] It is noteworthy that dam and reservoir restrictions could easily be handled in the IFPRI and IWMI models by the use of scenarios that limit the increase in irrigation withdrawals.

Conclusions

52. None of the exercises attempted to provide answers to some of the basic questions raised earlier. For instance, how much extra irrigation will become available in the next quarter century? How much extra irrigation will be profitable enough in the next quarter century to draw more private-sector investments in the context of contracting public-sector investment and multi-national financial-institutional lending? As these are important questions guiding the investment needs and resource allocation for portfolio projects for the multi-national and regional banks and in promoting public-private partnerships to close the resource gaps, future efforts toward the projection of global water demand should attempt to address these concerns.

5.5. CONSIDERATION OF INTERSECTORAL WATER DEMAND AND WATER-PRICING EFFECTS

53. Irrigation water consumes a large part of globally available freshwater resources. The irrigation sub-sector, however, is increasingly facing competition due to a growing demand for water in other sectors of the economy. The conventional approach to estimating water requirements usually deals with the supply side, the sole purpose being the delivery of water for food production. Due to increased urbanization and industrial activities, however, water available for irrigation is adversely affected and less land is available for developing irrigated agriculture. The underpricing of irrigation water has resulted in increased water demand and the wasteful use of available water resources. The pricing of irrigation water, as well as other types of water use (e.g., drinking water and water for industrial use), may produce the right signals regarding its scarcity. The incomplete treatment of prices in either of these sub-sectors could result in less realistic projections of water demand.

54. How far have the models incorporated the intersectoral water demand and water-pricing issue in projecting water demand for agriculture? The FAO projection considers nonagricultural withdrawals, but in a crude manner, and puts the emphasis on agricultural withdrawal, because the consumptive use of agriculture is much higher than other sectors. The IWMI/PODIUM model considers water demand for domestic water supply and industrial water use by 2025, but no assumptions are made to link the implications of intersectoral water demand and the withdrawal of water for irrigation purposes.

55. The IFPRI model provides some useful insights on intersectoral water demand and pricing-policy effects on water demand for agriculture. The model considers water demand in other sub-sectors—livestock, municipal, and industrial—and incorporates water-price elasticities for domestic, industrial, and agricultural water demand. The water prices are differentiated for the developing and the developed world. The irrigation-water price is assumed to increase twice in the developed countries and almost three times in the developing countries by the year 2025. All of the scenarios run with assumptions of high prices for irrigated agriculture resulted in large reductions of water withdrawal, higher basin efficiency, and full water reservations for environment. But there were relatively modest impacts on food production, primarily because price response is low in agriculture. On the contrary, water-price-induced efficiency gains in irrigation-water use would be significant. While the irrigation-water demand is expected to decline, availability of irrigation may increase because nonirrigation takes less water (the model assumes nonirrigation always takes the first priority for water supply). However, the model doesn't take into account the uncertain results of such reforms.

Conclusions

- The revised scenario results indicated that while pricing policy would have a significant impact on the improved WUE, as the price elasticity of demand is low in irrigation water, policy integration should focus on a range of economic-incentive measures for improving the water-use efficiency in the irrigated agriculture.

- To achieve efficient water allocation and therefore a more realistic projection of future water demand, it is necessary to consider intersectoral water needs and how pricing structure would govern the water demand in various sectors of water use. Future studies on global water projections should attempt to explicitly incorporate the sectoral water pricing and the interlinkages between different sectors of the economy. Such considerations are also important to equalize the marginal benefits of water use across sectors and increase the allocative and economic efficiency of water use.

5.6. Consideration of Water-Recycling and Water-Harvesting Potential

56. Growing water scarcity and the increasing cost of water augmentation necessitate the need to consider brackish water, water-recycling options, and the promotion of water-harvesting techniques. In many arid and semi-arid areas, available brackish water can be used for certain crops or as a supplement to freshwater. Likewise, the recycling of sewage water may be a supplement to freshwater for irrigation in highly water-scarce areas. The IWMI/PODIUM considers the reuse of water but does not consider other options like the recycling of sewage water or use of brackish water. The model uses the concept of (river) basin-wide efficiency, which includes the return flow water recycling, or water multiplier effects.

57. The IFPRI/IMPACT model considers both basin-wide WUE and the potential contribution of water-harvesting techniques for supplemental irrigation-water demand in the rain-fed areas. The model assumes that water-harvesting techniques could be adopted cautiously to provide farmers with improved water availability in some local and regional ecosystems. The following three of the revised scenarios consider improvements in the effective use of rainfall (Rosegrant, et al. 2002):

- NIER: No improvements in effective rainfall use would result in a significant reduction in rain-fed areas by 5.0 million hectares and reductions in rain-fed cereal production by 59 million tons. The total water consumption under this scenario is the same as in the base-case scenario of 1,480 km^3.

- LIV-HRF: Low-investment in irrigation development and water supply but a higher increase in rain-fed area and yield is expected to increase rain-fed area by 6 million hectares and rain-fed yield by 11%, with an additional 183 million tons increase in rain-fed production in comparison to the base case. This scenario would result in a decline of 256 km^3 (18% decline) in the volume of total-global water consumption. The potential reduction in irrigated cereal production of 170 million tons would thus be completely offset by the increased investment in water-harvesting techniques in rain-fed areas.

- LIV-HIER: Low-investment in irrigation development and water supply but a higher increase in effective rainfall use. The total water consumption and irrigated area in this case is the same as that of the LIV-HRF scenario of 1215 km^3, but the projected improvements in effective use of rainfall water would not fully compensate for the decline in production due to low-investment in irrigation development.

- GW-HRF2: The phasing out of groundwater overdraft with larger rain-fed agriculture development and a larger improvement in effective rainfall use. The latter of which is expected to cause: i) a decline in groundwater pumping by 169 km^3; ii) a decline in total irrigation-water consumption to 1394 km^3 from the baseline projection of 1480 km^3; iii) an increase in rain-fed area by 4 million hectares over the base case along with a decline in irrigated area by 4.1 million hectares with improvements in water productivity.

Conclusions

58. None of the models considers use of brackish water in arid and semi-arid areas and the recycling of sewage water when addressing the supply side of the global water projections. They also neglect to incorporate the multiplier effect of the reuse of drainage water or consider the potential contribution of water-harvesting techniques in the global water projections, which would provide interesting policy implications. Such implications would be:

- Improvements in rain-fed agriculture could offset the need for increased investment in conventional water, augmenting the process through building large dams and run-off-the-river diversion schemes. At the same time, crop genetics, particularly improvements in high-yielding varieties suitable to rain-fed areas, remains a challenge.
- Improvements in effective rainfall use through the adoption of water-harvesting techniques combined with land- and water-management practices could significantly reduce the overdrafting of groundwater and would result in local and regional environmental benefits and, therefore, an increase in the stocks of public goods.
- The potential for improving water-harvesting techniques, rain-fed yield, and total production, however, could be hampered by the lack of adequate modeling and data used to predict the "effective rainfall."
- There is a need for conceptualizing the irrigation-water investment programs differently from the conventional thinking of large investments for building dams and reservoirs toward the utilization of scarce resources in more cost-effective and environmentally friendly ways. The adoption of techniques such as water-harvesting in areas where additional demand for irrigation-water is essential to meet the growing food security concerns.[12]

5.7. Consideration of Environmental Factors

59. Considerations of environmental factors in global water projections include several positive and negative aspects: i) consideration of demand of water for ecological needs (e.g., the reduction of water availability for agriculture due to the increased demand for environmental purposes); ii) a decrease in irrigated area due to increased salinization; and iii) projections of water demand with consideration of the impacts of global climate change (e.g., likely droughts, increase in water demand due to increased evapotranspiration, CO_2 fertilization effects, farmers' adaptation practices, etc.).

60. Both the localized nature of some of the environmental effects and the lack of scientific validity of most global climate-change models when predicting vulnerability to climate change and its effects, make incorporating these various factors into the global water projections very complex. None of the three studies attempted to rerun the model with particular consideration of these factors. Although the IFPRI model has the capacity to handle the effects of climate changes, no attempts have been made to consider these effects on global water demand and supply. In the same fashion, though the IWMI study assumes that increasing problems of waterlogging and salinity could reduce the irrigated area, no particular assumption is made for incorporating climate-change effects. The study takes care of the environmental demand for water by imposing the restriction that the total evaporation cannot exceed 75% of PWS, leaving 25% of

[12] One reviewer believes that water-harvesting techniques are less costly compared to irrigation and are environmentally friendly in many, though not in all, cases.

PWS for environmental benefits (e.g., provisions of environmental supplies to estuaries and coastal areas plus the flushing of salts and other pollutants).

61. Likewise, the IFPRI study, while computing the maximum-allowable water withdrawal, assumes that the committed flow for environmental and ecological maintenance, political agreements, and in-stream uses such as recreation, hydropower generation, navigation, etc., constitutes a significant portion of the total renewable water—ranging from 10% to 50% depending on the availability of runoff and relative demands of these in-stream uses in different basins.

Conclusions

- Considerations of environmental factors, though important, are restricted by the lack of data at present, and efforts should be made to improve the environmental database.
- Limiting the availability of freshwater for irrigation-water use, as assumed in the IWMI and IFPRI studies, or considering the ecological limits of water use (whether ground or surface water) would further increase the scarcity of water for agriculture.
- Since the forecasts made by all the studies do not consider these factors, and since the reliability of global climate-change models is still being questioned, efforts should be made to make farmers aware of the adaptation process to cope with the uncertainties of climate change and its impact on water availability.

5.8. CONSIDERATION OF IMPROVEMENTS IN INSTITUTIONAL PERFORMANCE OF WATER-RESOURCE PROJECTS AND THE IMPLEMENTABILITY OF THE ASSUMPTIONS MADE

62. The implementability of the different assumptions made and the scenario results constitute the most important aspect of any practical exercise aimed at guiding agencies at both the national and international levels. The term "implementability" in this context refers to both the realistic bases of the assumptions made and the practical aspects of the implementation of the scenario results. Projections made without due consideration of the institutional aspects (e.g., potential for operation and maintenance performance, restructuring of irrigation agencies and private-sector participation within a sector of broader national reforms, building public-private partnerships for increased investments, etc.) would have little significance in addressing real-world problems. Also, very little efforts have so far been made toward addressing efficient water-pricing mechanisms or the issue of appropriate fee collection and management for ensuring water service delivery through an enabling system of operation and maintenance.

63. The IWMI study makes two fundamental assumptions about the institutional aspects of the future performance of water-resource projects. First, it assumes that countries will continue to pursue a self-sufficiency policy, as a large percentage of their populations in rural areas will attempt to become self-sufficient in agriculture. The self-sufficiency policy would also reasonably help to conserve foreign exchange and provide sustainable rural livelihoods. The situation, however, might change gradually over time as exports grow, the growth of the labor force slows down, and employment opportunities in other sectors start to improve. Second, it is assumed that irrigation effectiveness—and consequently the irrigation intensity—will increase as a result of the developing countries' continued emphasis on, and investment in, overall rural development (including that of irrigation infrastructures and the formulation and adoption of policies helpful in increasing WUE).

64. Likewise, the FAO exercise assumes that demand management will play an important role in improving irrigation efficiency in water-scarce regions, but in the humid areas, the issue of irrigation efficiency is much less relevant and is thus likely to receive little attention. Next, the study assumed that about 2.5% of the existing irrigation infrastructures have to be rehabilitated or substituted by new irrigation infrastructures each year. Under this assumption, nearly four-fifths of some 202 million ha considered would be rehabilitated for net expansion. Another assumption on the average life of irrigation schemes was 40 years. Neither of these two studies, however, attempts to estimate the required investments needed to expand and rehabilitate the irrigated area.

65. Finally, the IFPRI study makes some implicit assumptions in terms of the availability of investments rather than estimation of the required level of investments in its two projected scenarios. LIV-HRF and LIV-HIER both assumed low-investment in irrigation development and attempted to provide an answer to the what-if questions about investment gaps and the benefits, or lack thereof, in investmenting in surface-water augmentation and water harvesting in rain-fed areas (see section 4.6).

Conclusions

- Each of the models has several limitations in finding answers to the issues linked to institutional aspects. Complexity also arises because of the heterogeneity of institutional capacity, the pace of capacity building, and the differences in irrigation-sector performance of countries and regions.
- Institutional dimensions such as water rights deserve consideration because the nature of water rights substantially affects the selection and implementation process of water-pricing policies and the trading of scarce water resources. Both instruments play an important role in improved WUE and in reducing the total demand for irrigation water.[13]

[13] See footnote 7, Rosegrant and Cai (2002), and Rosegrant, Cai, and Cline (2002).

6. Validation Exercise and the World Bank Rural Development Strategy: Implications and Key Actions

6.1. Validation Exercise: Major Findings and Operational Linkages

66. The first part of the validation exercise attempted to review the existing model structure or components, assumptions made, scenarios, and scenario results to look for answers to some of the emerging issues and challenges facing the agriculture-water sector. The major findings of the review of the existing models, assumptions, scenarios, and the validation exercise that was carried out by the three agencies is summarized in box 6.1.

Box 6.1 Major findings of the validation exercise

- To meet the increased 2025 water needs, the world's primary water supply will need to increase by 22% (from around 2,120 km^3 per year in 1995 to 2,718 km^3 per year in 2025). This amounts to an increase in surface- and subsurface-water storage sufficient to release roughly 600 km^3 of water over the 30-year period.
- Considerations of irrigation potential, as addressed by the FAO study, indicate that agricultural-water demand should not exceed the available water resources. The FAO estimates of irrigation potential are based on renewable water resources, i.e., the resources replenished annually through the hydrological cycle. In those arid countries where mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is usually larger than the irrigation potential. In terms of seasonal water needs, countries suffering from a lack of precipitation, and therefore most in need of irrigation, are also those where water resources are naturally scarce. In addition, the water balance presented is expressed in yearly averages and cannot adequately reflect seasonal and interannual variations.
- The various scenarios developed under assumptions of low-investment in irrigation (e.g., low-investment, high intersectoral-water demand, low groundwater pumping, etc.) indicated that the availability and reliability of water supply would be largely reduced by 2025 under these scenarios. The reduction in the amount of water available for irrigation is large under these water-stressed scenarios, with the biggest reductions in developing countries.
- Reduction in the availability of water for irrigation directly reduces the irrigated harvested area and increases the year-to-year variability in irrigated area. For example, irrigated area in the world declines by 8 million ha on average between 2021–2025 under the low-investment in irrigation scenario and by 4 million ha under the high municipal- and industrial-water-demand scenario as shown by the IFPRI study (compared to the baseline scenario values in 2021–2025). In addition to reducing the irrigated area harvested, the more water-scarce scenarios reduce the amount of water available per hectare in the remaining irrigated area.
- Finally, there could be a significant drop in irrigation supply (or effective demand) for the alternative scenarios compared to the baseline in 2025. The low-groundwater-pumping scenario has smaller impacts on these large regional averages, because the impacts are concentrated in the basins that have an overdrafting of groundwater. Compared to the baseline scenario, the alternative scenarios result in lower irrigation-water depletion, lower irrigated harvested area and lower production of cereals for both the developing and the developed world.

67. Figure 6.1 provides the summary of some of the major findings, implications for RDS, level of policy interventions, and suggestions for building partnerships.

68. *The importance of the improved water-use efficiency in solving the growing water crisis*: The results of the revised scenarios indicated that improved WUE would help in reducing the volume of global irriga-

tion-water consumption significantly, and the national governments and international agencies should concentrate their efforts toward improving the various facets of WUE. All three studies considered the potential for improvements in various facets of WUE and the likely contribution towards meeting the global water demand. Specifically, the findings of these studies indicate that:

- The demand for improved WUE, and hence efforts toward improving irrigation efficiency, would mostly take place in water-scarce areas, such as in the Near East, North Africa, and southern Asia. Some countries in these regions are also increasingly facing food scarcity, and efforts to solve food-scarcity problems should be combined with applications of various means (economic, physical, and institutional) to improve WUE.

- Efforts toward improving WUE should also address basin-wide efficiency, as it can help to reduce the total level of water consumption, as shown by the IFPRI study. This has been dealt with in the IWMI study by introducing the concept of "multiplier effects" of water. National governments and development agencies should therefore focus on improving basin-wide efficiency as a part of the solution to the growing water-scarcity problem, rather than concentrating only on the improvements in field-application efficiency.

69. *The role of technology in improving water-use efficiency:* Technology would play an important role in the improved WUE, in raising water productivity, and in solving future water-scarcity problems. Considerations of water-scarcity problems and efforts to solve them, especially in the arid and semi-arid areas, need to integrate research on high-yielding, drought-tolerant crop varieties.

- The IWMI-study results indicated that improvements in crop genetics in the drylands could significantly increase the amount of food produced with less water. It would also help in improving water productivity in irrigated areas, as well as the yields in rain-fed areas, thereby reducing pressure on the irrigated areas and on scarce water resources.

- Further, as illustrated by the IFPRI case study, there is a need for a shift from addressing only land productivity (kg per ha) to water productivity (kg per unit of water applied), especially in the dry and semi-arid areas.

70. *Impacts of intersectoral water demand on irrigation-water availability*: Considerations of the link between intersectoral water demand and the impacts of pricing policies on future water availability for irrigation (e.g., scenarios developed with some restriction on future water supply for agriculture with increased intersectoral water demand) indicated that it would result in large food-production deficits in most water-scarce regions.

- The IWMI/PODIUM model considers water demand for domestic use and industrial use by 2025. The findings indicated that the domestic sector represents the smallest sector, at only 11% of diversions, but is the most rapidly growing sector, with an increase of 84% over the period. Likewise, the industrial diversions would comprise 22% of the total 2025 diversions, growing at the rate of 60% over the period. However, no scenario analysis was made linking the implications of intersectoral water demand and the withdrawal of water for irrigation purposes.

- The IFPRI model considers water demand in other subsectors—livestock, municipal, and industrial—and incorporates water-price elasticity for domestic, industrial, and agricultural water demand. The price of irrigation water is assumed to increase twofold in the developed countries and almost threefold in the developing countries by the year 2025 (compared to the base-case scenario). Although the details of the scenario results are yet to be made available, the general indication is that while the demand for irrigation water is expected to decline, availability of irrigation water may increase because nonirrigation takes less water (the model assumes nonirrigation always takes the first priority for water supply) due to reforms in water-pricing policy.

71. *The reuse of drainage water in water-scarce areas*: Although none of the models considers the use of brackish water in arid and semi-arid areas and the recycling of sewage water when addressing the supply side of the global water projections, the incorporation of a multiplier effect of the reuse of drainage water,

and especially consideration of the potential contribution of the water-harvesting techniques in rain-fed areas, provides interesting policy implications for solving the growing water crisis.

- First, improvements in rain-fed agriculture could offset the need for increased investment in conventional water augmentation (e.g., through building large dams, run-off-the-river diversion schemes, etc.). However, research on crop genetics, particularly on high-yielding varieties suitable for rain-fed areas, remains a challenge.

- Second, improvements in effective rainfall through the adoption of water-harvesting techniques combined with land- and water-management practices could significantly reduce the overdrafting of groundwater and could also result in local and regional environmental benefits, thereby increasing the stocks of public goods.

- Third, the potential for improving water-harvesting techniques, rain-fed yield, and total production could be hampered by the lack of adequate statistics needed to predict the "effective rainfall" and the optimal utilization of the potential.

- Finally, the increased potential of rainwater-harvesting techniques in solving water-scarcity problems, indicates the need for broadening the scope of irrigation-water investment programs from conventional options (e.g., large investments in building dams and reservoirs).

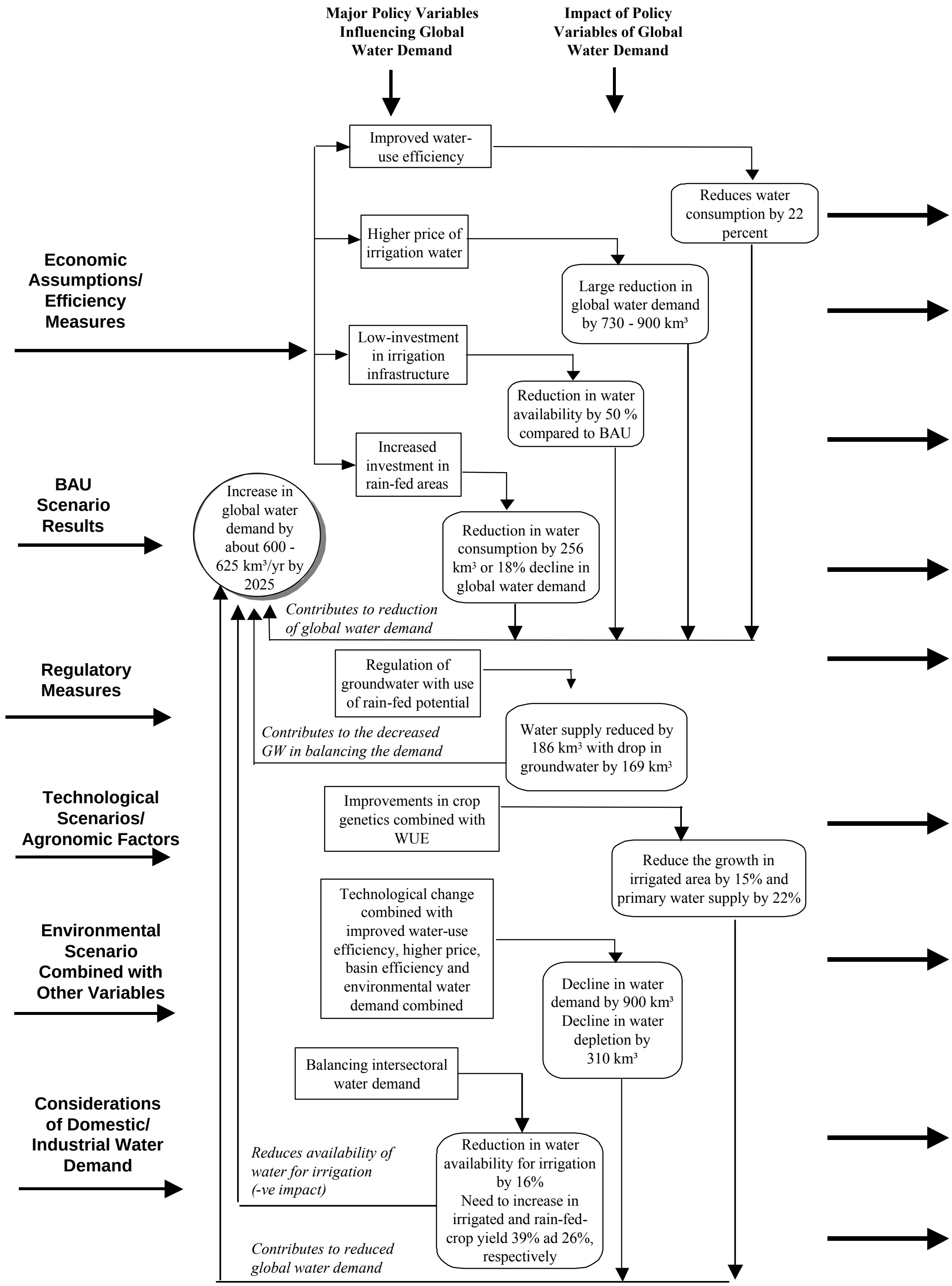
72. *Environmental water demand as a limitation on irrigation-water availability*: Considerations of environmental factors, though important, are hindered by the lack of data at present, and efforts should be made to improve the environmental database. Yet some of the considerations of the environmental aspects of water demand in the scenario analyses of these agencies indicate that:

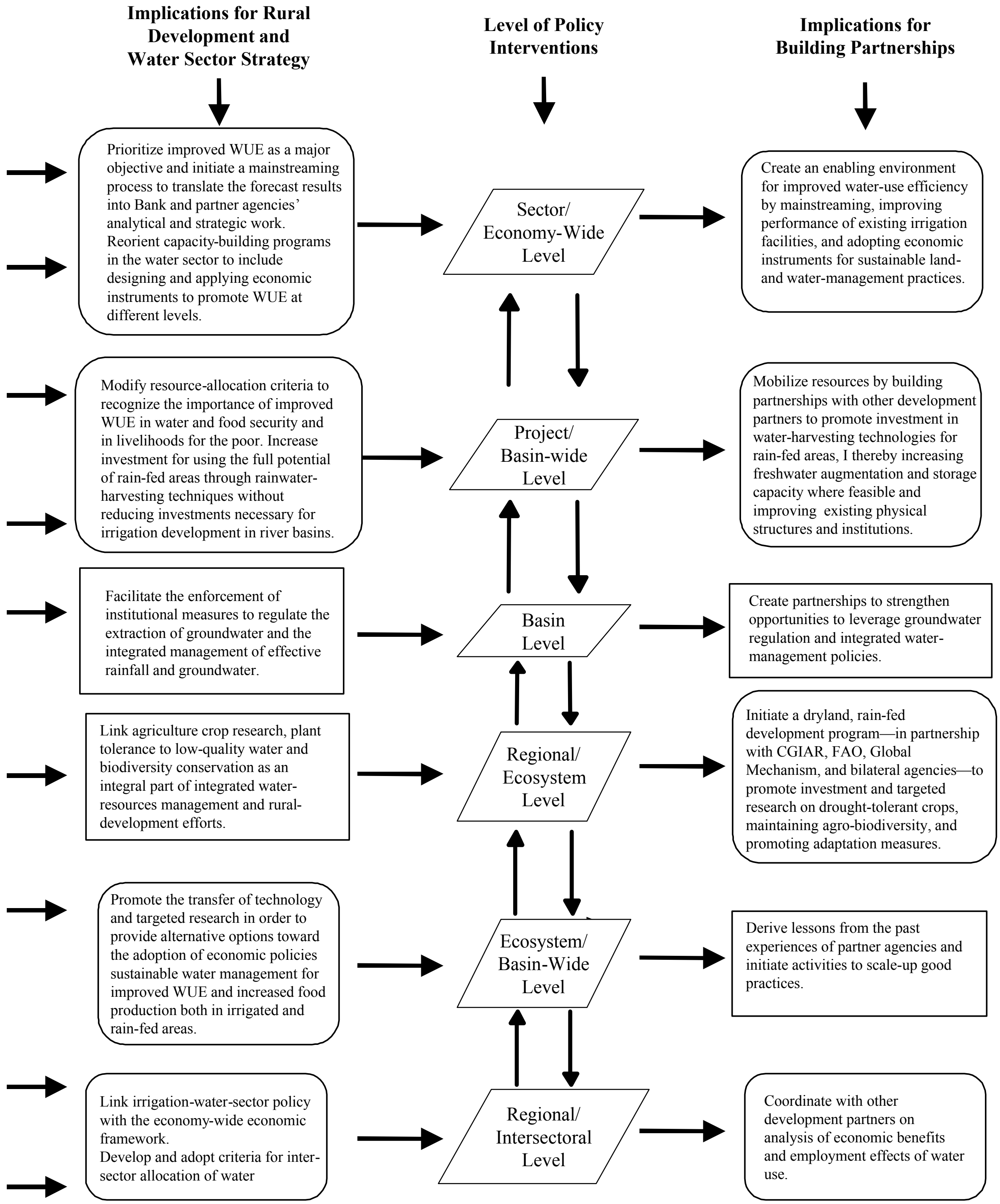
- Limiting freshwater availability for irrigation use, as assumed in the IWMI and IFPRI studies, and the ecological limits of water use—whether ground or surface water—would further aggravate the scarcity of water for agriculture.

- Since the forecasts made by all the studies do not explicitly consider these factors, and the reliability of global climate-change models remains suspect, efforts should be made to make farmers aware of the adaptation process in coping with climate-change uncertainty and its potential impacts on water availability.

73. *Institutional aspects*: Each of the models is limited in addressing the issues linked to the institutional aspects. Complexity also arises because of the heterogeneity of institutional capacity, the tardy pace of capacity building, and differences in irrigation-sector performance in the countries and regions. This further suggests that institutional dimensions, such as water rights, are important enough to consider since the nature of water rights greatly affects the process of selection and the implementation of water-pricing policies and the trading of scarce water resources. Both of the economic instruments are important for improved WUE and reducing the total demand for irrigation water. Future modeling efforts need to incorporate these various institutional- and market-based policy-incentive measures in order to help the national policy makers and international agencies reshape structures and policy measures that affect the sustainable management of water resources.

Figure 6.1 Major findings of the validation exercise and some implications for the rural development strategy and the building of partnerships





Implications for Rural Development and Water Sector Strategy
Level of Policy Interventions
Implications for Building Partnerships
Prioritize improved WUE as a major objective and initiate a mainstreaming process to translate the forecast results into Bank and partner agencies' analytical and strategic work. Reorient capacity-building programs in the water sector to include designing and applying economic instruments to promote WUE at different levels.
Sector/ Economy-Wide Level
Create an enabling environment for improved water-use efficiency by mainstreaming, improving performance of existing irrigation facilities, and adopting economic instruments for sustainable land- and water-management practices.
Modify resource-allocation criteria to recognize the importance of improved WUE in water and food security and in livelihoods for the poor. Increase investment for using the full potential of rain-fed areas through rainwater-harvesting techniques without reducing investments necessary for irrigation development in river basins.
Project/ Basin-wide Level
Mobilize resources by building partnerships with other development partners to promote investment in water-harvesting technologies for rain-fed areas, I thereby increasing freshwater augmentation and storage capacity where feasible and improving existing physical structures and institutions.
Facilitate the enforcement of institutional measures to regulate the extraction of groundwater and the integrated management of effective rainfall and groundwater.
Basin Level
Create partnerships to strengthen opportunities to leverage groundwater regulation and integrated water-management policies.
Link agriculture crop research, plant tolerance to low-quality water and biodiversity conservation as an integral part of integrated water-resources management and rural-development efforts.
Regional/ Ecosystem Level
Initiate a dryland, rain-fed development program—in partnership with CGIAR, FAO, Global Mechanism, and bilateral agencies—to promote investment and targeted research on drought-tolerant crops, maintaining agro-biodiversity, and promoting adaptation measures.
Promote the transfer of technology and targeted research in order to provide alternative options toward the adoption of economic policies sustainable water management for improved WUE and increased food production both in irrigated and rain-fed areas.
Ecosystem/ Basin-Wide Level
Derive lessons from the past experiences of partner agencies and initiate activities to scale-up good practices.
Link irrigation-water-sector policy with the economy-wide economic framework. Develop and adopt criteria for inter-sector allocation of water
Regional/ Intersectoral Level
Coordinate with other development partners on analysis of economic benefits and employment effects of water use.

6.2. The World Bank Rural Development Strategy and the Water Sector

74. The evolving Rural Development Strategy (RSD) of the World Bank focuses on four major aspects: i) the provision of basic needs to the rural poor; ii) the promotion of sustainable growth in farm and nonfarm sectors in rural areas; iii) the adoption of broad-based rural development; and iv) the enhancement of stakeholder participation. Water plays an important role in all aspects of broad-based rural development, and the irrigation subsector is a major player in the livelihood of those living in rural areas.

- First, meeting the basic needs of the poor, among others, includes the provisioning of potable water and sanitation facilities. More than 50% of the poor in rural areas of developing countries still lack safe drinking water and sanitation facilities. A provision of water supply to this large segment of population would result in significantly increased competition for water for other uses.
- Second, as discussed in this paper, achieving sustainable agriculture production and meeting the increased demand for food and fiber would require both the effective usage of available supplies of water and the further augmentation of freshwater through different sources.
- Third, promotion of nonfarm income opportunities in rural areas such as the promotion of fisheries and livestock, agro-food processing and other small-scale industries, nontimber forest products through better management and conservation of watersheds, etc., would involve the sharing of available water resources for industrial use and the maintainance of ecological stability.
- Fourth, broad-based rural development, such as the promotion of hydropower and meeting the energy requirements of small-scale and medium-sized industries, would demand a balanced and effective use of scarce water resources (e.g, surface and groundwater, rainfall, and reuse and recycling) to achieve the overall goal of satisfying the basic needs of the rural poor.
- Finally, enhancing stakeholder participation in achieving these objectives would require efforts in building and promoting partnerships at various levels (e.g., promoting stakeholder participation at the on-farm level, community-based organizations to river-basin and transboundary-level organizations and mainstreaming the Bank's water-sector strategy into a country-assistance strategy to other development partners' strategies through building partnerships).

75. How are these issues to be addressed in the RDS water sector, and what would be the implications of the validation exercise? What would be the key strategic options for the forthcoming water-sector strategy? The RDS water-strategy paper focuses mainly on the four key areas linked to different uses and provisions of water. First, the paper emphasizes the need to rethink irrigation in order to satisfy the needs of the poor—such as food security and employment generation in the agriculture sector because the agriculture sector still continues to provide the basic means for the sustainable livelihood of the poor. It also emphasizes providing a fair share of water–resource-development benefits to the poor, empowerment and participation of the poor in the development activities, as well as increased private-sector involvement in providing the necessary infrastructures. Second, the paper provides an overview of the Bank's current irrigation and drainage portfolio and puts emphasis on the efficient allocation of resources for increasing productivity of irrigated agriculture, institutional reforms, investment in irrigation and drainage infrastructures, and the maintainance of environmental sustainability. Third, the RDS paper highlights the challenges and opportunities for increasing productivity or irrigated agriculture, institutional reforms, environmental sustainability, investment in irrigation and drainage infrastructures, economic viability, and sustainability aspects. Finally, the RDS paper outlines the priorities for Bank assistance in areas of promoting productivity and reducing rural poverty, as well as irrigation reforms within a river-basin framework, and in stimulating the reform process.

76. The major importance attached to these exercises lies in seeing to what extent these foci are relevant to the future demand of irrigation water and in addressing the physical, economic, and environmental limitations on matching the demand with an available supply of water. As for the question of the implications of the validation exercise on the RDS water-sector strategy, some of the assumptions made and scenarios developed, and the results available provide useful insights in shaping the priorities for Bank assistance.

6.3. VALIDATION EXERCISE AND THE RURAL DEVELOPMENT STRATEGY: IMPLICATIONS AND KEY ACTIONS

77. The summary of the major findings of the validation exercise indicates that the water sector, and especially the availability of irrigation water for agriculture, will continue to face even more competition in the years to come and will require unprecedented efforts in investment and the allocation of resources. In comparison to the existing forecasts, the validation exercise provides clear insights and useful policy implications for the RDS on several fronts. Some major implications, and a mix of key strategies that could be drawn from the validation exercise for the RDS water-sector strategy, are provided in the following paragraphs.

Productivity of agriculture as emphasized in the RDS paper would largely depend on improvements in WUE in irrigated areas and the effective use of available rainfall in the rain-fed areas.

78. All three studies considered the potential for improvements in the various facets of WUE and the likely contributions needed to meet the global water demand. These studies indicate the large potential of improved WUE in solving the growing water crisis and increasing agricultural productivity. The analysis on spatial scale indicates that efforts for improved WUE would be essential in water-scarce areas, such as in the Near East, North Africa, and southern Asia. Some countries in these regions are also increasingly facing food scarcity. Therefore, efforts towards a broad-based rural development as envisaged in RDS need to be combined with applications of various means (economic, physical, and institutional) for improving WUE. The scope of policy intervention and investments in promoting WUE should include basin-wide efficiency, as this would help to reduce the level of total water consumption, as shown by the IFPRI study. This has also been dealt with in the IWMI study by introducing the concept of "multiplier effects" of water, and investment strategies should focus on how to improve basin-wide efficiency.

Key actions

- Promote the Bank's portfolio projects for improving physical infrastructures and institutional mechanisms at the basin-wide scale, especially in those countries and areas where there is an immediate need for promoting WUE in order to attain food security.

- As the river-basin-wide approach involves different sectors of water use, vast geographical areas, and economic opportunities, the adoption of the river-basin approach would require the mainstreaming of water-sector strategy in the Country Assistance Strategy (CAS) and country, economic, and sector work in order to promote country capacity. This could be done through linking different sectors of water use (e.g., the economic and social returns and environmental benefits associated with each use) and making the link part of the rural-development efforts at the river-basin/regional level. Recent evaluations of the Bank's past water-resource projects has shown that the CAS has often failed at mainstreaming the water-sector strategy and that less than 40% of the Bank's water-resource projects were responsive to the water-resource policy (Pitman 2002).

- Create an enabling environment for improved water-use efficiency through building partnerships in areas of: i) mainstreaming improved WUE measures into operational programs of development partners; ii) the promotion of investments in water-efficient technologies; and iii) the use of economic-incentive measures for the adoption of such technologies and the adoption of sustainable-land-management practices with the internalization of irrigation-induced environmental externalities for promoting WUE and water productivity.

Market-based instruments have been greatly emphasized in promoting WUE as one of the options for solving the growing water crisis; so the rural-development strategy should focus on promoting institutional mechanisms for the adoption of such instruments.

79. The areas regarding the linkage of intersectoral water demand and the impacts of pricing policies on the future availability of water for irrigation (e.g., scenarios developed with some restriction on future water supply for agriculture and increased intersectoral water demand) indicated that while the demand for irrigation water is expected to decline, the availability of irrigation water may increase because nonirrigation takes less water (the IFPRI model in this case assumes that nonirrigation always takes the first priority in water supply) due to reforms in water-pricing policy. In addition, the general indication is that it would result in large food-production deficits in most of the water-scarce areas. The implication is that although the adoption of market-based instruments may help in solving the water crisis, the poor people, at the same time, might be seriously affected by the deficits in food production in the rural areas. In designing such measures one should thus consider the impacts on the poor and introduce revenue-recycling mechanisms to protect them.

Key actions

- Promote institutional mechanisms (water rights and ownerships, water users' groups, local governance for monitoring and evaluating developed institutional mechanisms, etc.) and the adoption of market-based measures as part of the rural-development strategy.

- Design market-based incentives based on the analysis of linkages between the different sectors of water use, rather than only on the estimation of costs and benefits or the willingness to pay/accept in the respective sectors. For example, water-pricing reforms in other sectors of water use as part of overall rural development strategies would have beneficial impacts on the availability of water for irrigation; while the removal of existing subsidies on irrigation would help improve WUE and leave surplus water for other uses. In addition, as the application of water-pricing policies would differ when considered at the basin-wide scale (e.g., upstream and downstream users with and without environmental costs), there is a need to develop guidelines for the adoption of economic instruments at the river-basin level.

- Develop revenue recycling and compensation mechanisms for the small-scale farmers and poor people. Their willingness to pay (and hence the economic benefits associated with their economic activities) would be lower, and if not compensated, growth-induced benefits for the poor from the rural development efforts alone would not help to bring progress toward alleviating poverty.

Rural-development investment strategies for investing in water-resource-development infrastructures also need to be revisited and should promote investment in developing technology (rather than the transfer of technologies) that will improve the management of water resources and close the yield gaps.

80. The validation-exercise results also indicate that if the global communities have to reduce a food deficit, the irrigated yield of all countries must be increased by 27% over the base scenario. On the other hand, if the total production deficit is to be reduced through additional growth in rain-fed yield, the rain-

fed yield is estimated to increase by 22% over the base scenario. As shown by the IFPRI study, technology would play an important role in the improved WUE, in raising water productivity, and in solving future water-scarcity problems. Considerations of water-scarcity problems and solutions, especially in arid and semi-arid areas, need to integrate research on, and the adoption of, high-yielding, drought-tolerant crop varieties. Results of the IWMI study indicated that improvements in crop genetics in dry areas could significantly increase food production using less water. It would also help to improve water productivity in irrigated areas and the yields in rain-fed areas, as well as to reduce pressure on irrigated areas and areas with scarce water resources. Further, as illustrated by the IFPRI analysis, there is a need for a shift from addressing only productivity of land (kg per ha) toward productivity of water (kg per unit of water applied), especially in dry and semi-arid areas.

Key actions

- Promote investment in integrated agricultural land and water development, as well as management activities that combine technologies that promote the efficient use of water in irrigated and rain-fed areas. Promote research, the adoption of drought-tolerant crops, and management practices.
- A shift from a project-based to a basin-wide approach also requires a long-term investment strategy. The current level of investment in the water sector is too small to divert resources for improved WUE and the accommodating basin-wide programs. This would require a greater mobilization of resources through existing financing mechanisms and innovative sources.
- Integrate regional and local rural-development strategies with the CGIAR Millennium Challenge Program on droughts and desertification in order to facilitate the adoption of integrated land- and water-development/management approaches, especially in the drylands areas.[14]
- Design and adopt economic incentive measures, such as transfer of payments for the generation of global environmental goods associated with the adoption of integrated land and water management (e.g., promotion of soil-carbon sequestration and agro-biodiversity) in order to encourage farmers to adopt such sustainable land- and water-management measures.
- Develop operational guidelines/toolkits for the irrigation and drainage portfolio for Bank managers and partner organizations for making investment decisions based on these various changing needs and potentials as indicated by the scenario analysis carried out by the various agencies.

The allocation of resources or investment decisions for augmenting additional freshwater in either sector (agriculture and industrial) should take place with the examination of generating additional employment and other direct benefits for the poor instead of the maximization of the single objective of agricultural or industrial production benefits.

81. As seen in the validation exercise, the domestic sector represents the smallest water user but is the most rapidly growing sector, with an increase of 84% by 2025. Likewise, the industrial diversions would comprise 22% of the total 2025 diversions, growing 60% over the period. In addition, the diversion of water to provide safe water to the majority of the rural poor as outlined in the RDS would have a signifi-

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[14] The CGIAR Millennium Challenge Program aims at the CP aims of carrying out focused research on the links between agriculture, land degradation in dry areas, and drought. It also focuses on the examination of soil fertility and land- and water-management strategies that might mitigate drought and protect the natural-resource base. See "A CGIAR Challenge Program on Agriculture, Poverty, and Combating Desertification" summary note for further details.

cant impact on water availability for irrigation. The scenario analysis also showed that the implications of increased intersectoral water demand would have a significant impact on the irrigation subsector. It would result in decreased food production, and thus, there would be some trade-offs in the efficient allocation of scarce water among the different sectors of water use. However, the increased utilization of water in the industrial sector through the expansion of rural industries would also create additional employment opportunities for the rural poor.

Key actions

- Consider poverty alleviation as a major factor in making investment decisions and examine the link between water use in different sectors and the potential for the generation of additional employment for the rural poor. Give priority to the allocation of scarce water to the sector generating that additional employment.
- Analyze the transaction cost involved in the reallocation of water from one use to another use that would generate additional employment opportunities. In some cases, economic benefits could be lower compared to the costs of water diversion. The transaction costs involved and investments in such cases (investments in nonfarm income-generating opportunities) would be more helpful in achieving the goal of poverty reduction than investing in the delivery of more water to meet food security needs through increased agriculture production.

The increased potential of rainwater-harvesting techniques in solving water-scarcity problems indicates the necessity changing the focus of irrigation-water investment programs from the conventional emphasis on large investments in dams and reservoirs.

82. One important implication of the validation exercise bears upon the potential contribution of water-harvesting techniques in increasing agriculture production and meeting food security needs. The validation-exercise results indicate that if the total production deficit is to be reduced through additional growth in rain-fed yield, the rain-fed yield will need to increase by 22% over the base scenario. It would also contribute to a reduction in the overdrafting of groundwater and generate local and global environmental benefits. Increasing the potential of rainfed areas and closing the yield gaps is thus vital for solving the water-scarcity and environmental-externality problems.

Key actions

- Focus on integrated land- and water-management programs in the rain-fed areas rather than only in the large- and medium-scale surface-irrigation schemes in the river basins. In the past, emphasis has largely been placed on the conjunctive use of surface and groundwater at the basin-wide level. There is a need for a shift toward optimizing the conjunctive use of ground and effective rainfall in rain-fed areas.
- Help implement regulatory measures and economic instruments, such as the taxing of groundwater extraction, and then recycle the generated tax revenue to promote water-harvesting techniques in the rain-fed areas. This would make the extraction of groundwater more costly, thus encouraging farmers to promote and adopt water-harvesting techniques.
- Strengthen the coordinated efforts of the CGIAR centers, FAO, and the Bank in order to promote research on harnessing the potential of the effective utilization of rainfall and on minimizing the yield gaps in the rain-fed areas. The country case studies on rainwater harvesting in the Middle East and North Africa (MENA) indicated that inadequate technology, the lack of motivation among the beneficiaries, the lack of hydrological information, and the lack of research and long-term policies have

hampered harnessing the potential of effective utilization of rainfall through water-harvesting techniques. (Nasr 1999)

Achieving environmental sustainability is one of the priorities considered in the Bank's investment decision making, but considerations of environmental aspects of water demand alone would greatly limit the availability of freshwater for irrigation—as assumed in the IWMI and IFPRI studies.

83. Although the forecasts made by the three studies did not explicitly consider these factors, and the reliability of global climate-change models is still being questioned, meeting the environmental demand of water would greatly reduce the water availability for irrigation. On the other hand, meeting the ecological demand for water (e.g., for maintaining water flow and the stock of fish downstream, maintaining wetlands, etc.) would also help in promoting employment opportunity and income for the poor. Likewise, while the impacts of global climate change on water availability are not explicitly considered in the models, there is much uncertainty and risk involved in promoting activities based only on these predictions. Since rural-poverty-alleviation efforts are closely linked to food and water security and employment opportunities in different water-use sectors, the Bank should cooperate with other agencies to minimize the impacts of climate change on water availability, especially by promoting adaptation practices.

Key actions

- Cooperate with partner agencies in analyzing the potential impacts of climate change on water availability, particularly in dry areas.
- Launch programs in cooperation with others to research suitable adaptation processes and the capacities of local farmers to adopt the techniques that would help them to cope with the risks and uncertainties associated with climate change.

7. Conclusions and the Way Forward

7.1. Conclusions

84. This document provided analyses of existing forecasts, expert opinions on the existing forecasts, and revised scenario results conducted by the three agencies as part of the validation exercise on global projections of agricultural water supply and demand. Finally, some policy implications of the revised scenario results were outlined for the World Bank Rural Development Strategy (RDS).

85. The major importance of this validation exercise lies in finding to what extent it is relevant in determining the future demand of irrigation water and in addressing the physical, economic, and environmental restrictions on matching demand with supply. The IWMI revised scenarios specifically attempted to address the experts' comments on the following: i) improvements in crop genetics and water-use efficiency; ii) technological change and water use; iii) the demand for irrigation lands; iv) the demand for water from different perspectives; and v) the demand for water for environmental purposes. Likewise, IFPRI responded to the experts' comments and suggestions by adding some of the scenario results that address some of the concerns raised regarding water-use efficiency as linked to the concept of water productivity, the impacts of crop genetics with assumptions on a potential increase of crop yields both in the rain-fed and irrigated areas, water crises associated with the lack of investments in irrigation development, increased water supply using water-harvesting techniques, and water pricing and the effects of intersectoral water demand. The FAO response, however, was limited to the clarification of the existing forecasts in regard to the experts' comments. Some of the revised scenario assumptions and results found by IWMI and IFPRI indicate an important departure from existing forecasts regarding the role of crop genetics, water-use efficiency, water productivity, and the contribution of rain-fed agriculture. These are:

- The IWMI scenario results corresponding to the assumption of the potential impact of likely improvements in crop genetics showed a significant increase in net cereal-production surpluses for 100 developing countries equivalent to 6.4% of the total cereal consumption in 2025.

- An additional increase in irrigation efficiency assumed at 50% and a reduction in non-crop evapotranspiration over the base case would reduce the growth in irrigation by 15% and the total primary water supply by 22%, which corresponds to the 3% and 2% reduction from the level of increase under the base case.

- Under the slower growth (of irrigated area) scenario and with no improvements in crop genetics and water-use efficiency, the primary water supply is expected to go up by 21%, which is 3% more than the base-case result. The total primary water supply is expected to increase by 26%, a 4% increase over the base case. On the contrary, if the primary water supply is limited to the base case, there will be a substantial food deficit in the developing countries.

- If the production deficit of all countries is to be reduced through growth in irrigated and rain-fed yield, the crop yield of all countries will have to increase by an additional 39% and 26% respectively by 2025.

- The IFPRI revised scenarios indicate that improvements in the crop yields of rain-fed areas, as well as increased water productivity in irrigated areas, are possible. These would help to reduce the food deficit in developing countries. The IFPRI revised scenario (with an assumption of low-investment in irrigation development and water supply but a higher increase of rain-fed area and yield) indicated that compared to the baseline condition, rain-fed area is expected to increase by 6 million hectares with an 11% increase in rain-fed yield and a 183 million tons increase in rain-fed production. This would result in a decline of 256 km^3 (18%) in the volume of total-global water consumption. The potential reduction in irrigated cereal production of 170 million tons would thus be completely offset by the increased investment in promoting water-harvesting techniques in rain-fed areas.

- The next scenario carried out by IFPRI, which included the phasing out of groundwater overdraft and larger rain-fed-agriculture development with a larger improvement in effective rainfall use, indicated a decline in groundwater pumping by 169 km^3, total irrigation-water consumption to 1394 km^3 from the baseline projection of 1480 km^3, an increase in rain-fed area by 4 million hectares over the base case along with a decline in irrigated area by 4.1 million hectares, and improvements in water productivity.

86. These revised scenario results and existing forecasts indicate that improved WUE would help to reduce global irrigation-water consumption significantly. National governments and international agencies should concentrate on improving different facets of WUE. Improvements in rain-fed agriculture could offset the need for increased investment in conventional water-augmentation processes, such as building large dams and run-off-the-river diversion schemes. At the same time, crop genetics, particularly improving high-yielding varieties suitable for rain-fed areas, remains a challenge. Thus, there is a need for refocusing the irrigation-water investment programs from the conventional large investments in dam and reservoir building to the utilization of scarce resources in more cost effective and environmentally friendly ways. The adoption of techniques such as water harvesting in areas where the demand for irrigation water is essential for meeting growing food-security concerns is an option. These important departures in scenario results from the existing forecasts, and other scenario results summarized in chapter 6, provide some clear insights, useful policy implications, and key strategies for the RDS on several fronts. A coordinated effort between the CGIAR centers, FAO, and the World Bank is necessary.

7.2. THE WAY FORWARD

87. While the investigation so far has demonstrated that the various approaches used by FAO, IFPRI, and IWMI help to identify important issues concerning the future of irrigated agriculture, it is clear that there are still issues that have to be investigated further. Some areas to study include: the different concepts of WUE, the role of science and technology, the role of combined economic incentive measures, the issue of poverty, the impact on meeting the Millennium Development Goal of providing safe water to millions of the poor by 2015, and its impacts on intersectoral water demand. Other important issues are the interaction between irrigated agriculture and the environment; the integration of irrigated agriculture in a global, institutional, and economic structure; and the social cost of the measures needed to bring about the change that will allow irrigated agriculture to continue to be the fuel for the engine of rural growth.

88. To further distill our understanding of how future irrigated agriculture could meet the world's needs while sustaining the use of limited land and water resources, additional efforts have to be made in both analytical work and dialogue among experts and policy makers. A first step could be for FAO, IFPRI, and IWMI to join forces to improve the modeling capability. Indeed, IFPRI and IWMI have started to merge their two models, the IMPACT and the PODIUM, into one improved framework, recognizing the relative strengths and weaknesses in each. In this context, a few strategic collaborations with the partner agencies are suggested.

- First, the approaches and the results of the three analyses will be shared via joint dialogues with more experts and developing-country policy makers in international forums (such as professional meetings, the Third World Water Forum, etc.). It is recognized that the present validation exercise is only the beginning of the long-term, concerted effort that is needed in order to move the dialogue toward integrated irrigation and agricultural development; that is, beyond the aspects addressed by the FAO, IFPRI, and IWMI analyses.

- Second, it has been recognized that the measures that have been evaluated in the FAO, IFPRI, and IWMI analyses are only part of the equation. What is needed further is to provide a complete picture for the policy makers concerning the necessary investments. Therefore, quantification of the necessary investment associated with each scenario of the future development of the irrigated agricultural sector is needed.

- Third, cooperation between the World Bank and the CGIAR centers should focus on the ongoing Millennium Challenge Program on Agriculture, Poverty and Combating Desertification[15] in order to address both the water and food-security needs as outlined in the Millennium Development Goals (MDG) and the WSSD Plan of Action.[16]

- Finally, the forthcoming Water Sector Strategy of the World Bank should be fine-tuned to incorporate these major shifts and their implications in shaping the Bank's, and other development partners', investment decisions, as highlighted in section 6 based on the operational linkage between the validation exercise and the Rural Development Strategy.

[15] See "A CGIAR Challenge Program on Agriculture, Poverty, and Combating Desertification" summary note. For further details see web page www.CGIAR.org.

[16] The World Summit on Sustainable Development (WSSD) Plan of Action (paragraph 38 among others) calls for the development and implementation of integrated land-management and water-use plans that are based on the sustainable use of renewable resources and on integrated assessments of socioeconomic and environmental potentials and for the strengthening of the capacity of governments, local authorities, and communities to monitor and manage the quantity and quality of land and water resources in order to achieve the Millennium Declaration target of halving, by the year 2015, the proportion of the world's population without access to safe drinking water and meet the food-security needs at the same time.

Appendix 1 The Various Definitions Of Water-Use Efficiency

89. A central factor in the analyses of FAO, IFPRI, and IWMI is the water-use-efficiency (WUE) variable. Unfortunately, each of the analyses used a different definition of WUE, which can be limiting when comparing the outcomes of their analyses. This appendix aims to clarify the differences between the various definitions of WUE. It is based (without use of references) on "Role and Use of Economic Incentives in Irrigated Agriculture" (Tiwari and Dinar 2002a).[17]

A1.1 THE VARIOUS FACES OF WATER USER ASSOCIATIONS AND WHAT THEY MEAN

90. In simple terms, water-use efficiency in an irrigation system refers to the ratio of water volume applied at the crop-root zone to the total water volume entered into the main delivery system. Traditionally, the efficiency in water use has been looked upon from a technical point of view. The technical efficiency rate used in engineering design and the economic efficiency rate used in measuring the overall economic returns from the irrigation system, however, provide only a partial basis for measuring efficiency and implementing means to improve it. The term "efficiency" in irrigation-water use thus should not be limited to technical efficiency or to water conveyance and distribution. In the face of growing water scarcity and changing patterns of water demand, there is a need for redefining efficiency and understanding the existing links between the various faces of WUE.

Technical efficiency

91. The technical concept of efficiency of irrigation-water use is usually measured by the ratio between total water supplied by the system to the total water used by the plant. Technical efficiency differs from the overall concept of WUE in that it is measured in terms of the physical layout of the canal systems (such as conveyance, distribution, and application efficiencies). Following is the accounting for the loss of irrigation water due to seepage and percolation, as well as evaporation during conveyance and water use at the farm level. The irrigation efficiency of the major surface-irrigation systems of the world is estimated to be very low (between 37–50%).

92. These various measures of technical efficiency—conveyance, distribution, and application efficiency—are mainly influenced by topography, type of soil, the materials used in the canal lining, and the methods of water application. The economic implication is this: how can we increase the existing low level of technical efficiency of irrigation systems by introducing the use of economic-incentive measures at the various levels of water conveyance and applications?

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[17] See also Tiwari and Dinar (2002b).

Economic efficiency

93. The economic efficiency of irrigation-water use is measured in terms of crop output per unit of water applied (or overall financial returns in terms of net benefits from the project). Economic efficiency is usually measured in terms of a cost-benefit ratio and has long been used in investment decision making. It seeks to derive a maximum return from the irrigation system over the life of the project. It includes the impacts of price policies as well as incentives for farmers to move to high-value crops. The definition of WUE itself is rooted in the concept of economic efficiency, which implies that water needs to be used with the maximum possible efficiency. It can be defined in various ways:

- In general, economic efficiency indicates the Pareto optimality condition and considers not only the private costs and benefits but also the internalization of the nonfinancial social costs and benefits.
- Economic efficiency also refers to the maximization of overall socioeconomic net benefits from different water-using sectors and seeks to minimize intersectoral and intrasectoral socioeconomic opportunity costs. The term also applies to policies involving the reallocation of water to different users (e.g., within the agricultural sector or from agricultural use to urban or environmental use).
- From the sustainability viewpoint, the concept of economic efficiency can be defined in terms of weak sustainability considering water as a "critical capital." To some extent, increasing investment in water augmentation could also minimize the scarcity of water.
- Finally, economic efficiency also refers to the productive efficiency—indicating a chosen trade-off between production and conservation with the least cost. At the basin level, productive efficiency refers to the percentage of catchment yield applied to productive uses rather than the part lost to evapotranspiration or unrecoverable groundwater pollution (Winpenny 1997).

The term *economic efficiency* thus needs to be considered in a broader perspective and should involve technical efficiency, opportunity cost of water, and externality costs generated by irrigated agriculture.

Ecological and environmental efficiency of water use

94. Ecological efficiency, in the case of irrigated agriculture, is deeply rooted in the concept of environmental sustainability. It implies that available water resources must be managed in a way so as not to reduce the potential use of future generations for various ecological reasons. In operational terms, ecological or environmental efficiency indicates that available water should be allocated to meet the need for consumptive use of water without having adverse effects on the ecological health of the surroundings. From an economic viewpoint, the lost-opportunity benefit of water in terms of its impacts on ecological health of water transfer also needs to be considered while making water-allocation decisions. This is for various reasons:

- First, although the term WUE itself is widely perceived to mean a beneficial reduction of water use or conservation of irrigation water, it needs to be taken into consideration that there are negative impacts of water withdrawal and use. For example, one can refer to the impacts on the wetlands or aquatic ecosystems from the diversion of river water. The diversion of large amounts of river water for irrigation purposes affects ecological functions, such as aquatic life downstream.
- Second, water used for irrigation purposes can result in increased waterlogging, salinization, and soil erosion. These are also "externality costs," which are not usually incorporated into the economic price of irrigation water.

- Third, there is a need to recognize the ecological limits of water use. For example, in case of groundwater use, although water is used more efficiently, the total water withdrawn may exceed the sustainable supply.
- Fourth, increasing ecological degradation, such as wetland and upper-watershed degradation and the excessive withdrawal of groundwater, could also affect the availability of water for future use in agriculture.

95. The implication of the environmental measure of efficiency is that economic incentives should not be limited to water conservation. There is also a need to incorporate ecological concerns in a given agro-ecological setting.

Other faces of WUE

96. There are some other concepts of WUE. These include end-use efficiency and productive efficiency (often related to on-farm water use), operational measures of efficiency (such as institutional efficiency), and finally, temporal measures of efficiency such as static and dynamic efficiency. These various faces of WUE are defined and used in different contexts under different agro-ecological settings. The reported irrigation-efficiency and water-loss figures in developing countries indicate that many irrigation systems are performing poorly with respect to conveyance and distribution. Therefore, raising WUE through reduction in water losses could substantially increase water conservation.

97. Improvements in WUE involve measures that directly help to reduce different types of water loss,. while improving the handling of water at various levels. Various decision makers can be approached. Farmers' behavior can be affected in order to maximize the returns from, or to minimize the waste of, scarce irrigation water. On the other end, there are things water suppliers can do, such as better managing reservoirs and coordinating their efforts in water-supply scheduling.

98. As has been argued so far, WUE is affected by many factors, some of which are exogenous to the decision maker. Water loss due to evaporation from open channels, wind drift, bare soil, and weeds is usually responsible for 20–30% of total water loss. Various factors such as surface losses, canal flow not applied to the field, runoff from the field, and outflow from drains are responsible for water loss. These factors are mainly influenced by agro-ecological characteristics, the types of technology and methods of cultivation practiced by farmers, socioeconomic factors, and organizational effectiveness. Efforts toward reducing water loss and improving WUE thus require an integrated approach combining these various aspects.

A1.2 FEEDBACK FROM REVIEWERS ON WUE[18]

99. It is proposed to use the several concepts in the following way: water productivity (kg/withdrawals or kg/ET); classical efficiency (ET – effective precipitation)/withdrawals; and basin efficiency (beneficial consumption (ET + industry and domestic)/available water).

[18] David Molden, IWMI, Colombo, Sri Lanka.

Water productivity

100. Generally, water productivity is an increase in mass of produce or value of output per unit of water, either in terms of ET or withdrawals. The idea is that by increasing the mass of produce there will be less need for more ET or withdrawals. This frees up water for other uses. Water productivity can be increased through better water management in irrigation, better crop and soil management, and through changing crop varieties. IWMI, and now the CGIAR in its challenge program and comprehensive assessment, place a lot of emphasis on increasing the productivity of water.

Classical efficiency

101. This term was created by Jack Keller. The basic definition is this: ET - effective precipitation/water withdrawals. Drip irrigation is aimed at either reducing withdrawals or increasing ET relative to withdrawals. Water pricing is often aimed at reducing withdrawals. When people, particularly engineers, want to improve efficiency they like to improve classical efficiency. Note that one way to do this is to increase ET relative to withdrawals minus an increase in agricultural consumption (and usually production). Recently, however, there has been a lot of discussion about the idea that increasing classical efficiency does not always lead to real, basin-level water savings.

Basin efficiency

102. This is a relatively new idea. It is defined as beneficial depletion divided by water available for use (after subtracting environmental requirements and downstream commitments). Basin efficiency gives an indication of the scope for water savings. A danger is that (depending on how it is defined) an efficiency level that is too high may not be environmentally sustainable or desirable because too much water is “burned up” in agriculture.

103. Increasing basin efficiency to acceptable levels and considering environmental requirements is important because it lessens the need for additional water for irrigation. Higher basin efficiency does not necessarily reduce the need for withdrawals for irrigation.

104. There are generally two paths to increased basin efficiency: increasing classical efficiency by more precise irrigation or stopping leakages or reusing and recycling water (which is already prevalent in many basins). We are finding that, especially in water-stressed basins, basin efficiency is already very high—or too high—and there is little room for water savings. The only remaining option is to increase the productivity of water.

105. Investments in classical efficiency may not increase basin efficiency because of existing recycling. They can be important in providing better service and control, and in reducing pollution. But it is not clear whether someone relying on pumping groundwater or drainage water has better water control and service than someone relying on surface water irrigation.

Appendix 2 Review of Global Irrigation-Water-Demand Projection Assumptions, Scenarios, and Results by Three International Agencies (IWMI, FAO, and IFPRI)

106. With increased population, the demand for food and fibers is expected to rise. Irrigated agriculture is one of the major contributors to the supply of food and fibers in the world. With increased competition for scarce water and land resources, the question is where the additional food will come from. With this in mind, three agencies—the International Water Management Institute (IWMI), the United Nations Food and Agriculture Organization (FAO), and the International Food Policy Research Institute (IFPRI)—have developed analytical frameworks of various rigor to address these issues. The models are based on different assumptions, and all admittedly provide only a partial picture of the future of irrigation-water demand and supply by 2025 and 2030. The models include various scenarios of future development in the water sector. This brief note presented in the appendix is an attempt to initiate evaluation of the forecasts that were produced by existing models and approaches. It also summarizes the major assumptions made, the scenarios developed, and the results and analysis made by the three agencies. Appendix A-2.1 presents the basic components of the models, assumptions, and scenario results in the Policy Interactive Dialogue Model (PODIUM) developed by IWMI for projecting the global irrigation-water demand and supply by 2025. Appendix A-2.2 presents a brief note on the FAO study of irrigated agriculture and basic assumptions made as part of the FAO Study entitled "Agriculture AT 2015/30." Finally, IFPRI's IMPACT-WSM model's components, basic assumptions, scenario analysis, and results are presented in appendix A-2.3.

A2.1 THE IWMI PROJECTIONS OF WATER SUPPLY AND DEMAND BY 2025[19]

Background

107. This chapter presents the model components and the processes needed to evaluate the forecasts of irrigated area that were produced by existing models. It summarizes the major assumptions made, the scenarios developed, and the results and analyses made in PODIUM developed by IWMI. The PODIUM consists of two versions: the *country model* and the *global model*. The model covers about 100 countries with 96% of the world's population. The version of the model reviewed in this brief note is the global model, which includes 45 countries in the major regions of the world and with 80% of the population. It also includes a less detailed analysis of 80 countries that has been used in the preparation of a water-scarcity map (IWMI 2000). In this application of PODIUM, the model is used to test the three scenarios—base business-as-usual, no growth in irrigated lands, and growth in irrigated lands. In all three scenarios, the year 1995 is taken as a base year to represent the actual situation, while the year 2025 stands for the future situation. The global-level model is presented in Excel Spreadsheet format, and the results

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[19] This brief note is based on " World Water Supply and Demand: 1995 to 2025." Draft Version, 29 February 2000, IWMI/ World Water Vision/CGIAR. The description of alternative scenarios in section IV is, however, based on the January 2000 version available on the web at www.worldbank.org/essd/rdv/vta.nsf/Gweb/water.

obtained from the individual country model are grouped to provide a global scenario of water demand and supply by 2025.

Model components and the methodological process

108. The different components of PODIUM and the methodological process adopted for the projection of water demand and supply for irrigated agriculture involve the following four major components:

Component I: The estimation of national food requirements based on assumptions regarding population growth, daily calorie intake and composition of diets, and conversion ratios from feed stuff to animal products.

Component II: The projection of cereal production based on expected yields and the cultivated area—under both irrigated and rain-fed conditions—and the comparison of projected cereal production to compute the food deficit/surplus.

Component III: The conversion of projected food production into water demand and the comparison of the computed water demand to the actual water diversions to that of the base year (1995) and the available renewable water resources.

Component IV: Analysis of the results done by grouping the countries by degree of water scarcity, assuming several criteria for the classification of degree of water scarcity.

109. These different PODIUM components with basic assumptions made are shown in figure A-2.1.

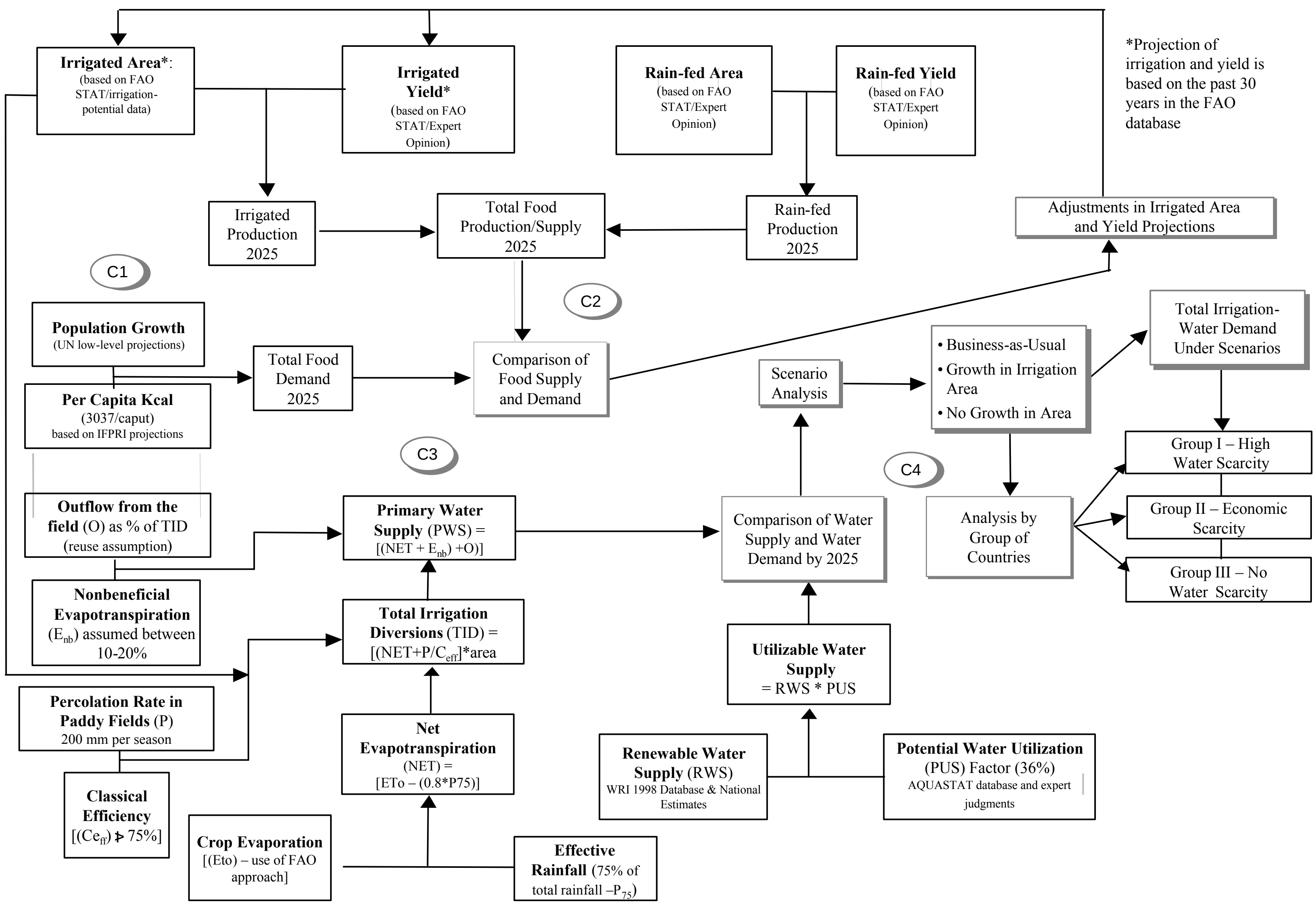
Basic model assumptions

Socioeconomic aspects (population projections and estimations of total food demand)

- *Population growth* and total population assumed for the computation of total food requirements by 2025 is based on the average of the United Nations medium- and low-level population projection scenarios (UN 1998).

- The *diet composition* used for the estimation of the total food requirements is derived from the FAOSTAT database for the base year 1995. The projections regarding calorie intake and diet composition for the year 2025 are based on the results obtained from IFPRI's IMPACT model, using the Vision 2025 scenarios. Total calorie (kcal) consumption per capita, per day for all the countries is assumed/estimated to increase from 2,771 in 1995 to 3,037 in 2025, or about 10%. The total calorie supply from cereal products and animal products is estimated to increase by 32% and 58% respectively.

Figure A2.1 PODIUM components and assumptions under the business-as-usual scenario



- The *demand for cereal foods* is estimated to increase by 32%. The demand for cereal for feed is estimated to increase by 50%. The total cereal demand including waste is estimated to increase by 38%.

Assumptions on food production (area and yield)

- Use of FAOSTAT database (average of 1994–1996) for the base year for *agriculture area.*
- Use of *irrigated yields and areas* from FAO's study "World Agriculture: Towards 2015 and 2030" (FAO 2002). Rain-fed yields and areas are computed by subtracting irrigated production from the total production as given in the FAOSTAT database.
- Projections of yield and areas under both rain-fed and irrigated conditions follow the observed trends in the previous 30 years from FAOSTAT. It is expected that in countries where actual crop-yield levels were low, yields will grow faster than in countries where yields are already quite high.
- The *expansion of irrigated area* for individual countries' growth rates were adapted by taking into account observed trends over the past 30 years and the irrigation potential.
- The information on irrigation potential was obtained from the FAO AQUASTAT database and specialists' knowledge of individual countries. The projection of total food production was calculated as the sum of rain-fed and irrigated-agriculture-area production.

Assumption/estimation of global food trade

The study assumes that: i) the production potential of the food exporting countries will be sufficient to meet the increased needs for cereal imports of the food-importing countries without severe financial or environmental damages, ii) the trade positions of many countries would be changed or diversified, and iii) the net cereal exports, as a percentage of the total cereal consumption in the world as a whole, would decrease from about 3.3% in 1995 to 1.8% in 2025. But the PODIUM does not directly include these assumptions/estimation in the computation of irrigated area or total water demand.

Hydrological aspects (effective rainfall, freshwater withdrawals, and groundwater use)

- The *effective rainfall* is approximated as a percentage of the 75% probable rainfall in the computation of net water requirements.
- The *renewable water supply* (RWS) is assumed to be the average annual run-off of past and present precipitation.
- *Utilizable water resources* in the model is considered to be the percentage of the annual RWS that is potentially usable under the concept of the *potential-utilization factor.* The potential-utilization factor depends mainly on the seasonal and interannual variability of precipitation. Potential storage facilities are assumed at only 36% (primarily due to large river basins in Bangladesh, Brazil, and monsoon floods of India). Most of the countries have utilization factors of around 60%, and the dry countries up to 85%.
- Both the available renewable water resources and the potential-utilization factor are used to compute the total *utilizable water supply* (UWS) of a country. It is defined as the amount of water that can ultimately be utilized.
- The model also makes the distinction between *total diversions* (TD) and *primary water supply* (PWS) by introducing the concept of the recycling of return flow for the use of irrigation (also known as *wa-*

ter multiplier effect). Further, the model distinguishes between the evaporatively-used water, or evaporated water which is the sum of water depleted by crop evaporation and nonbeneficial evaporation.

- The PWS, which is the annual average amount of UWS that is presently being utilized through water-storage and -conveyance facilities, also includes the part of PWS that is recycled through various uses in the system. Thus, the total amount of diversions as computed in the model is much larger than PWS.
- Crop-water requirements are percolation rates, water-use efficiency, reuse of drainage and wastewater, computation of net irrigation requirements.
- *Crop evapotranspiration* is estimated as transpiration by crops plus non-beneficial uses such as evaporation from bare soil and from water bodies (canals and reservoirs). This is accounted for by a factor expressing nonbeneficial evaporation as a percentage of net evapotranspiration (NET). This factor varies between 10% and 20% in PODIUM.
- The volume of water required is estimated by multiplying the NET and the irrigated area. The model assumes the same net irrigation requirements in the base year and 2025. That is, only the irrigated area varies under the scenario compared to the base year.
- *Percolation rate for paddy fields,* unless stated otherwise is assumed at 200mm per season and is to remain at a constant level in 2025.
- *Classical water-use efficiency* was obtained from available global databases and it was assumed that irrigation efficiency cannot exceed 75%, which is considered to be the maximum achievable efficiency. The concept of water-use efficiency used, however, is river-basin-wide efficiency rather than on-farm water-application efficiency. The river-basin-wide efficiency includes the return flow or the water-recycling/water-multiplier effects.
- The *net irrigation requirement* is computed by subtracting the effective rainfall for two different seasons. The *total irrigation diversions* are estimated by dividing the sum of net irrigation requirements and the amount of percolation by the assumed irrigation efficiency.

Assumptions on intersectoral water allocation/needs (e.g., for domestic and industrial water use)

The PODIUM also considers water demand for domestic water supply and industrial water use by 2025, but no assumptions are made on the implications of intersectoral water demand and withdrawal on the irrigation-water demand and withdrawal by 2025.

Environmental aspects (assumption on considerations of ecological use of water in-situ condition, if any)

The study indicates that the growing waterlogging and salinity problem could reduce irrigated area, but no particular assumption is made of the water demand or supply regarding environmental concerns. The study assumes that total evaporation cannot exceed 75% of PWS, leaving 25% of PWS for environmental benefits (such as provisions of environmental supplies to estuaries and coastal areas plus the flushing of salts and other pollutants). The study makes no assumptions or incorporation of issues directly related to the potential impact of climate change.

Assumptions related to policy, institutions, and technology

110. The study assumes that countries will continue to pursue a self-sufficiency policy because a high percentage of the population in rural areas will attempt to be as self-sufficient as they reasonably can be in order to conserve foreign exchange and provide rural livelihoods. The situation, however, is expected to change gradually over time as exports grow, the growth of the labor force slows, and employment opportunities in other sectors improve.

111. The next major assumption is related to the increase in irrigation intensity. It is assumed that irrigation effectiveness, and consequently irrigation intensity, will increase as a result of developing-countries' continued emphasis on, and investment in, overall rural development. This includes irrigation infrastructures and formulation and the adoption of policies that will help increase water-use efficiency.

Projection scenarios: major assumptions and links to the model

112. The model analyzed the IWMI base scenario and the no-growth-of-irrigated-areas scenario.

IWMI base scenario: major assumptions and scenario results

- It is assumed that growth in the net cereal-growing irrigated area is an indicator of the net irrigated-area growth, and a substantial part of the total gross area growth is expected because of the irrigation-intensity increase.
- The net irrigated area of the 45 countries is projected to increase by 22% from 233 million (M) ha in 1995 to 285 million ha in 2025. The gross irrigated area is projected to increase by 29% from 336 million ha in 1995 to 434 million ha in 2025. The difference in the projected net and gross irrigated area of 26 million ha is due to the irrigation-intensity increase.
- The irrigation efficiency and recycling is assumed to increase in varying degrees for different countries.
- The overall irrigated cereal yield of the 45 countries is assumed to grow by 40%, and the rain-fed yield by 12%, over the thirty-year period.
- Under this scenario, the total diversions for the three sectors (irrigation, domestic, and industrial) of the 45 countries are estimated to increase by 29% from 3196 km^3 in 1995 to 4124 km^3 in 2025. The PWS is estimated to increase by 28% from 2120 km^3 in 1995 to 2718 km^3 in 2025. The difference in the projected growth of total diversions and PWS is due to increased recycling.
- China, India, and the United States are by far the greatest water users, and they together will account for 1,439 km^3 of PWS, 53% of the total PWS of the 45 countries by 2025.

IWMI base-scenario results (January 2000 version based on the study of 100 countries)

- The net irrigated area of the 100 countries is projected to increase by 24%; from 253 million ha in 1995 to 312 million ha in 2025. The total increase in gross irrigated area over the thirty-year period is projected to be 30%, from 354 million ha in 1995 to 466 million ha in 2025. The difference between the projected gross and net irrigated area, i.e., 53 million ha, is due to the increase in irrigation intensity. More than 85% of the area gained due to intensity increase is in developing countries.
- Under this scenario, the primary irrigation-water supply of the 100 countries is projected to increase from 1708 km^3 to 2021 km^3.

- Total water diversions and total primary water supply for the agricultural, domestic, and industrial sectors is expected to increase by about 1040 km^3 while primary supply will increase by 577 km^3. Most of the additional water diversions (about 935 km^3 total water supply and 464 km^3 primary water supply) will be in the developing countries.

No-area-growth scenario results

113. This scenario assumes no growth in irrigated or rain-fed cereal-growing area and slower growth in irrigated yield. The study also assumes irrigated yield growth at half compared to the business-as-usual scenario. While the paper highlights the food-scarcity situation in different regions, no discussion on the water demand or water balance was included.[20]

Summary of scenario results

114. Overall results of the study for the 45 countries under the IWMI base scenario indicated that:

- By sector, irrigation is, and will remain, the largest single user of water, accounting for about 68% of both total diversions and PWS in 2025. But compared with the other two sectors (domestic and industrial), the irrigation sector would be the slowest growing water sector, with PWS increasing by only 17% over the period.
- The domestic sector represents the smallest sector, at only 11% of diversions, but is the most rapidly growing sector, with an increase of 84% over the period. Likewise, the industrial diversions would comprise 22% of total 2025 diversions, growing 60% over the period.

115. The no-area-growth scenario indicates:

- Less demand for irrigation water and hence less strain on water demand.
- Substantial deficits in cereal production.
- The developing countries, especially in southern Asia, eastern Asia, and in sub-Saharan Africa, are the most affected in terms of food-production deficits.

Analysis of the results by group of countries

116. For the purpose of analysis of water scarcity, the 45 countries studied were grouped into three basic categories using the water-scarcity criteria.[21]

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[20] This section is from the January 2000 based on the study of 100 countries.

[21] The first criterion is based on the degree of development, which defines the countries in Group I, those are in a state of physical water scarcity (expressed as the percentage of PWS to UWS exceeding 60%). The second criterion, growth of PWS, defines the countries in Group II, which are in a state of economic water scarcity. This is the rate at which PWS must be developed over the 1995–2025 period to attain the objectives of the base scenario. In this case, the rate of growth of PWS is assumed equal to, or greater than, 25% and would be stressful in terms of the financial and development capacity for most countries. The Group III is countries without water scarcity. These countries are not water-scarce and need to develop less than 25% of additional PWS to meet their 2025 needs.

117. *Group I* consists of countries in the Middle East, southern Africa, the drier regions of western and southern India, and northern China and contains 33% of the total population that face water scarcity in 2025. The results of the study indicated that:

- even with the highest-feasible efficiency and productivity of water use, these countries do not have sufficient water resources to meet their agricultural, domestic, industrial, and environmental needs in 2025.
- many of these countries are facing difficulties even in meeting their present needs. They have some costly options such as desalinization plants, reducing the amount of water used in agriculture, transfering it to the other sectors, or importing more food.
- some alternatives exist for the interbasin transfers that are being considered in India and northern China.
- *Group II* represents countries that do have sufficient water resources to meet 2025 needs. Major implications of the study for this group of countries with 45% of the total population include the need to increase water supplies through additional storage, conveyance, and regulation systems by 25% or more over 1995 levels to meet their 2025 needs and that severe financial and development constraints may pose a threat to meeting their water needs.

118. *Group III* consists of countries that will need to develop less than 25% more water supplies to meet their 2025 needs. They represent 22% of the total population. While in most cases this will not pose a substantial problem, several countries in this group could actually decrease their 2025 water supplies from 1995 levels because of increased water productivity.

Implications for water resources development

119. The IWMI-study results indicated that in order to meet increased water demand by 2025, the world's primary water supply will need to increase by 28%, from around 2,120 km^3 per year in 1995 to 2718 km^3 per year in 2025. This amounts to an increase in surface- and subsurface-water storage sufficient to release roughly 600 km^3 water over the 30-year period.

120. With consideration of factors such as the continued reduction in storage capacity of the existing water-storage capacity (assumed at 1% per annum) as a result of sedimentation and the overdraft of groundwater (assumed at 10% beyond the sustainable level), the total amount of additional water storage and conveyance required by 2025 is around 860 km^3 per year. This represents a total requirement for 2025 of nearly 3,000 km^3, or effectively a 41% increase of PWS.

A2.2 FAO PROJECTIONS OF IRRIGATION-WATER DEMAND BY 2015 AND 2030[22]

Background

121. Irrigated agriculture in the developing countries accounts for 20% of the arable land and contribute some 40% of total crop production (nearly 60% of cereal production). The FAO study, "Agriculture: Towards 2015 and 2030," projects the likely expansion in irrigated area and total water demand by 2015 and 2030. The projections made, however, do not correspond to past trends. The projections made are deviations from past trends. The base year for the study is the three year average (1997–1999), and the projections are made for the years 2015 and 2030. The year 2015 was chosen in order to assess the prospects for progress toward meeting the goal of the 1996 World Food Summit (WFS) of halving the number of chronically undernourished persons in developing countries by no later than 2015. The time horizon of 2030 was chosen to offer a sufficiently long period to analyze issues of technical agriculture and sustainability.

122. Irrigation potential in the FAO 2015 and 2030 study is considered to be the area of land suitable for irrigation development (including land already under irrigation). Methods used in assessing irrigation potential vary from one country to another. In most cases, it is computed on the basis of available land and water resources, but economic and environmental considerations are taken into account to a degree. Except in a few cases, no consideration is given to the possible double counting of water resources shared by several countries, and this may lead to an overestimation of irrigation potential at the regional level. Wetlands and floodplains are usually, but not always, included in the estimation of irrigation potential. Although an overestimation of irrigation potential at the regional level is possible at the initial stage, the availability of water resources is taken into account when the final projections are made for land under irrigation in 2015 and 2030. This brief review attempts to summarize the methodological process involved, basic assumptions made, and the results of the study on the projections of irrigated area and water withdrawals for agriculture by 2015 and 2030.

Model components and methodological process

Component 1: Projection of commodity demand-supply balance in the form of supply-utilization accounts (SUAs).[23]

Component 2: Development of Global Agro-Ecological Zone (GAEZ) database on agro-ecological classes and identification of potential areas for rainfed and irrigated agriculture based

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[22] This brief note is based on Alexandratos (1995), Fischer, et al. (2000), and FAO (1997, 2002).

[23] The SUA is an accounting identity showing for any year the sources and uses of agricultural commodities in homogeneous physical units, as follows:

Food (direct consumption) + Industrial Non-food Uses + Feed + Seed + Waste = Total Domestic Use = Production + (Imports - Exports) + (Opening Stocks - Closing Stocks)

The AT2015/2030 database has one such SUA for each commodity, country, and year (1961–1999). The data preparation work for the demand-supply analysis consists of the conversion of the about 350 commodities for which the primary production, utilization, and trade data are available into the 32 commodities covered in this study while respecting the SUA identities. For more details see FAO (2002).

on the FAO/UNESCO digital map of the world with more than 9.2 million grid cells and other maps and databases on climate change, land cover, etc.

Component 3: Generation of land-use balances in great detail (by agro-ecological classes and with distinctions between harvested and arable land) and controls for land availability constraints including availability of renewable water resources for irrigation-water supply purposes and an estimation of irrigation potential.

Component 4: Computation of actual crop area, yield, etc., for the base year taking the average of 1997–1999 database available from FAOSTAT and the use of very diverse sources of data and knowledge contributed by the specialists on different countries and disciplines for the projection of expansion in irrigated area, yield, etc.

Component 5: Computation of water balance and water withdrawals by 2015 and 2030. Calibration of the water-balance results were obtained by comparing calculated values for water resources per country (i.e., the difference between precipitation and actual evapotranspiration under nonirrigated conditions) with data on water resources for each country using the AQUASTAT information system.

123. Figure A-2.2 below provides a tentative sketch of these various components of the estimation of irrigated area and total water withdrawal for agriculture by 2015 and 2030.

Basic model assumptions/specifications

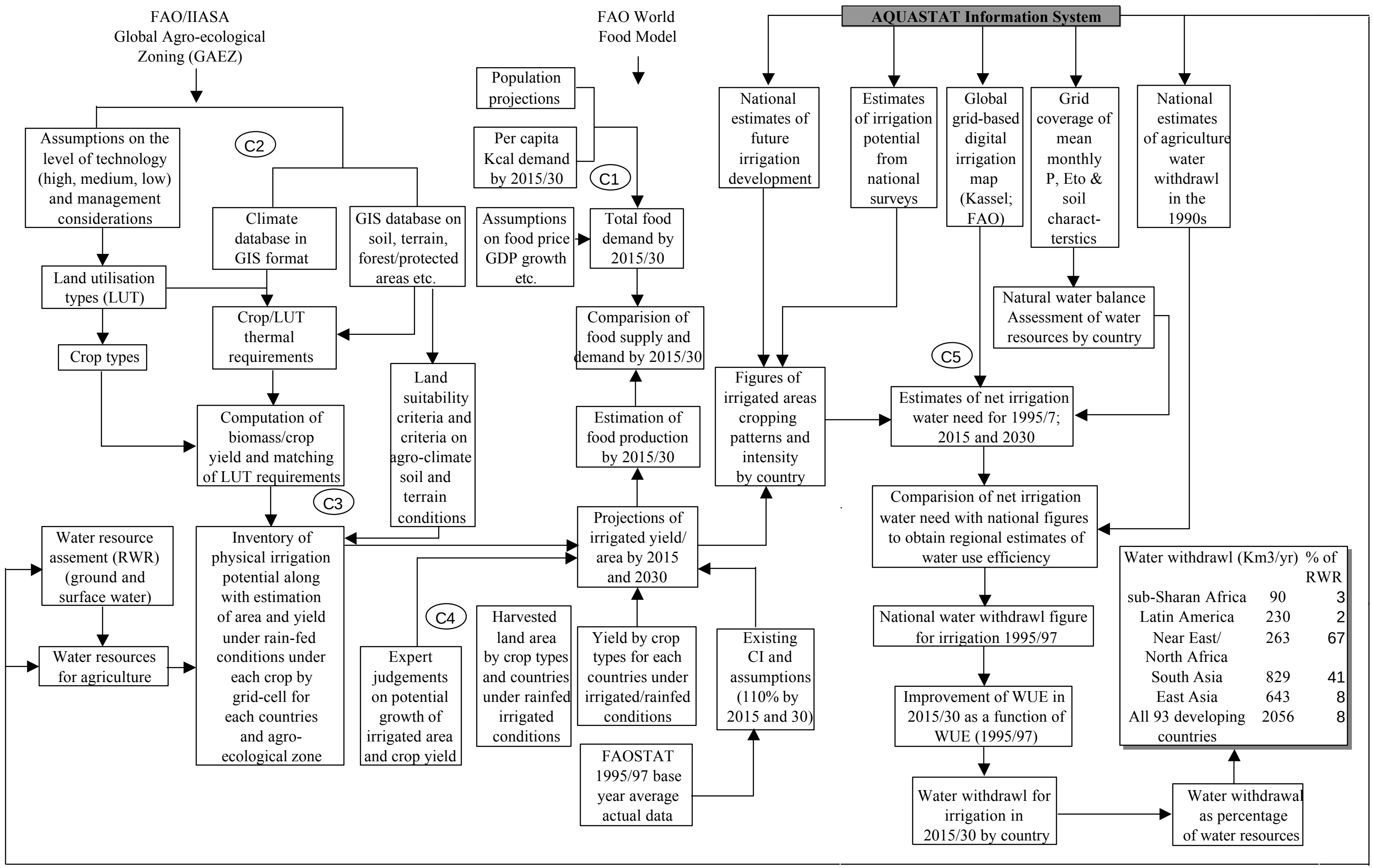
124. Basically, assumptions made regarding crop intensity and irrigation efficiency, among others, play a critical role in the computation of total water withdrawal for irrigation in the FAO study, "Agriculture: Towards 2015 and 2030." This section provides a brief summary of both the general and specific assumptions made on various aspects (socioeconomics, estimation of irrigation potential, hydrology, water requirements, cropping intensity, and irrigation efficiency) in the study.

Socioeconomic aspects (population and estimation of food demand)

- The population projection is based on United Nations population projections (1998). Global population is estimated to grow from 5.75 billion (the three year average 1995–1997) to 7.15 billion (1.3% growth per annum) and 8.1 billion in 2030 (0.3% growth per annum).
- The GDP growth rates to 2015 are those projected by the World Bank for each country, extended to 2030 by FAO.
- The per capita, per year kcal (in the case of cereals) is projected to increase from 2626 kcal in 1997–1999 to 2803 kcal in 2015, and 3050 kcal in 2030.
- The rate of growth of the world meat demand is projected at 1.9% per annum until 2030 compared with the 2.7% in the past decades.
- The demand for cereals is projected to increase almost by another billion tons by the year 2030 from its current level (1997–1999) of 1.86 billions tons.

125. These assumptions and food-demand projections are indirectly linked to the projections of irrigated agriculture through the necessity of increasing total production, especially by increasing crop intensity and irrigated yield. The latter is largely based on the GAEZ database and expert judgments.

Figure A2.2 Model components and basic assumptions in the computation of irrigation water demand by 2015 and 2030



Assumptions on food production (area and yield): GAEZ methodology[24]

- Land area considered to have irrigation potential includes land in the existing rain-fed areas, used and unused, and varies with economic development as a result of competition for domestic and industrial water use.
- Irrigated cereal yields are expected to increase from 3.93 tons/ha in 1997–1999 to 5.30 tons/ha by 2030. The average annual growth rate of rain-fed and irrigated yields would be 1.0% by 2030 compared to the growth rate of 2.5% per annum recorded for 1961–1999.

126. These assumptions and projections are linked to the estimation of irrigation-water withdrawal in the computation of consumptive water use.

Calculations of water resources

127. A simple soil-water-balance model is used to calculate actual evapotranspiration and surface runoff. The water balance is assumed to be a function of precipitation, reference evapotranspiration, and soil–moisture-storage properties The computation of water balances was carried out by grid cells of 10×10 km, using a GIS database. The characteristics of the area covered by 10×10 km grid cell is lumped in a single spatial unit. The water balance is calculated in monthly time steps and consists of annual values by grid cell for the actual evapotranspiration and runoff. A few characteristics of input and output of the model are described below:

- The average annual precipitation for the 93 developing countries is considered around 1040 mm.
- The *surface runoff* is calculated as that part of the precipitation that neither evaporates nor can be stored in the soil. It is considered to be equal to the difference between precipitation and actual evapotranspiration. Incoming and outgoing flows between countries have been taken into account by superimposing the surface runoff over a digital elevation model. However, incoming flow from one region to another, which is of major importance in some regions (the Near East, North Africa, and south Asia), are not considered adequately.
- *Internal renewable water resources*, as calculated by the soil- and water-balance model, vary between the developing regions from 15% of precipitation in the most arid areas (the Near East and North Africa), where precipitation is a mere 180 mm per year, to about 50% in humid eastern Asia, which has the high precipitation rate of about 1250 mm per year.

Calculation of water requirements

128. The *irrigation-water requirements* are calculated as a function of the water balance as described above in combination with the extent of areas projected under irrigation. The estimation was carried out for all major crops for 1997–1999 and 2030 and consists of annual values for consumptive water use in irrigation. The following assumptions are made in the computation of irrigation-water requirements as outlined in the box 4.3 and section 4.4:

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[24] Details on the GAEZ methodology is provided in Fischer, et al. (2000). Some of the components are shown in figure 3.1.

- The *actual evapotranspiration* for crops under irrigation, estimated in millimeter (mm) and based on location-specific data for each grid cell, is assumed to be equal to the potential evapotranspiration.

- The *potential evapotranspiration* of a crop under irrigation is calculated by multiplying the reference evapotranspiration with a crop coefficient derived for four different growing stages: the initial phase, the development phase, the midphase, and the late phase. It is assumed that the initial, development, and late phases all take one month for each crop while the midphase lasts for several months. The value of the crop coefficients are assumed to be different for different months.

- The *consumptive use of water* in irrigated agriculture is defined as the water required in addition to water from precipitation (soil moisture) for optimal plant growth during the growing season. Optimal plant growth occurs when actual evapotranspiration of a crop is equal to its potential evapotranspiration. For each grid cell as mentioned above, the difference between the calculated evapotranspiration of the irrigated area and actual evapotranspiration under nonirrigated conditions is equal to the consumptive use of water in irrigated agriculture.

129. These assumptions/computation processes are directly linked to the estimation of total water withdrawal for irrigation by 2015 and 2030.

Assumptions on water-use efficiency and cropping intensity

- It was assumed that the irrigation efficiency will increase from 38% to 42%. There will be more of an increase in water-scarce regions (e.g., from 40% to 53% in the Near East/North Africa region) than in regions with abundant water resources (between 0 and 4 percentage points in sub-Saharan Africa, Latin America, and eastern Asia).

- The overall cropping intensity is expected to increase from 93% (1997–1999) to 99% (2030); for irrigated land, 127% to 141%.

- The concept of irrigation-efficiency used follows the traditional approach to assessing technical efficiency and has direct, as well as indirect, impacts on the estimation of total water demand for irrigation by 2015 and 2030.[25]

Assumption on investment and demand management

- The first assumption made was that the management of demand will play an important role in improving irrigation efficiency in water-scarce regions, but in humid areas the issue of irrigation efficiency is much less relevant and is likely to receive little attention.

- The next assumption was regarding improvements in existing irrigated lands. It was assumed that about 2.5% of existing irrigation must be rehabilitated or substituted by new irrigation each year. Under this assumption, nearly four-fifths of some 202 million ha considered would be rehabilitated for net expansion. The average life span of irrigation schemes was assumed to be 40 years.

130. These assumptions have direct implications on the estimation of total irrigated area and thus on the projections of total water demand by 2015 and 2030.

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[25] The technical efficiency is usually defined as the ratio of irrigation- water used by the crops of an irrigation farm during their growth period, to the water diverted from the canals during the same period of time.

Computation of water balance and calibration of the results

131. The water balance for each country and year is defined as the difference between the sum of precipitation and incoming runoff and the sum of actual evapotranspiration and the use of water in irrigated agriculture for that year. This is, therefore, the balance of water without accounting for water withdrawals for other needs (industry, household, and environment).

132. As outlined in section 3.2, calibration of the results were carried out by comparing calculated values for water resources per country (i.e., the difference between precipitation and actual evapotranspiration under nonirrigated conditions) with data on water resources for each country. In addition, the discharges of major rivers as given in the literature was compared with the calculated runoff for the drainage basin of these rivers. If the calculated runoff values did not match the values as stated in the literature, correction factors were applied to one or more of the basic input data on precipitation, reference evapotranspiration, soil-moisture storage, and open waters.

Projection scenarios: major assumptions and results[26]

Results on expansion of irrigated land projections

133. The aggregate result for the group of developing countries shows that the area equipped for irrigation in this group of countries will expand by 40 million ha (or 20%) over the projection period. This means that 20% of the land with irrigation potential not yet equipped at present will be brought under irrigation and that 60% of all land with irrigation potential (402 million ha) would be in use by 2030. The overall results of the study on the expansion of irrigated area indicated that:

- Due to a continuing increase in the cropping intensity on both existing and newly irrigated areas, the harvested irrigated area will expand by 84 million ha and account for about half of the increase in all harvested land.
- The projected net increase in arable irrigated land of 40 million ha is less than half of the increase over the preceding 36 years (99 million ha). In terms of annual growth, it would be “only” 0.6%, well below the 1.9% for the historical period.
- The projected slowdown reflects the projected lower growth rate of crop production combined with the increasing scarcity of suitable areas for irrigation and water resources, as well as the rising costs of irrigation investment. Most of the expansion of irrigated land is achieved by converting land in use as rain-fed agriculture or land with rain-fed production potential into irrigated land.
- The share of irrigated agriculture to total agriculture production is expected to increase from 59% in 1997–1999 to 64% in 2030.
- For the 93 countries, irrigation-water withdrawal is expected to grow by about 14%, from the current 2128 km^3/yr to 2420 km^3/yr in 2030. This increase is low compared to the 33% increase projected in the harvested irrigated area, from 257 million ha in 1997–1999 to 341 million ha in 2030. Most of this difference is explained by the expected improvement.

[26] Only one scenario, the baseline scenario, is provided. There are no alternative scenarios with different assumptions in the FAO "World Agriculture: Towards 2015 and 2030" study.

Results by groups of countries and region

134. The developed countries account for a quarter of the world's irrigated area—67 out of 271 million ha. Their annual growth of irrigated area reached a peak of 3.0% in the 1970s before dropping to 1.1% in the 1980s and to only 0.3% in the 1990s. This evolution pulled down the annual growth rate for global irrigation from 2.4% in the 1970s to 1.3% in the 1980s and 1990s.

135. Among the developing countries, it is estimated that of the 207 million ha irrigated at present, 42 million ha are on arid and hyperarid land, and of the projected increase of 39 million ha, about 2 million ha will be on such land. In some regions and countries, irrigated arid and hyperarid land form an important part of the total irrigated land presently in use: 18 out of 26 million ha in the Near East and North Africa region, and 17 out of 81 million ha in South Asia.

136. The total water withdrawal by region varies from 80 km^3/year in sub-Saharan Africa to 895 km^3/year in south Asia. In terms of the available renewable water resources, however, the scarcest regions appear to be the Middle East and North Africa accounting for 58% of RWR by 2030.

Implications for water resources development

137. The assessment of irrigation potential already takes into account water limitations, and the projections to 2030 assume that agricultural water demand should not exceed available water resources. Estimates of irrigation potential in the study are based on renewable water resources, i.e. the resources replenished annually through the hydrological cycle. In those arid countries where the mining of fossil groundwater represents an important part of water withdrawal, the area under irrigation is usually larger than the irrigation potential.

138. In terms of water scarcity, those countries suffering from a lack of precipitation, and therefore most in need of irrigation, are also those where water resources are naturally scarce. In addition, the water balance presented is expressed in yearly averages and cannot adequately reflect seasonal and interannual variations.

139. The net increase in the irrigated area in developing countries of some 45 million ha by 2030 will have environmental benefits, because flat or well-terraced irrigated lands are not generally the cause of, or prone to, serious erosion. However, unless there is an increased investment in greater water-use efficiency and drainage, there could be growing problems from the lowering of water tables, salinization, and waterlogging. Overextraction of groundwater could lead to several million hectares of irrigated lands falling out of production.

A2.3 IFPRI PROJECTIONS OF IRRIGATION-WATER SUPPLY AND DEMAND BY 2025[27]

Background

140. The IFPRI study (2001) attempts to project and analyze how water availability and demand will evolve over the next three decades (from the base year of 1995), taking into account the availability and

[27] This appendix is based on Rosegrant M.W. and X. Cai (2000).

variability of water resources, the water-supply infrastructure, and irrigation and nonagricultural water demands. It tries to ascertain what the impact of alternative water policies and investments on water supply and demand would be. This brief note attempts to highlight the methodological processes, major assumptions made, alternative scenarios, and results.

141. The study uses the International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) for the projection and analysis of food supply and demand and the Water Simulation Model (WSM) for projections of water supply and demand. In the IMPACT model, the world is divided into 36 spatial units including individual countries and regions, combining several countries. In the IMPACT-WATER simulation modeling, China, India, and the United States, which together produce about 60% of cereal in the world, are desegregated into major river basins. Both water supply and demand and food production is assessed at the river-basin scale. Crop production is summed to the national level, where food demand and trade are modeled.[28]

142. The study also attempts to study irrigation-water demand under several alternative scenarios and considers changes in irrigated area and cropping patterns, the change in water-use efficiency, the change in rainfall-harvest technology, and the change of water allocation among sectors to be the main drivers of policy shifts. As pointed out in the other two models, global climate change and the adaptation measures that could be employed could have a significant effect on irrigation-water supply and demand projections. However, this aspect is not directly incorporated into the current modeling framework.

Model components and process

Component 1: Projection of food supply and demand with the use of the FAO (2002) database and the IMPACT (International Model for Policy Analysis of Agricultural Commodities and Trade) model.

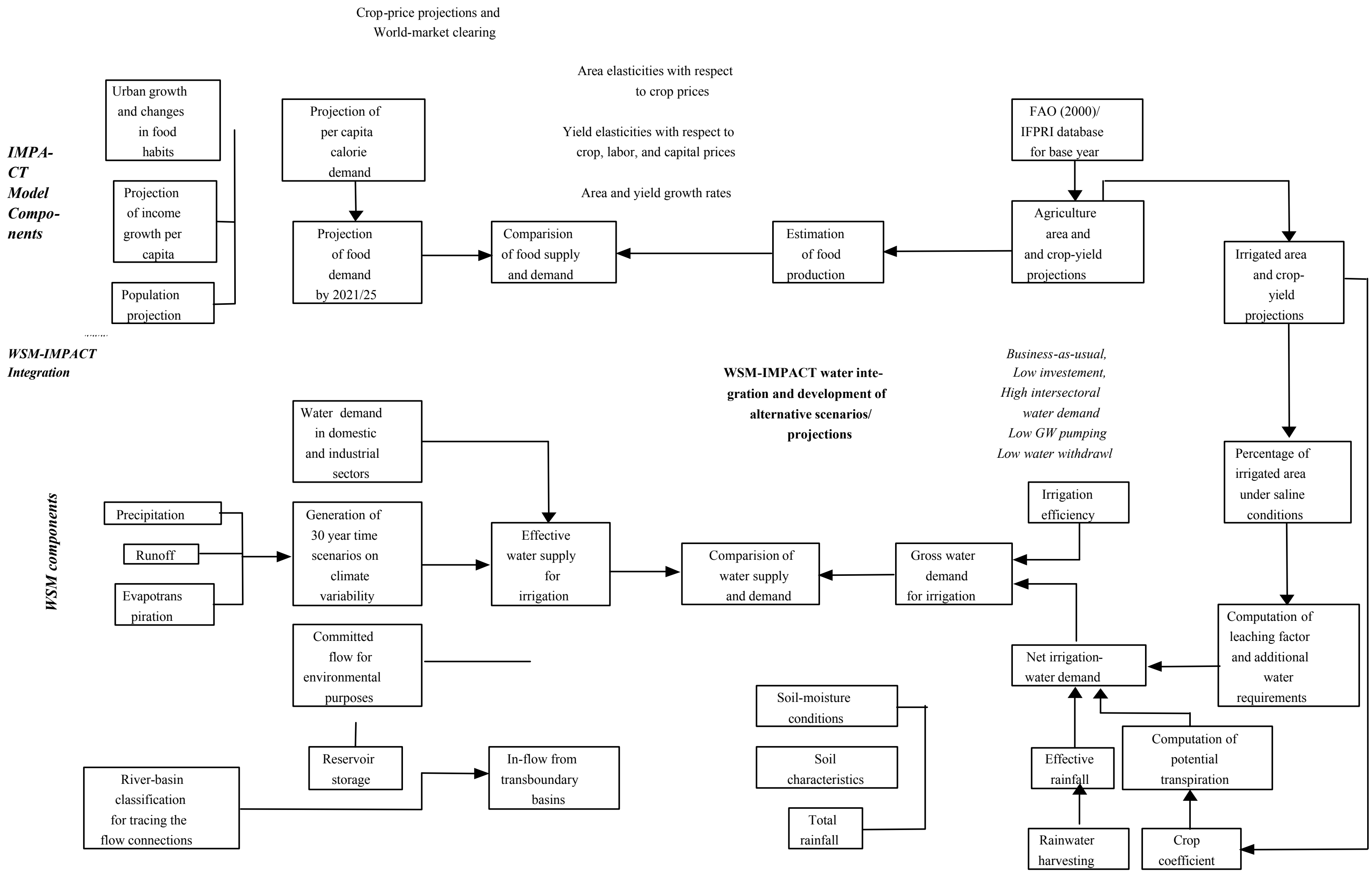
Component 2: Development and use of the Water Simulation Model (WSM) for the estimation of water supply and demand (water balance at the river-basin level) and analysis of alternative scenarios.

Component 3: The integration of IMPACT-WSM into an interactive model for analyzing the impacts of water supply constraints on food production, trade, and food-security concerns.

143. Figure A-2.3 provides a tentative sketch of these model components and the method adopted for the computation of water balance and alternative scenarios.

[28] The discussion on IFPRI-IMPACT model in this appendix, however, is limited.

Figure A2.3 WSM-IMPACT water model components and integration for estimation of water balance and projections of alternative scenarios



Basic model parameters and assumptions

Component 1 (IMPACT): baseline assumptions

144. The primary IMPACT model simulating food production, demand, and trade year-to-year over the next 30 years, is based on a calibrated base year of 1995. The basic assumptions and projections made on the socioeconomic aspects (population and income growth, food-income-demand elasticity, etc.) are as follows:

- The population-growth rate is assumed for different regions to vary from 2.4% growth per year in sub-Saharan Africa to just 1.7% and 0.7% growth per year in India and China, respectively, by 2020. The total-global population is projected to increase to 7,456.4 million by 2020 from the base-year population of 5,787.9 million.

- The GDP growth rate in the model is projected to change from 3.5 to 6.0% for East and Southeastern Asia; 3.6% to 4.5% for Latin American countries; from 3.2% to 3.8% for sub-Saharan Africa; 2.0% to 3.0% for eastern Europe and the former Soviet Union; and 2.2% to 2.7% for the rest of the developed countries by 2020.

- The income elasticity in the food-demand estimates in the model are based on the assumptions that there would be a gradual shift in the food-demand structure from the main staple foods to high-value products, such as meat, in the developing countries as a result of a rise in per capita income, rapid urbanization, and the commercialization of food production. This indicates that cereal-demand elasticities are expected to be significantly lower compared to meat-demand elasticity.

145. These assumptions and projections play a significant role in the computation of crop-productivity and area-growth projections by the year 2025 without considerations of any water-supply constraints. The study also makes use of the FAO database (FAO 2002), which classified irrigated- and rainfed-crop yield and area by countries and regions.

Component 2 (WSM): Model Sub-Components and Assumptions[2]

Hydrological aspects

Effective rainfall (PE) in the model represents rainfall that can be effectively used for crop growth, which is generally the only water source for rain-fed crops.

Renewable water (*RW*) refers to water that can be renewed by the natural cycling of water through the earth and atmosphere. *Inflow* is surface and groundwater that flows to the region from other regions.

Total water availability (TWA) for a single region is the sum of the renewable water, artificial basin/regional-water transfer, desalinated water, nonrenewable groundwater (which is only available for a limited period), and saltwater that is only available for limited uses.

Limits to water withdrawal or water supply for agriculture

146. *Maximum-Allowed Water Withdrawal* (*MAWW*): The water withdrawal capacity (surface-water-diversion capacity and groundwater-pumping capacity) available for agricultural, municipal, and industrial water uses. It refers to physical capacity and environmental constraints.

147. In the computation of MAWW, it is assumed that the committed flow for environmental and ecological maintenance, political agreements, and in-stream uses such as recreation, hydropower generation, and navigation, constitute a significant portion of total renewable water, ranging from 10% to 50%, depending on the availability of runoff and the relative demands for these in-stream uses in different basins.

148. *Effective Water Supply for Irrigation* (*EWIR*): field water supply that can be fully used for crop evapotranspiration. For one region in a specific time period, effective water supply for irrigation is subject to water availability; maximum allowed water withdrawal; water allocation between agriculture, municipal, and industry sectors; water quality (e.g., salt concentration); and water-use efficiency.

149. *Water-use efficiency* measures the ratio of beneficial water depletion (the water actually evapotranspirated by crops) to total water depletion. It reflects the water supply and application-infrastructure level and water-management quality of the river basin, irrigation system, and farm.

Assumptions regarding technology

150. Water-harvesting techniques will be adopted more cautiously to provide farmers with improved water availability in some local and regional ecosystems. It can also provide broader environmental benefits through reduced soil erosion. Although improved water harvesting is often associated with traditional agriculture, it also has potential in highly developed agriculture.

151. Advanced tillage practices of farmers as a measure of watershed conservation can also increase the share of rainfall that goes to infiltration and evapotranspiration. Contour plowing, which is typically a soil-preserving technique, can act to detain and infiltrate a higher share of the precipitation. Precision leveling can also lead to greater relative infiltration and, therefore, a higher percentage of effective rainfall.

Computation of water withdrawal

152. Finally, water withdrawal in the WSM is calculated as total water depletion divided by the water-depletion coefficient. The water-depletion coefficient in the context of the river basin is a function of water conveyance, distribution, recycling systems, pollution discharge and wastewater-treatment facilities, and the relative fraction of agricultural and nonagricultural water use (i.e., larger agricultural water use corresponds to a higher value of the water-depletion coefficient). Water withdrawal is made up of surface-water withdrawal and groundwater pumping.

153. The projections of both terms depend on the maximum-allowed water withdrawal (MAWW) of surface water and of groundwater. The maximum-allowed water withdrawal (MAWW) for a basin as defined earlier depends on several factors: the physical capacity of water withdrawal for agricultural, domestic, and industrial uses; in-stream flow requirements for navigation, hydropower generation, recreation, and environment purposes; source availability with particular concern for deep groundwater; and water demand.

Model Component 3: Connecting IMPACT and WSM

154. The WSM first computes the total effective water supply for irrigation (EWSI) in each time period and then allocates the total EWSI to crops based on their profitability, sensitivity to water stress, and their irrigation-water demand. In this computation process, higher priority is given to the crops with higher profitability, which are more drought sensitive and/or that require more irrigation water. From WSM, the monthly effective-irrigation-water supply by crop and by basin, over a 30-year time horizon, is generated and inputed into IMPACT. Other water parameters that are inputted into IMPACT include effective rainfall maximum crop evapotranspiration (ET_m).

155. The integration of WSM and IMPACT-WATER provides a wide range of opportunity for analysing water availability and food security at the basin, country, and world scales. Many policy-related water variables are involved in this modeling framework, including potential irrigated area and cropping patterns, MAWW with both surface and groundwater, water-use efficiency, water-storage and interbasin-transfer facilities, rainfall harvest technology, allocation of agricultural and nonagricultural uses, and the allocation of in-stream and off-stream uses.

156. These driving forces are then included in the WSM. The WSM output—reflecting the effects of these driving forces—are then included into IMPACT-WATER to compute the food supply, demand, trade, and prices. Policy implications related to these scenarios are explored based on the output from both WSM and IMPACT-WATER.

Scenario assumptions and results

Scenario S1: Baseline Scenario (BAS)

157. The baseline scenario in the IFPRI projections of water supply and demand by 2025 contain the best estimates of the policy, investment, technological, and behavioral issues in the food and water sectors. These assumptions are as follows:

Hydrological aspects

158. The projected *hydrologic regime* between 1995 and 2025 is modeled based on data (regarding things like precipitation, evapotranspiration, and runoff) from the period between 1961 and 1991. Results were derived from this run and from running 30 climate scenarios to assess the impact of hydrologic uncertainty.[29] The results of the projections for the single 30-year hydrologic-regime simulations are reported in terms of annual averages for 2021–2025, and the results of the multiple hydrological regimes are reported for the average for 2025 across the multiple scenarios.

159. *Maximum-allowed groundwater pumping*: it is assumed that the current rates of exploitation will not be maintainable over the projections period. While in areas like northern India, northern China, WANA (west Asia and North Africa), and the western region of the United States, overpumping will continue, it would be at slightly reduced levels. However, in other regions, it is assumed that a gradual increase in extraction in areas with more plentiful groundwater resources will take place. Net global groundwater pumping is projected to increase gradually to 922 km^3 by 2025 (20.9% of total-global water withdrawals), up from 817 km^3 in 1995 (21.9% of total water withdrawals).

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[29] From WaterGap 2.0, Kassel University, Germany (Alcamo 2000).

160. *Reservoir storage*: the total-global reservoir storage for irrigation and water supply is estimated at 3,428 km^3 in 1995 (47% of total reservoir storage for all purposes) and is projected to reach 4049 km^3 by 2025, a net increase of 621 km^3 over the next 25 years.[30]

161. *Rainfall harvest:* the potential for increased investments in rainwater-harvesting techniques is expected to increase the amount of effective rainwater by 3% to 5% (from 1995 levels).

162. *Total maximum-allowed water withdrawals:* total-global water withdrawals were 3,722 km^3 in 1995, which was 7.8% of the global renewable water resources. Water withdrawals for the base year 1995 are estimated at 2,796 km^3 in developing countries and 926 km^3 in developed countries.

Assumptions on basin-irrigation efficiency (BIE)

163. The average BIE for 1995 was assessed to be 0.56 globally (0.53 in developing countries and 0.64 in developed countries). Relatively high increases in BIE are assumed under the baseline scenario for developed and developing countries where renewable water-supply infrastructure is highly developed (e.g., India, China, and WANA). For other regions, such as sub-Saharan Africa and southeast Asia, where water-supply facilities are still fairly underdeveloped, only small increases in BIE are projected.

Based on the above assumptions, the average BIE is projected to reach 0.61 worldwide, 0.59 in developing countries, and 0.69 in developed countries by 2025. On a global basis, with the assumed improvement of water-use efficiency in the baseline, the global-water consumption demand is expected to decline 8% by 2025, relative to what it would be if effective efficiency remained constant.

Projections of irrigated agriculture under the baseline scenario

Under the baseline scenario, the total irrigated harvested area is expected to increase from 355 million hectares in 1995 to 417 million hectares in 2025.

Assumptions regarding intersectoral water demand including livestock water demand

Total-global *municipal and industrial (M&I) water* depletion, including rural domestic water use in the base year of 1995 was estimated at 331 km^3, with 175 km^3 in developing countries and 156 km^3 in developed countries.

The *livestock water demand* (consumption) was assessed as 38 km^3 in the world in 1995, with 22 km^3 in developing countries and 16 km^3 in developed countries.

Results of baseline scenario

The developing world is projected to have a much higher growth in potential irrigation-water demand than the developed world between 1995 and 2021–2025, with the potential demand in the developing world rising from 1445 billion cubic meter (BCM) in 1995 to 1615 BCM (average) in 2021–25, or 11.8%.

The potential irrigation demand in the developed world is expected to decrease from 313 BCM to 308 BCM (by only 1.5%).

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[30] Surface reservoir storage under the baseline is estimated based on values from the International Committee of Large Dams (ICOLD 1998), while FAO (1995) provide estimates for countries that are not members of ICOLD.

The global potential irrigation-water demand is 1758 BCM in 1995 and 1924 BCM in 2021–2025, an increase of 9.5%.

Results based on the concept of the Irrigation-Water Supply Reliability Index (IWSR)[31]

For developing countries as a whole, the IWSR is expected to decline from 0.80 to 0.71 in 2025. While the potential demand for irrigation water in developing countries rises by 11.8%, the realized demand is expected to increase by only 4.2% due to supply-related restrictions. In the IWSR, basins and countries (or regions) are projected as follows:

Regions with IWSR less than 70% (meaning 30% of water shortage relative to the potential demand) include the Hai-luan River basin; the Yellow River basin; most basins in India, including the Indus River basin and the Ganges River basin; central Asia; the Russian Federation; Mexico; Argentina; Nigeria; northern SSA; eastern SSA; Egypt; WANA; Bangladesh; Pakistan; and some Southeast Asian countries.

Countries in Latin America will basically maintain their base-year water-supply reliability—measuring 75% in Mexico, Brazil, Argentina, and Colombia and 85% in other Latin American countries. Mexico will undergo slight declines.

In the case of countries in transition, IWSR can be maintained above 85% in most developed countries and river basins (the value of IWSR in eastern Europe and the Russian Federation will increase significantly from 60–70% in 1995 to 85% in 2021–2025) because of declining water demand for municipal and industrial uses.

In the case of developed countries, though IWSR remains relatively high over time, irrigation is susceptible to considerable risk. Some basins in the United States, including the Colorado River, the Rio Grande, downstream Mississippi River, Missouri River, Texas Gulf, and White-Red-Arkansas River basins have IWSR as low as 60% in some dry years in the latter stages of the projection period, which means as much as 40% of the irrigation-water demand cannot be satisfied in those years.

Finally, under the baseline scenario, considering the intersectoral water demand, increasing M&I water demand will drive the fraction of total worldwide water depletion by agriculture (including irrigation and livestock) from 81% in 1995 to 74% in 2021–2025, including a decline from 65% to 61% in developed countries and from 87% to 78% in developing countries.

Scenario S2: Low Infrastructure Investment (LINV) Scenario

This scenario attempts to examine the effect of even LINV on global and regional food production. It assumes that any improvements in these drivers due to existing investments and water-management reforms will be offset by a faster depreciation of existing infrastructure and a more rapid siltation of reservoirs.

Major assumptions

Reductions in the growth rates in reservoir storage for irrigation and water supply: the net increase of global reservoir storage for irrigation and water supply only increases by 325 km^3 between 1995 and 2025 under the LINV scenario compared to an increase of 621 km^3 under the baseline scenario.

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[31] IWSR is defined as the ratio of water supply available for irrigation over the potential demand for irrigation water.

Reductions in water-use efficiency: under this scenario, the global average basin-irrigation efficiency is assumed to increase to only 0.57, compared to 0.61 under the baseline, corresponding to a water-consumption savings of 23 km^3 under the LINV scenario compared to 115 km^3 under the baseline.

Potential irrigated area: the projection of potential irrigated area is assumed to be the same as under the baseline scenario.

Scenario results

The net increase in MAWW between 1995 and 2025 is only 301 km^3 under the LINV scenario compared to 844 km^3 under the baseline scenario.

Under this scenario, irrigated cereal production will be reduced by 103 million metric tons (Mt) by 2025. Cereal production is expected to decline by 1% for the developed countries and 5% for the developing countries, which would result in food imports decreasing by 11 million tons for the developing countries.

Scenario S3: High M&I Water Demand (HMI)

This scenario attempts to assess the most-constrained-possible condition for agriculture-water use due to the rapid increase of M&I water demand, defined as a High-M&I Water Demand Scenario (HMI).

Major assumptions

Compared to the baseline level of 534 km^3 in 2025, municipal and industrial water demand (depletion) under this scenario is projected to reach 642 km^3—31% of the available water for all demands.

The global M&I water depletion in 2025 will be double in 1995 and 26% more than depletion in 2025 under the baseline scenario.

Scenario results

The total M&I demand is projected to reach 642 km^3.

Irrigated cereal production will be reduced by 58 million MT by 2025. The cereal production under this scenario is expected to decline by 2% under HMI for the developed world and 4% for the developing countries. This would cause a decline in food imports by 4 million tons for the developing countries.

Scenario S4: The Sustainability Scenario: Low Groundwater Pumping (LGW)

This scenario attempts to examine the effects of the potential limits of groundwater pumping, especially in those countries and regions that are unsustainably using their water and would need to be phased-out over the next 25 years through a reduction in the ratio of annual groundwater pumping to recharge.

Major assumptions

Compared to levels in 1995, LGW groundwater pumping in these countries and regions is assumed to decline by 163 km^3, including a reduction by 11 km^3 in the United States, 30 km^3 in China, 69 km^3 in India, 29 km^3 in WANA, and 24 km^3 in other countries.

Scenario results

The projected increase in pumping for areas with more plentiful groundwater resources remains almost the same as under the baseline scenario. However, the total-global groundwater pumping in 2025 falls to 753 km^3, a decline from the value in 1995 of 817 km^3 and from the baseline 2025 value of 922 km^3.

Under this scenario, irrigated cereal production is expected to decline by 4% and cereal imports to developing countries will increase by 7% (16 million tons) in 2021–2025.

Scenario S5: Low Irrigated Area and Low Water Withdrawal (LIA-LWW).

This scenario attempts to assess the impact of policies for a less-irrigation infrastructure and to answer what-if questions about the slight decline in global irrigated area over the next 25 years.

Major assumptions

Under this scenario, it is assumed that the growth of potential irrigated area in those basins, countries, and regions that have a growth in irrigated area under the baseline will drop to zero. Declines in other basins, countries, and regions will remain the same as under the baseline.

Under this assumption, irrigated area is projected to be only 210 million ha in 2025, which is 29 million ha less than that under the baseline.

Scenario results

This scenario indicates that the total maximum-allowed water withdrawal (MAWW) worldwide will decline by 150 km^3, corresponding to the reduced withdrawals associated with the reduction in potential irrigated area.

Irrigated cereal yield is expected to increase (from 4.7 to 5.0 tons/ha), but with most of the improvements taking place in the developed countries. Total cereal production is expected to decline by 36 MT with a decline of 47 MT in the developing countries and an increase of 11 MT in the developed countries.

Comparison of baseline and alternative scenarios

Compared to the baseline scenario, all alternative scenarios result in lower irrigation-water depletion, lower irrigated harvested area, and a lower production of cereals for both the developing and the developed world.

First, under the alternative scenarios—LINV, HMI, and LGW—the availability and reliability of water supply would be reduced. The reduction in the amount of water available for irrigation is large under these more water-stressed scenarios, with the biggest reductions in the developing countries. For example, compared to the baseline scenario, the reduction of irrigation-water supply in 2021–2025 is 282 km^3, 97 km^3, and 82 km^3 for the developing world under LINV, HDI, and LGW respectively (and 27 km^3, 56 km^3, and 3 km^3 for the developed world respectively).

Second, the reduction in the availability of water for irrigation directly reduces the irrigated harvested area and increases the year-to-year variability in irrigated area. For example, irrigated area in the world declines by 8 Million ha on average—2021–2025 under the low-investment in irrigation scenario and 4 million ha under the HMI. In addition to reducing the irrigated-area harvested, the more water-scarce scenarios also result in the reduction of the amount of water available per hectare in the remaining irrigated area.

Finally, there could be a significant drop in irrigation supply (or effective demand) in 2025 in alternative scenarios compared to the baseline scenario. The LGW scenario has smaller impacts on these large regional averages because the impacts are concentrated in the basins that have an overdrafting of groundwater.

Appendix 3 Summary of Expert Comments and Suggestions

A3.1 The potential for improving water-use efficiency (WUE) and the validity of the assumptions made

164. None of the models adequately takes into account the improvement in water-use efficiency (crop productivity per unit of evapotranspiration) that can be anticipated in the next 30 years in both rain-fed and irrigated areas. These gains in WUE will result from improvements in crop genetics and cultivation technologies (tilling, mulching, fertilizing), from improved on-farm irrigation (soil-moisture management), and from deficit irrigation in water-short areas. There are huge tracts of waterlogged/salinized land with low or zero yields that are presently producing vast amounts of nonbeneficial evapotranspiration. Improved drainage, lower water table, and leach salts could result in a great increase in production with little increase in actual water consumption

165. A major part of the existing irrigation system was built during the 1960s and 1970s and is getting close to being 40–50 years of age. Just to keep the efficiency of the aging irrigation system at its present level will require enormous investment, and if not made, could result in a decrease in irrigated areas. This situation needs to be addressed.

166. The three models assume that the performance of the existing infrastructure will be improved through rehabilitation and policy reforms, consequently increasing the water-use efficiency, the cropping intensity, and the crop yields. These assumptions have to be backed by some reasoning. The risk of failure has to be incorporated in the analysis through use of sensitivity analysis in both directions (success and failure).

A3.2 The effect of technological changes on water use and WUE

167. There is a need to account for the contribution of genetics and the adoption of new varieties (enhanced drought-tolerant crops). Low adoption rates by farmers are the result of the low-reliability of the irrigation distribution system. These two factors have to be re-evaluated and incorporated into the models.

168. In general, technological changes of different types could be included in the assumptions of the three models (although IFPRI's does take some of that into consideration). One could expect improvements resulting from improved in-situ water delivery (as in drip for vegetables and fruit trees), increased efficiency of plants in water use, increased plant tolerance to low-quality water, and increased plant tolerance to stress (low water availability). Equally, the social dimension (water-users association and related) has been of critical importance to the success or failure of projects—and the multilateral and regional-development banks have a lot of experience with this. Its inclusion in the models would create a more accurate reflection of the possible rates of success or failure of the new areas.

A3.3 THE NEED TO CONSIDER THE INSTITUTIONAL ASPECTS OF IRRIGATION-PROJECT PERFORMANCE

169. The underlying assumptions (or scenarios) in each of the models should attempt to clarify their "implementability." For example, the O&M performances of both irrigation agencies and irrigators on government-operated, gravity-fed irrigation schemes in developing countries in Asia (the largest irrigated areas of the world) are dismal. While significant progress has been made in some countries (Mexico in particular), little has been done to restructure irrigation agencies and private-sector participation within broader national reforms. Likewise, little has been done to achieve efficient water pricing and appropriate fee collection or the better management of water-service delivery. The difficulties encountered in achieving satisfactory O&M deserve to be incorporated into the model. In any event, considerable investment (not only for O&M but also for modernizing the irrigation networks) combined with managerial changes would be needed to achieve the assumptions made in the various scenarios. It's not clear whether this aspect has been given sufficient attention in the models

A3.4 CONSIDERATION OF WATER DEMAND FOR ENVIRONMENTAL PURPOSES

170. The environmental community and some others project that water withdrawal for irrigation should be reduced and not increased. For example, the Kassel U projection suggests a reduction of 8% in the amount of water withdrawn for agriculture.

A3.5 THE NEED TO INCORPORATE IMPACTS OF GLOBAL CLIMATE CHANGE ON WATER SUPPLY AND DEMAND

171. The expected increase in the variability of weather, and eventually climate change, will be of significance in the next decades, especially for developing countries. This does not seem to be incorporated into any of the three models either.

172. Both temperature and CO_2 are important factors in the development of crops. Mention of them is missing in the assumptions of all three models. CO_2 concentration is about 360 ppm and is predicted to increase to about 750 ppm by the year 2075. CO_2 enrichment has been shown to increase growth by stimulating tillering in wheat (1, 2) and rice (3,4). The increase in tillering is associated with the increase in grain yield. (Sionet, et al. 1980, 1981; Baker, et al. 1990, 1992)

173. Likewise, genetic variability for stomatal conductance has allowed the inadvertent selection of "heat avoidance" (evaporative cooling) in a hot environment (Radin 1994).

A3.6 CONSIDERATION OF WATER-STORAGE NEEDS AND CAPACITY

174. The need for reservoir storage has to be addressed in the modeling of global water demand and supply**.** The feasibility and implementabilty of adding 621 km^3 over the next 25 years also needs to be assessed, particularly in light of the latest report of the World Commission on Dams and the uproar that any new dam causes. Is it financially, economically, socially, and environmentally possible to build so many large dams in the next 25 years? Have the costs been estimated and the feasibility of solving the associated financial aspects been studied?

A3.7 The need to consider projections of economic demand for irrigated areas

175. The studies are directed more toward determining irrigation "requirements" to meet projected demand for agricultural commodities rather than projections of the economic demand for irrigated area or for irrigation capacity. The World Bank currently has been, and may continue to be, less active in financing irrigation development and renovation than they were from 1960–1990. Most national-development-assistance agencies appear even less enthusiastic (or able) to fund irrigation development. Thus, it looks quite doubtful that irrigated area will actually expand by the 15–22% that will be required to meet the projected 2025–2030 agricultural production levels.

176. What does a model need to incorporate in order to answer the question at hand? Let's start with, What is the question? It looks as if the models are seeking to address the question, How much irrigation will be needed? That is a technocratic, central-planning approach and intrinsically not a very useful question. How much extra irrigation will become available in the next quarter century? is a much more useful question. But it leads immediately to, How much extra irrigation will be profitable in the next quarter century? This pushes us in some useful directions.

A3.8 The estimation of agriculture-water demand from different perspectives

177. The models should address these problems and solutions: (i) areas without irrigation and drainage systems (1,100 million ha)—use crop diversification, agricultural practices, water harvesting, improved soil treatment, (ii) rain-fed areas with drainage systems (130 million ha)—install drainage and irrigation, (iii) irrigated areas without drainage systems (210 million ha)—improve irrigation systems, install drainage systems; and (iv) irrigated areas with drainage systems (60 million ha)—improve irrigation or drainage systems.

178. The main question being posed by the models is the wrong one. They are trying to compute the level of additional water that agriculture will "need" to feed an expected population at some future date (e.g., 2025). They make various, apparently ad hoc, assumptions about improvements in water-use efficiency, irrigation intensity and crop yields, but the inevitable outcome is always that more irrigated area is needed and agriculture will require more water to be able to feed the world. The estimates from the various models are in the range of 20–40% increases in irrigated area and increases of above 10% in water needed. The obvious outcome is to underline the necessarily increased importance of irrigated agriculture for global food security. Only the IFPRI model explores alternatives to this basic scenario.

179. The more appropriate question to be explored should be, What will be required in terms of changes in water-use efficiency, cropping intensity, yields, prices (both for grains and water), and trade volume and direction to feed the world under the following two scenarios: (i) agriculture will get, at most, the same amount of water in 2025 as it now gets and that new or retrofitted irrigation system development just offsets realistic estimates of losses of land due to salinization and urbanization; and (ii) agriculture gets less water, say for example 10% less, and there is a net loss of irrigated area. These are more realistic future scenarios.

180. None of the reports refers to irrigated cotton area. Although exact area is not known, it could be between 10 and 13 million ha. In any event it is a significant area that within a 25-year period could be partly used for food production, particularly if cotton prices continue to drop.

A3.9 Considerations of Intersectoral Water Demand and Water-Pricing Effects

181. The models are simplistic in how they project (when at all) urban and industrial demand, and how they treat land loss due to degradation. Their assumptions regarding trade are naive. Self-sufficiency is a totally wrong policy for any country. Clearly one way to meet food needs is to import water in the form of a finished product. This is what is happening more and more in the Near East, and it is irreversible. Finally, the models' treatment of prices is incomplete in that product prices are endogenous only in the IFPRI model, and none have endogenous water prices. The water component of each model is technical and mechanistic. It is believed that water will increasingly have to be priced in order to ration it, and therefore, there is a need to explore the consequences for water pricing.

A3.10 Water Recycling and Harvesting Aspects

182. Brackish water. In many arid and semi-arid areas there is a lot of available brackish water that can be used for certain crops or as a supplement to freshwater. However, the entire document neglects to highlight the possibility of using recycled sewage water as an alternative to the use of freshwater for irrigation

183. Water harvesting. Systems based on the collection of runoff water are a viable approach for afforestation in arid and semi-arid zones. Many deserts are characterized by winter rainfall with rare runoff pulses. The time interval between runoff events is of the order of one year with an extremely hot and dry period in between, and it is therefore advantageous to store the largest volumes of water possible during a runoff event. Water will then percolate deep into the soil, increasing soil-moisture availability and allowing trees, annual crops, or a combination of both to grow.

A3.11 Validation of Available Information and the Models

184. Past experiences on the use of FAO STAT data on irrigation (when preparing investment projects for World Bank financing in the 1988–1996 period) shows that the available information differed greatly from in-country information. Since the models seem to rely on this database, the validation exercise of the database before model validation could be as important as the exercise itself. If this difference still continues to exist , it might deserve attention.

185. Any policy decision making on the basis of model forecasts of unclear statistical character is fraught with problems. Are the estimates of irrigation "needs" the best possible estimates of the expected values of the uncertain quantities? Or are they median/most likely/best bet/other? How reliable do the modelers feel any such estimates are? One way of expressing this could be the simultaneous reporting of estimates of standard errors to attach to the forecasts (I am presuming they are mainly expected values). It is not trivial to compute these sensibly, and modelers will complain that it is simply too difficult and costly, but without doing so, are they deluding themselves and possibly others about the accuracy and cogency of the forecasting exercises? If indeed such work is intended to influence the prioritization of investment amounting to some U.S.$2 billion a year, the expense could be justified. One can get a feel for this issue by observing that seemingly many of the key parameters are expressed to two significant digits (0.75 seems to crop up a lot, for instance). If such a number is really a random variable ranging over say, 0.5 to 0.9, there may be large consequences for the estimation of future irrigation requirements of the order of 3000 km^3. And in the models, many such uncertain parameters are compounded.

186. A related matter is the scaling up to global estimates based on parameters keyed to lower levels of aggregation. One such parameter is BIE as used in the IFPRI models. But there are probably many such numbers that get defined as "expert best judgments" (seems like a lot in the FAO model, for instance), and one worries about the possibility of fallacies of composition at the global level.

Appendix 4 IWMI, FAO and IFPRI's Revised Scenario Assumptions and Results

A4.1 IWMI's REVISED ASSUMPTIONS, SCENARIOS, AND RESULTS

Background

187. Most of the comments on IWMI's exercise were linked to the assumptions of growth of irrigated and rain-fed yield, growth in irrigated area and intensity, irrigation efficiency, and changes in NET and noncrop evapotranspiration. The IWMI specifically attempted to address the experts' comments regarding: i) improving WUE; ii) technological change and water use; iii) the demand for irrigation lands; iv) the demand for water from different perspectives; and v) the demand for water for environmental purposes. The IWMI responded by rerunning the PODIUM model and changing some of the assumptions (e.g., with higher or lower growth rates for appropriate parameters compared to the base-case assumptions).

188. The basic question that the IWMI revised results attempts to answer is, What would be the effect on food production if additional primary-water-supply (PWS) development for irrigation was restricted for various reasons (like lack of investments)? Some of the revised scenarios address this issue by assuming no-growth in net irrigated area and only 50% of the growth of irrigation intensity from the base scenario. These revised scenarios also attempt to estimate the additional growth needed in irrigation intensity and irrigated or rain-fed yield over the base scenario in order to have no production surplus or deficits for all countries. The next issue regarding the restrictions on water supply for irrigation from the diversion of water for other uses on the total food production is addressed in scenario 4. In addition, as in the previous case, this scenario attempts to address an important question regarding the need for increasing water productivity and crop yields through improvements in crop genetics with water-supply constraints. The base scenario used remains the same as in the original exercise (see appendix A-2.1).

Revised scenario: assumptions and scenario results

189. Seven alternative scenarios were developed as part of the validation exercise in order to address the various comments and suggestions provided by the group of experts.

Scenario AS11: high-growth scenario (1)

190. This scenario addresses three concerns raised by the experts: i) the role of crop genetics; ii) the operation and management of irrigation systems or improvements in system performance; and iii) the reuse of drainage water.

191. One general assumption under this scenario is that there would be significant improvements in crop genetics, which could contribute to increased crop yields in both irrigated and rain-fed areas. The scenario also makes the general assumption of uniform distribution of the adoption of crop genetics, as well as uniform improvements in crop yields over all countries. It is assumed that while the irrigated yield

would increase by 0.33 ton/ha (a 10% increase over the base case), the rain-fed yield would increase by 0.21 tons/ha (an 8% increase over the base case) for all groups of countries included.

192. On-farm water management, and therefore, WUE (defined as irrigation-application efficiency), would increase uniformly at 50% in all of the countries.

193. Finally, countries would initiate efforts toward the better management of drainage conditions which would then result in the decrease of noncrop evaporation from the base-case scenario. The noncrop evaporation as a percentage of irrigation drainage is assumed to decrease by 5% from the base-scenario level.

Scenario results

194. Corresponding to the assumption on potential impacts of improvements in crop genetics, the scenario results show a significant increase in the net cereal production surpluses of 165 million Mt for 100 developing countries—equivalent to 6.4% of the total cereal consumption in 2025. Countries experiencing food deficit under the base-case scenario will have a small food deficit, and countries in some regions like South Asia (SA) and East Asia and the Pacific (EAP) regions would experience a net surplus (compared to the small food deficit in the base-case scenario).

195. The increase in irrigation efficiency assumed at 50% and the reduction in noncrop evapotranspiration over the base case would reduce the growth of irrigation by 15% and the total PWS by 22%, which corresponds to the 3% and 2% reduction from the level of increase under the base case.

Scenario AS12: high-growth scenario (2)

196. This scenario also attempts to incorporate the link between crop-genetics improvements and its impacts on the net evapotranspiration. The latter is likely to decrease in the improved crop varieties. Like AS11, the alternative scenario AS12 assumes that only 95% of the 1995 NET is because of improvement of crop genetics and new varieties.

Scenario results

197. Under this scenario, the growth in irrigation PWS would be reduced by 6% from scenario AS11 and by 8% from the base case. The growth of total PWS for all countries is 18%, a reduction of 4% from the AS11 scenario, and a reduction of 6% from the base case.

Scenario AS13: less growth in net irrigated area, but higher growth in irrigation intensity

198. This scenario attempts to address the experts' concerns over growth in irrigated area. It assumes lower growth rates for area parameters such as cereal harvested area (7% less) and net irrigated area (assumed to be 5% less compared to the base case) for all countries compared to the AS12 scenario. Next, it is assumed that improvements in WUE and a reduction in NET would result in an increase in irrigation intensity, which is projected to increase by 30% in each country.

Scenario results

Under this scenario, the PWS corresponding to the increased irrigation intensity for all countries is likely to increase by only 7%, a reduction of 3% from AS12 and 10% from the base scenario. The growth in total PWS is only 16% under this scenario compared to 24% in the base case.

Scenario 21: slower growth scenario

199. This scenario attempts to ascertain what would happen to food production and the demand for irrigation water if there is no improvement in crop genetics or WUE from the base case. This is the opposite of scenario AS11. The annual growth of irrigated and rain-fed yields of each country is assumed to be less than 75% of the growth of all countries under the base-case scenario, and the growth in the irrigation efficiency of each country is assumed to be only 50% of the growth rate of the base case.

Scenario results

200. The lack of improvements in crop genetics or crop yields in both the irrigated and rain-fed areas assumed under this scenario would result in substantial production deficits in most regions and a total production deficit at the world level to 180 million Mt—equivalent to 7.4% of the 2025 total consumption. While all developing countries would record substantial production deficits, the SA and EAP regions would have a production deficit equivalent to 10% of their consumption in 2025.

201. The PWS is expected to go up by 21% (3% more than the base case) as a result of a decrease in WUE. Likewise, the total PWS is estimated to increase by 26%, which is 4% more than the base case.

Scenario 22: slow growth (including irrigated areas)

202. This scenario was developed in response to the experts' comments on the likely impacts of human and natural activities (e.g., urbanization and land degradation) on the land available for crop cultivation and the potential to increase irrigated area. Although the assumed figures are not based on the estimation of a likely reduction in land area due to urbanization or land degradation, this scenario attempts to answer what-if questions linked to the contraction of land area available for irrigated agriculture.

203. A specific assumption made under this scenario is that the growth of the total cereal-growing area and the net irrigated area for each country is assumed to be 2% and 6% less respectively, which is equivalent to 25% of the total growth of all countries, compared to the base case. The growth of irrigation intensity of each country is only 50% that of the base scenario's growth.

Scenario results

204. Under this scenario, the reduced growth rate in net irrigated area has made the irrigation PWS change by only 13%, which is 4% lower than the base case. As a result the production deficits are expected to increase further in all countries totaling up to 247 million Mt, which is equivalent to 10% of the total food consumption by 2025.

Scenario 31: low-growth in cereal-growing area

205. The total growth of cereal-growing area for each country is assumed to be 4% less than the base scenario. The irrigation efficiency is assumed to be same as in the base scenario; no-growth in net irrigated area is assumed for each country; growth in irrigation intensity of each country is only 75% of the

growth rates of the base scenario; and the total irrigation PWS available in 2025 would be less than that in 1995.

Scenario results

Less irrigation PWS is available in 2025 compared to 1995, and the growth of irrigation intensity in all countries under this scenario is 3% less than in the base scenario.

206. This scenario also results in substantial production deficits. The total production deficit (210 million MT) of all countries is equivalent to 9% of the total 2025 consumption. Next, if the total production deficit is going to be reduced through additional growth in irrigated yield, the irrigated yield of all countries will increase by an additional 27% over the base scenario. The irrigated yield of all countries would increase from 3.32 Mt/ha in 1995 to 4.65 Mt/ha under the base scenario to 5.54 Mt/ha under scenario AS3. On the other hand, if the total production deficit is to be reduced through additional growth in rain-fed yield, the rain-fed yield is estimated to increase by an additional 22% over the base scenario.

Scenario S41: low-growth in both cereal growing and irrigated area

207. These are the basic assumptions made: i) the total PWS of the world will remain the same compared to the base case; ii) there would be a reduction in the growth of cereal-growing area for each country by 4% and a reduction in net irrigated area by 7% for each country compared to the base case; and iii) there will be no growth in irrigation intensity or irrigation efficiency.

Scenario results

208. The scenario results indicated a reduction in PWS by 16% from the 1995 level to meet the demand of domestic and industrial sectors, and thus results in even higher production deficits than scenario 3. Next, if the production deficit of all countries is to be reduced through additional growth in irrigated and rain-fed yield, the crop yield of all countries will be required to increase by an additional 39% and 26% in irrigated and rain-fed areas, respectively, by 2025.

A4.2 FAO's RESPONSE TO EXPERT COMMENTS AND SUGGESTIONS

Background

209. To the experts' comments and suggestions on FAO's projection of global water demand, FAO responded with brief clarifications of each of the issues raised. It is noteworthy that the FAO exercise is largely based on the experts' judgments, but has been limited when revisiting some of the assumptions and development of scenarios as outlined by the experts. FAO's response as part of the validation exercise mainly addresses the issue of WUE, technological and environmental aspects, economic demand for irrigation water, and the estimation of water requirements for cotton crops. FAO responded to comments regarding the assumptions made about the estimation of actual evapotranspiration, the use of traditional technical efficiency of water use, the assumption about area rehabilitation for irrigation, food supply and demand related to trade, etc.

The potential for improving water-use efficiency (WUE) and the validity of the assumptions made

210. In response to the experts' comments that none of the models adequately take into account the improvement in water-use efficiency (crop productivity per unit of ET) that can be anticipated in the next 30 years in both rain-fed and irrigated areas, FAO asserted that the improvement of crop productivity per unit ET is implicitly taken into account in the increase of yield per unit of land. The reasoning and assumptions are given in section 4.5 of the AT2030 Technical Interim Report. A small increase in water-use efficiency is also assumed and varies with the degree of water scarcity.

Consideration of technological changes on water use and improved WUE

211. The technological changes mentioned will result in an increase of the water-use efficiency. This has been taken into account by assuming that future WUE will increase as a function of the actual WUE and available water resources. If there are abundant water resources available, it is not likely that the WUE will increase by a lot. If there is already a water shortage, the WUE will increase more.

Consideration of environmental aspects of water demand and impacts of global climate change

212. FAO assessment of global water projections does not work on the basis of scenarios but on the basis of what is most likely to happen. In developing countries, where competition for water is strong, it is likely that agriculture will continue to have negative impacts on the environment (although environmental concerns will play an increasing role in the search for trade-offs between agriculture and the environment).

213. The FAO exercise did not consider the impact of global climate change as discussed in section 8.7 of the AT2030 Technical Interim Report. It is true that this impact on water supply and demand had not been considered because of the many uncertainties and because the impact on agriculture will probably remain minor before 2030.

The need to consider projections of economic demand for irrigated area

214. The question that AT2030 attempts to answer is, What will the agricultural sector look like in the year 2030? It does not ask, How much irrigation will be needed? In the past, irrigation schemes have not been built solely because of their profitability. Although it is expected that profitability will become more important, it is not very likely that all irrigation will become profitable in the next 30 years.

The estimation of agriculture-water demand for different uses, including cotton

215. It is very difficult to maintain the argument that water withdrawal for irrigation should be reduced because of the current expected increase in population. This would imply that food has to be produced on rain-fed land. The areas where irrigation has the biggest impact on the environment are North Africa, the Near East, and southern Asia. Unfortunately, in these areas suitable land with crop-production potential is very limited.[33] The other option would be to increase water-use efficiency. However, under the assump-

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[33] See chapter 4.3 of the FAO AT2030 Technical Interim Report.

tions with regard to food production in AT2030, this would mean that in the areas mentioned (North Africa/Near East and south Asia), the water-use efficiency would need to increase from 40% to 79% and 44% to 56% respectively. Such increases are not very credible. Globally, the irrigation efficiency would need to increase from 38% to 48%.

Consideration of intersectoral water demand and the treatment of water prices

216. Self-sufficiency might be a totally wrong policy for every country, but during the mid-seventies until the mid-nineties it only declined by 6% (from 96% to 90%). In the oil exporting countries of North Africa and the Near East, food imports grew in the 1970s until the late 1980s. Since then, however, net imports have stagnated. Only Iran increased its imports substantially. Apparently, not everything can be explained by prices, and a free market doesn't seem to be considered to be the best solution by every country.

217. *Response to specific comments on the FAO exercise* (e.g., estimation of actual evapotranspiration, use of traditional technical efficiency of water use, assumption about area rehabilitation for irrigation, food supply and demand related to trade, etc.)

218. The current estimations for WUE for 1997–1999 considered in the model are: i) 40% for the Near East/North Africa; ii) 44% for southern Asia; iii) 25% for Latin America; iv) 33% for sub-Saharan Africa; v) 33% for east Asia; vi) 38% for the developing world as a whole. Likewise, figures assumed for 2030 on improved WUE are: i) 53% in the Near East/North Africa; ii) 49% for south Asia; iii) 25% for Latin America; iv) 37% for sub-Saharan Africa; v) 34% for east Asia; and vi) 42% for the developing world as a whole. FAO's response to other comments made by the experts include:

- Irrigation expansion in the FAO exercise is expressed in net terms. Further, it was assumed that the loss of existing irrigated land would be compensated through rehabilitation or substitution, and about 2.5% of existing irrigation must be rehabilitated or substituted each year.
- Regarding the experts' comments on the decrease in the rate of growth of meat, China was responsible for a substantial part of the rate of growth with a yearly increase of 2 kg per person per year. It is unlikely that this rate will continue for much longer because the country would surpass the consumption of industrialized countries.
- Differentiation has been made between cropping patterns per country. For big countries like China and India, the country has been split up into different climate zones.
- The potential reduction in resource use in the arid and semi-arid areas has not been taken into account in the model. For the forecasts of future irrigated areas' use the policy plans of countries have been used. Some countries do not seem to care to use fossil water for irrigation. These countries are generally the same that pump fossil oil. Further, agricultural demand can exceed available renewable water resources if fossil groundwater is used.
- Regarding experts' comments on the assumption about food supply and demand related to developments in global food trade, these aspects have been considered in the model and in chapter 3 of the AT2030 report.
- Nonagricultural withdrawals have been taken into account in the projections, but in a crude manner. The emphasis lies on agricultural withdrawal, especially since the consumptive use of agriculture is so much higher than that for other sectors.

A4.3 IFPRI'S RESPONSE TO EXPERT COMMENTS AND SUGGESTIONS

Background

219. IFPRI responded to the experts' comments and suggestions by adding a few scenario results in regard to: i) water-use efficiency linked to the concept of water productivity; ii) the impacts of crop genetics with assumptions about the potential increase of crop yields both in the rain-fed and irrigated areas; iii) the water crisis associated with the lack of investments for irrigation development; and iv) increasing water supply using water-harvesting techniques, water pricing, the effects of intersectoral water demand, etc. The IFPRI revised response also attempts to clarify other issues raised by the experts about environmental considerations such as climate change and institutional performance. Finally, IFPRI provided some clarification on the specific issues raised by the experts about the assumptions made and the scenario analysis.

Revised scenario: assumptions and results

220. The IFPRI/IMPACT model considers both basin-wide WUE and the potential contribution of water-harvesting techniques for supplemental irrigation-water demand in the rain-fed areas. The model assumes that water-harvesting techniques could be adopted more cautiously to provide farmers with improved water availability in some local and regional ecosystems. The following four revised scenarios outlined below consider improvements in the effective use of rainfall, low- and high-investments in irrigation and constraints on groundwater use (Rosegrant, et al. 2002):

Scenario 1: no improvements in effective rainfall use (NIER)

221. The baseline scenario assumes improvement in effective rainfall use by 3–5% and no increase in effective rainfall use. The scenario results indicated a significant reduction in rain-fed area of 5.0 million hectares and a significant reduction in rain-fed cereal production of 59 million tons. The total water consumption under this scenario is the same as in the base-case scenario with 1,480 km^3.

222. This scenario (see appendix A-2.3) was also used to estimate the water productivity in the irrigated and rain-fed areas. This was done by taking into account the impact that technology and management improvement and investment will have on water productivity. This scenario was also used to search for potentials in improving food security by enhancing water productivity. Both the increase of crop yield and the improvement in basin efficiency were expected to contribute to the increase in water productivity, with a major contribution coming from the crop-yield increase. The scenario results indicated that:

223. Water productivity (crop yield per unit of ET) of rice ranges from 0.15 kg/m^3 to 0.60 kg/m^3, while that of other cereals ranges from 0.2 to 2.4 kg/m^3 in 1995. Under the baseline scenario of our analysis, from 1995 to 2025 water productivity will increase, the global average of water productivity of rice will increase from 0.39 kg/m^3 to 0.52 kg/m^3, and the global average of water productivity of other cereals will increase from 0.67 kg/m^3 to 1.01 kg/m^3.

224. Next, the result indicated that water productivity of irrigated crops is higher than that of rain-fed crops in developing countries but lower in developed countries. This shows that in developing countries, irrigated agriculture is more efficient at resource utilization and food production than rain-fed agriculture, but it also points out the untapped potential for increasing the water productivity of rain-fed crops through research and infrastructure investment.

Scenario 2: low-investment scenario

225. This scenario assumes low-investment in irrigation development and water supply but a higher increase of rain-fed area and yield (LIV-HRF) than in the baseline scenario. Under these assumptions, rain-fed area is expected to increase by 6 million ha. Rain-fed yield will increase by 11%, with an additional 183 million ton increase in rain-fed production. It would result in a decline of 256 km^3, or an 18% decrease in total-global water consumption. The potential reduction in irrigated cereal production of 170 million tons would thus be offset by the increased investment in promoting water-harvesting techniques in rain-fed areas.

Scenario 3: low-investment in irrigated areas; some investment in rain-fed areas

226. This scenario assumes low investment in irrigation development and water supply but an increase in effective rainfall use (LIV-HIER). The total water consumption and irrigated area in this case is the same as that in the LIV-HRF scenario of 1215 km^3, but the projected improvements in the effective use of rainwater would not fully compensate for the decline in production due to low-investment in irrigation development.

Scenario 4: sustainability with restrictions on groundwater pumping but with larger rain-fed-agriculture development

227. This scenario, which assumes the phasing out of groundwater overdraft with large rain-fed agriculture development and a large improvement in effective rainfall use (GW-HRF2), is expected to cause a decline in: i) groundwater pumping by 169 km^3; ii) total irrigation-water consumption (to 1394 km^3 from the baseline projection of 1480 km^3). It will also increase rain-fed area by 4 million ha over the base case, a decline in irrigated area by 4.1 million ha, and improvements in water productivity.

IFPRI's response to the issue of institutional performance and the implementability of the major assumptions made

228. To this IFPRI responded that they support the experts' opinions and that further efforts to study the implementability of various institutional and technological measures assumed in the scenario analysis are needed. They also suggested the coordination of activities by the World Bank and other development banks (where data could conceivably be compiled from various databases, loan, and evaluation projects), IFPRI, and IWMI in order to carry out further exercises dealing with these aspects.

Consideration of water demand for environmental purposes

229. IFPRI responded that they had already considered some of the environmental aspects in their alternative scenario analysis, and the results are expected to be included in forthcoming publications. Likewise, though the IMPACT-WATER model provides a platform for analyzing the impact of global warming on world agriculture, this exercise has yet to be started, and IFPRI is considering collaborative efforts with the Intergovernment Panel on Climate Change (IPCC) and other relevant agencies.

230. IFPRI mentioned that drainage has a large impact on food production in many regions, but this aspect was not explicitly addressed in IFPRI's modeling exercise. It focuses more on water scarcity. Alternatively, several scenarios could be formulated and run that project cropland loss or yield reduction due to waterlogging and salinization through 2025. However, more information would be needed about the current status of waterlogging and salinization and further developments under various policies and tech-

nological changes. The current model includes a leaching factor for irrigated land, which specifies water required for salt leaching. Sensitivity analyses could be carried out on this variable.

Consideration of intersectoral water demand, the treatment of water prices, and subsidies

231. Regarding intersectoral water demand, the IFPRI model simultaneously solves for supply, demand, trade, and commodity prices, but does not attempt to run scenarios incorporating self-sufficiency as a goal or policy. Some scenarios are developed with higher water prices relative to the baseline scenario, and the results are currently being assessed. Water prices are differentiated by sectors and by the developing and developed world. Since agriculture-water prices are generally far below that of the "real prices," the high-price scenarios assume larger increases for agriculture than for other sectors (two times the price under the baseline scenario in developed countries and three times that in developing countries). For domestic water demand, higher prices are set for connected households but lower prices for unconnected households. For all sectors, water prices gradually increase from 2000 to 2025 and the following alternative scenarios are analyzed in order to address the issue of impacts of intersectoral water demand:

- High-price with higher basin efficiency and baseline environmental water share.
- High-price with higher basin efficiency and low environmental water share.
- High-price with higher basin efficiency and high environmental water share.
- High-price with basin efficiency under the baseline and environmental water share as assumed.
- High-price with basin efficiency under the baseline and low environmental water share.
- High-price with basin efficiency under the baseline and high environmental water share.

232. These scenarios combine water prices, intersectoral water demand, and environmental concerns. Food production, demand, and trade under these scenarios are derived through the IMPACT-WATER model. The scenario results indicated the following (Rosegrant and Cai 2002):

- Compared to the BAU, all of these high-price scenarios would result in large reductions of water withdrawal—in a range of 730–900 km^3 in the world. Under the scenario with high prices, higher *BE,* and full water reservation for environment, water withdrawal will decline by 900 km^3 and water depletion by 310 km^3 , and the ratio of water withdrawal to the total renewable water will be 8% compared to 10% under the BAU.
- Even very large percentage changes in water prices have relatively modest impacts on food production, primarily because price response is low in agriculture. However, water-price-induced efficiency gains in irrigation use would be significant.
- In most of the water-scarce regions, relatively small impacts of high water price on the water demand is due to the fact that irrigation-water demand is limited primarily by water availability.
- The scenario results also indicated that the impact of higher water prices on water demand and food production and prices is determined significantly by the dynamic effects of prices on induced-efficiency gains in water use, as well as by policy decisions on the allocation of saved water across sectors.

233. In the IFPRI model, domestic production and consumer prices are considered a function of world prices (expressed in the respective country/group currencies via an exchange rate to the U.S. dollar), pro-

ducer subsidy equivalents (PSE), consumer subsidy equivalents (CSE), and marketing margins. The effects of country- and region-specific trade and subsidy policies are thus expressed in terms of trade-distorting PSE and CSE and marketing margins between the world price and producer and consumer prices. PSE and CSE measure the level of taxation or subsidy borne by producers or consumers relative to the world prices. They account for the wedge between domestic and world prices. Marketing margins reflect factors such as transport costs. In the model, PSEs, CSEs, and marketing margins are expressed as percentages of the world price. The future exercise will include alternative scenarios for trade (and subsidies) including full trade liberalization and the elimination of agricultural subsidies and increased agricultural protection.

Validation of available information and the models

234. IFPRI's model uses country sources for irrigated/rain-fed area (harvested area) in the case of India, China, and the United States. For other countries, the model uses data from FAO's more detailed, recent assessment on irrigated/rain-fed area in individual countries, rather than from FAOSTAT. FAOSTAT's irrigation data was not used in IFPRI model, and the results presented indicate projections, not forecasts.

235. IFPRI's recent exercise addresses the uncertainty produced by random climate and hydrologic parameters, which significantly impact crop-water requirements and irrigation-water availability. To assess the impact of climate variability, a scenario-based approach is used by running the model over a number of climate scenarios. Taking 1995 as the baseline year, the model projects the hydrologic and climate regime between 1996 and 2025 (including precipitation, evapotranspiration, and runoff) based on the climate regime during the period 1961–1990. Climate scenarios are defined based on this series and operate under the same other assumptions but with various year sequences as given below:

Scenario 1 , 1961, 1962, … 1991

Scenario 2 , 1962, 1963, … 1991, 1961

Scenario 3 , 1963, 1964, … 1991, 1961, 1962

Scenario 30, 1991, 1961, … 1988, 1989, 1990

236. Projected results are reported in terms of averages and standard deviations of the major water and food outputs across the sample scenarios for each year between 1996–2025. Alternative climate scenarios, such as global climate change, can also be input into the model.

The issue of aggregation of variables in the global-water-demand projections

237. In fact, IFPRI's model does not scale water parameters, including basin efficiency, up to the global scale, since this is physically not realistic. Water requirement and availability are simulated at the basin scale. Only some food issues, such as food production and trade, are aggregated to the global scale. This is appropriate for global-food-market simulation. So far, the IFPRI exercise includes some of the major river basins in China, India, and the United States, which together produce 60% of cereals in the world.

238. The scale issue is an important concern in this global model. For the models mainly focusing on the global perspectives, a basin-based approach has been used, which takes the river basin as the basic modeling unit. For each basin, all surface reservoirs at both the main river and the tributaries are aggre-

gated into an "equivalent basin reservoir," and all groundwater sources are lumped into a single groundwater source. This aggregation assumes a full water-transfer capacity within one basin; that is to say, water in one sub-basin may be used for other sub-basins where needed. The maximum allowed water withdrawal (*MAWW*) for a basin depends on several factors: i) the physical capacity of water withdrawal for agricultural, domestic, and industrial uses; ii) the instream-flow requirements for navigation, hydropower generation, recreation, and environment purposes; iii) source availability; and iv) water demand. Total water withdrawal in a basin is restricted by the *MAWW*, which will prevent water withdrawal beyond the engineering capacity in the basin. While we think this aggregation is reasonable for modeling on a global scale, it may not be suitable for detailed basin studies in which spatial distribution of water supply and demand are often required to be explicitly represented.

Accounting for the loss of water and water availability

239. Regarding flood loss, IFPRI's model does simulate monthly water spill for each spatial unit. So flood loss is accounted for in calculating water availability. It is important to consider water loss caused by floods in the calculation of water resources, because floods occur even in dry countries. In terms of hydrology, the maximum rainfall intensity causing a flood varies little from region to region compared to total annual precipitation, which varies greatly. It was generally estimated that almost 30% of river runoff is lost by floods even though dams were to be built in every possible site in one particular Japanese river.

240. Regarding water availability, IFPRI's model is supported by a monthly water-simulation model for each modeling unit over the time horizon. Effective water availability simulated in IFPRI's model is a function of runoff, infrastructure (such as reservoir storage and withdrawal and pumping capacity), and policies on groundwater pumping and environmental committed flow.

Estimating water demand as a function of food prices

241. The suggestion of expressing water development (public investment) as a function of food prices is interesting, but IFPRI's model does not include such a relation explicitly. Significant research would need to be done to estimate such investment function. However, realized irrigated area is estimated as a function of crop prices among other variables (see above).

IFPRI's response to expert comments on model assumptions

242. IFPRI's exercise develops a number of scenarios in which the assumptions regarding basin efficiency varies. The Irrigation-Water Supply Reliability Index is expected to decline for developing countries from .80 to .71, meaning 29% of water shortage relative to the potential demand. It has been suggested to carry out a sensitivity analysis of such change because of its high value.

243. Water-use efficiencies at the river-basin scale basically extend the efficiencies at the local scale to the basin scale. Following Keller and Keller (1995), irrigation efficiency is defined at the basin scale as the ratio of crop-water evapotranspiration to total water depletion for irrigation in the basin. The latter specifies the fraction of potential water depletion that can be effectively used for crop growth. The basin efficiency at the baseline is assessed based on estimated beneficial water depletion for irrigation and given total irrigation-water depletion from Shikolomanov (1999) and other sources. Projections on changes of basin efficiency are made for future years and are mainly subject to investment rates and rates of reform in water management.

244. IFPRI's model simulates water use for livestock as a separate sector. The estimated livestock water demand in the base year is based on livestock production and water consumption per unit of livestock

product produced (this includes beef, milk, pork, poultry, eggs, sheep and goats, and aquaculture fish). Consumptive-use coefficients for water for livestock products are estimated for the United States using several sources and are adapted to other developed countries based on FAO livestock data. For all of the livestock products except fish, it is assumed that the projection of livestock water-demand in each basin, country, or region follows the same growth rate of livestock production. Livestock water-demand is determined as a linear function of livestock production, assuming no change in water consumptive use per unit of livestock production.

245. The water demand for fish production is assumed to grow at the weighted average of livestock-water-demand growth. Direct water consumption by livestock is very small, but due to the rapid increase of livestock production, especially in developing countries, livestock water demand is projected to rise to 65 km^3 in 2025, 72% more than the 38 km^3 in 1995. While the developed world sees only a 19% increase of livestock water demand between 1995 and 2025 (from 16 km^3 to 19 km^3), livestock water demand is projected to double in the developing world (from 22 km^3 to 46 km^3). Livestock water demand is only 1.7% of the total water demand (depletion) in 1995. By 2025 it will be 2.6% of the total.

IFPRI's response to experts' comments on model scenarios

246. Although combined scenarios would produce some realistic results, individual scenarios are still considered useful for the analysis of the impact of individual technological or policy changes.

247. Many reviewers have argued that IFPRI's baseline projections for growth in irrigation-water demand are too high. These projections are the best estimates, but in any case should be used in conjunction with alternative scenarios. In addition, the high-investment scenarios that include more rapid growth of irrigation development have also been developed.

248. More optimistic scenarios could include faster basin-efficiency improvement, more rapid growth of potential irrigated area, larger water-withdrawal capacity in those wet regions, higher environmental-flow allocation, faster growth of the degree of connection in domestic water supply, and other important variables.

249. Actually, water stress did exist in many regions in the last five years, as well as today. Our model shows that stress will become worse without appropriate investment and policy changes. We think the model results will be similar even when running it from a different base year. However, running the model starting from a different year means a large amount of data collection and model calibration, and we think the payoff is unlikely to justify the effort. The collection and calibration of data for the base year of 1995 required in excess of one year.

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