Water and Agriculture
Implications for Development and Growth

Essays from the CSIS and SAIS Year of Water Conference

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FOREWORD

Jessica P. Einhorn and Erik R. Peterson

Each year, the Paul H. Nitze School of Advanced International Studies (SAIS)—a leading international relations graduate school—selects a timely, substantive theme to address during the academic year through events and lectures, an external speaker series, and an in-depth conference. For the 2008–2009 academic year, SAIS partnered with the Center for Strategic and International Studies (CSIS) in Washington, D.C., for the "Year of Water" program.

Across the globe, water is a subject of huge importance and relevance to regional cooperation, poverty alleviation, competitiveness in both manufacturing and agricultural production, and therefore trade. At a time of mounting population pressures, environmental declines, and growing demand for water, SAIS and CSIS—positioned at the nexus of academic study and policy analysis—led a robust exploration of the full spectrum of water-related issues.

Efforts to understand water and its linkages to other critical resources—particularly agriculture—are now more important than ever. As it stands, agriculture accounts for more than 70 percent of global water use, and already 1 billion people are chronically hungry. The global demand for food is expected to double in the next 40 years, yet water scarcity, land degradation, volatility in energy prices, and the changing climatic conditions will place unprecedented strains on water and agricultural systems.

Fittingly, the Year of Water culminated in a one-day conference, "Water and Agriculture: Implications for Development and Growth." The conference underscored the vital link between agriculture and water and the importance of economic prosperity, competitive interests, and technologies in promoting global production and cooperation. This volume summarizes the ongoing research of the international leaders involved in the conference. It shares unique insights of experts from the academic, public, and independent sectors alike, representing diverse perspectives from across disciplines and from countries across the globe.

In the realm of technology and innovation, contributing authors point to drip irrigation, drought-resistant plant breeding, wastewater treatment for irrigation reuse, and satellite-based assessments as promising tools to enhance water efficiency and agricultural production. On the micro level, there is a need to improve the livelihoods of smallholder farmers through small-scale soil and water management practices and entrepreneurial, market-based approaches.

Resolving the resource conundrum will require concerted political will and action at all levels. Contributing authors suggest that water should be priced correctly to incentivize efficient use; that the public sector should pursue more multi-stakeholder partnerships; and that development approaches should integrate the complex nexus of food, water, and energy into policymaking and management.

Although the challenges are vast, experts agree that it is indeed possible to create a future in which water resources and agriculture represent forces of resilience rather than vulnerability.

ACKNOWLEDGMENTS

The CSIS Global Water Futures Project and SAIS would like to express sincere gratitude to the keynote speakers and panelists who participated in our events throughout the Year of Water, particularly our March 2009 conference, "Water and Agriculture: Implications for Development and Growth," which was supported by a grant from the Bill & Melinda Gates Foundation. We appreciated our participants' willingness to share their expertise and engage in open dialogue, which made our program—and this publication—possible.

In particular, we would like to thank Geoff Dabelko and his colleagues at the Woodrow Wilson International Center for Scholars for their collaboration as well as Jerry Delli Priscoli for his guidance. We would also like to offer our thanks to Valentina Valenta and the Bipartisan Congressional Water Caucus for their support in raising awareness of global water issues on Capitol Hill.

We appreciate the involvement of our colleagues across CSIS and SAIS, from interns to professors, who helped make the Year of Water a reality. Special thanks go to Rachel Posner, Katryn Bowe, Emily Kessler, Ashley Rogers, Krystle Kaul, and Audrey Villinger.

1 WATER, AGRICULTURE, AND DEVELOPMENT

THE QUALITY OF ADVICE?

John Briscoe

Much has been written over the past year about the food crisis. Institutions like the International Food Policy Research Institute and the World Bank[1] have done detailed global analyses of trends of demand and supply. It is not my pretension—nor my comparative advantage—to repeat or summarize these studies. Rather, I will give a personal view of the challenges of water, agriculture, and development, based in general on four decades of experience, but more particularly on three recent engagements.

The first recent engagement was leading a struggle to get the World Bank to reengage with infrastructure and the associated effort to make sure that the voices of developing countries—rather than the voices of the donor community and northern nongovernmental organizations (NGOs)—decide on priorities. The second recent engagement was in the field, with the daunting water and agriculture challenges faced by India, Pakistan, and Bangladesh. Recent engagement three was in Brazil, where as the World Bank's country director, *inter alia*, it was my fate to try to explain to the country in the world that has undoubtedly done the best in tropical agriculture over the last 30 years why the donors and NGOs who had failed the developing world in these areas were now confidently lecturing Brazil about how it should manage its agricultural matters.[2] Finally I pull together some of these strands, outlining some of the principal water and agriculture challenges facing the world and suggesting ways in which the sea changes in global economic balances might affect the responses to these challenges.

Lessons Learned before Joining the World Bank

The "recent engagements" were preceded by decades of work on development. Of the many marks left by these prior engagements, two particularly affected the perspective I brought to policy and implementation debates in the World Bank.

The first of these came from my experience, in the late 1970s, working as a civil servant in the government of Samora Machel's newly independent Mozambique. I was one of a legion of Marx-

1. World Bank, *World Development Report 2008: Agriculture for Development* (Washington, D.C.: World Bank, 2008), http://www.worldbank.org/wdr2008.

2. A personal note: During my years at the World Bank, one of the most galling of experiences was to listen to a series of ex-Bank managers and staffers give advice about how the Bank should change and reform, when they had said and done nothing on those issues while they were in the Bank. Although I fail many consistency tests, this is not one of them—the views I express in this chapter are consistent with those that I expressed, on these issues and on others including many more controversial, during my tenure in the Bank. In a few cases (Sebastian Mallaby, *The World's Banker: A Story of Failed States, Financial Crises, and the Wealth and Poverty of Nations* [New York: Penguin, 2006], and World Bank, *Brazil Country Partnership Strategy 2008–2011* [Washington, D.C.: World Bank, 2007]), my views made some difference.

ists who descended from all corners of the earth to help build the "new man" in Africa. We made many sacrifices—monetary and, for some, their families and lives—but were compensated by the heady prospect of molding the policies of a new and emblematic country in our image of what the world should be. The result was a disaster of what Lenin called "infantile leftism." And when the price came to be paid, it was not we, with PhDs and passports in our pockets, who paid this price. It was the people of Mozambique, who suffered enormously. No one has searched his soul more deeply on such issues than the great Pakistani Akhter Hameed Khan. Reflecting on his role in the 1943 famine in Bengal, he noted:

> Like most young men I was a pseudo-socialist and the prospect of puncturing bloated banias (merchants) pleased me. I considered it a great achievement when, in one fell swoop, I captured half a million maunds of rice from the banias of Bogra. . . . Shortly after, the price of rice rose from fifteen rupees to fifty rupees in the denuded Dacca markets. Thousands who lacked purchasing power perished. I understood that the Bogra operation, which had given me pleasure, was a crude blunder. It was childishly easy to destroy an old system. Subsequent experience proved that it was not so easy to build a new one.[3]

The second of these experiences was, coincidentally, in a part of Comilla District of Bangladesh where Akhter Hameed Khan had later developed his remarkable cooperative movement. Now it was I, another young pseudo-socialist, who railed against the proposed Asian Development Bank embankment around the island where I lived in the 1970s. The embankment would, my careful and objective analytics showed,[4] simply further strengthen the landed elite and impoverish the poor. Just as Akhter Hameed had lived to see things turn out otherwise, so too did I. When I returned to "my village" 20 years later,[5] I found that people's lives were, indeed, transformed. Now there were flourishing markets where none had existed before, now there were three crops a year instead of one, and now a Bengali girl would expect to live 20 years longer than her mother just a generation earlier. And what, I asked the villagers whom I knew, were the reasons? No, not the much (and rightly) celebrated Grameen Bank and Bangladesh Rural Advancement Committee (BRAC) efforts, but infrastructure—roads and bridges and, above all, the embankment. Yes, it was true that the government had handled resettlement badly. Yes, it was true that the embankment had collapsed in the first year. Yes, it was true that there was a lot of corruption. But it was also true that this imperfect infrastructure had given large numbers of people the possibility of a productive life that had not existed before.

And what was the reaction of "the development community"? It included an energetic and colorful multimedia denunciation of the embankment by a major environmental NGO[6] and a politically correct poverty analysis by the World Bank,[7] the executive summary of which mentioned today's development buzzwords ("education," "health," "microcredit," and "NGOs") 37 times, and infrastructure once.

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3. Akhter Hameed Khan, "A History of the Food Problem in East Pakistan," Agricultural Development Council (New York: Agricultural Development Council, 1973).

4. John Briscoe, "Energy Use and Social Structure in a Bangladesh Village," *Population and Development Review* 5, no. 4 (Population Council, December 1979), http://www.jstor.org/pss/1971974.

5. John Briscoe, "Two Decades of Change in a Bangladeshi Village," *Economic and Political Weekly* (Bombay: Population Council, October 6, 2001).

6. Proshika, "In Quest of a Golden Dream," 37-minute video (Dhaka, Bangladesh, 1992).

7. World Bank, *Bangladesh: From Counting the Poor to Making the Poor Count,* Report No. 17534-BD (Washington, D.C.: World Bank, 1998).

Three Recent Engagements: Lessons Learned

1. Struggling to Put Infrastructure Back on the Development Agenda

"Development specialists" make a bewildering and constantly shifting array of recommendations for what developing countries need to do to grow their economies. A primary, primitive filter is seldom used: "Is the recommended path one that has been traveled by most countries that have developed?" The logical corollary follows: (1) if the recommended action is one taken by every country that has developed, then the burden of proof is fairly low, but (2) if the set of actions has never been taken by any country that has grown rich, then the burden of proof, presumably, should be set very high.

If one applied this filter to the dominant development agenda, at least two answers would emerge. First, consider the Millennium Development Goals (MDGs),[8] the lodestone of the development community for the last decade. The MDGs make no mention of employment, agriculture, infrastructure, or the rule of law but prioritize social goals that have historically been a consequence rather than a cause of economic development. One would imagine that the supporting proof for this "road never traveled before" would be extensive and persuasive. In fact, UN Declarations, emanating from the post-affluent perspective of the rich development donors, are offered as the substitute for analysis and proof.

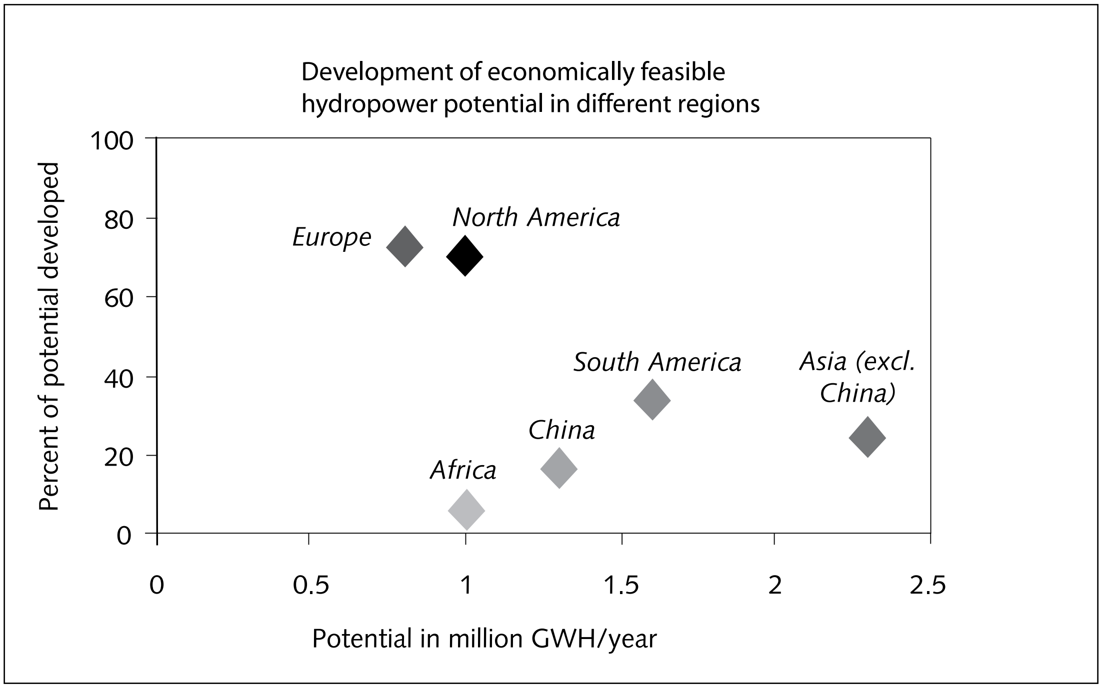
Second, consider infrastructure. No country that is currently rich has become so without extensive investment in major infrastructure during its growth period. For this reason, the early focus of the World Bank was almost entirely on infrastructure. The uninitiated would imagine that there could never be a proposed development path that would not consider infrastructure to be a necessary (although certainly not sufficient) condition for growth. But the development world is often an Alice in Wonderland world. And thus it is perfectly normal for the development minister of, say, Norway or Switzerland (where industrialization was built on the back of cheap, renewable hydropower and where 80 percent of hydropower potential is long developed) to propound that she does not support the building of a hydropower plant in impoverished Ethiopia or Nepal, where development options are limited, where hydropower potential is vast and less than 1 percent developed. Or that she would support such investments only if they "met standards, such as the guidelines of the World Commission on Dams," which were so stringent that they not only had never been met in the growth periods of currently rich countries, but could not be met, today, by any country, rich or poor.[9]

How did this surreal state of affairs come to pass? Basically because of two factors—first, the moral hazard inherent in the aid process and, second, the fact that single-issue, rich-country NGOs have become, in recent decades, a strident and prominent constituency in aid discussions. Within the World Bank—the bellwether institution for development philosophy—the consequences were dramatic. When he became World Bank president in 1995, James Wolfensohn wanted to

8. United Nations (UN), *End Poverty 2015: Millennium Development Goals* (New York: UN, 2000), http://www.un.org/millenniumgoals/bkgd.shtml.

9. World Bank, *Water Resources Sector Strategy* (Washington, D.C.: World Bank, 2003); Ryo Fujikura and Mikiyasu Nakayama, "Perception gaps among stakeholders regarding the WCD guidelines," *International Environmental Agreements: Politics, Law and Economics* 3 (2003): 43–57; Michael Fink and Anne Cramer, "Towards Implementation of the WCD Recommendations: Experiences and Reflections after 5 Years," *Water Politics and Development Cooperation*, ed. W. Scheumann, S. Neubert, and M. Kipping (New York: Springer, 2008), 33–54.

Figure 1.1 Hydropower in the Rich and Poor Worlds



Source: World Bank data.

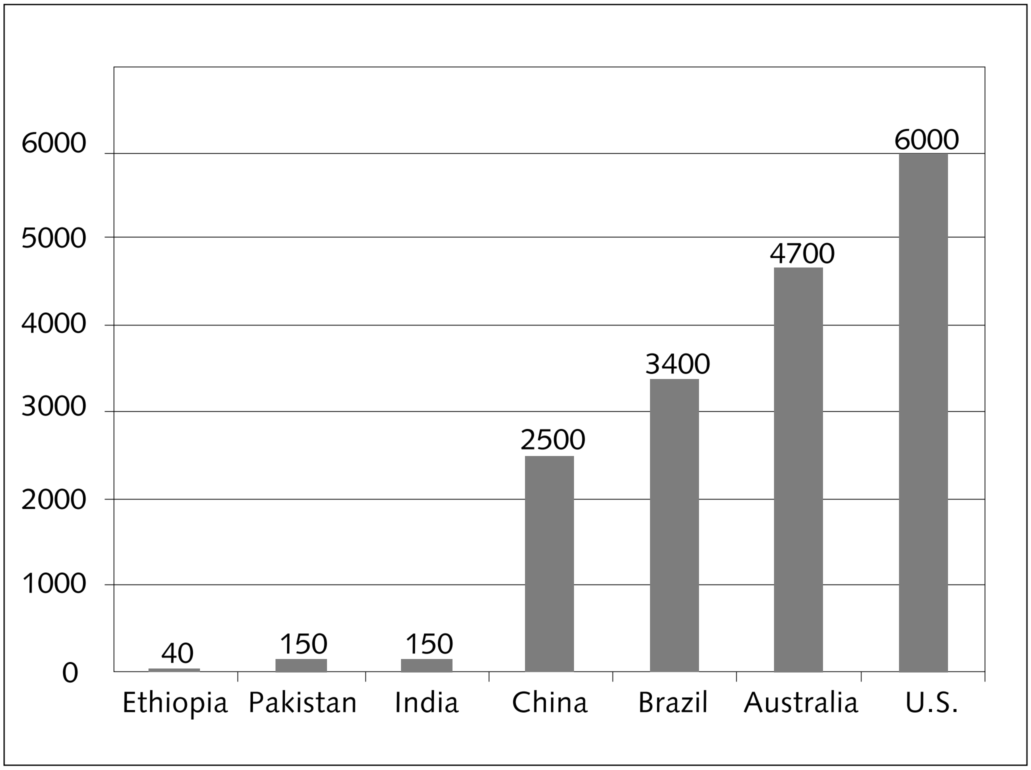
get the advocacy NGOs off his (and the Bank's) back. And thus one of his first major decisions was to abandon the Bank's commitment to the medium-sized Arun hydropower project in Nepal. For a poor mountainous country whose primary resources are gravity and water, this effectively meant abandoning the country to poverty. In the world of development, however, punishment is imposed only for sins of commission, not for sins of omission, and so there were no consequences for Bank management, even as Nepal sunk further into poverty and chaos.

In the late 1990s, as the Bank's senior water adviser, I was entrusted with responsibility to prepare a new water strategy for the World Bank Group. A starting point was obvious—the vast gap between infrastructure endowments in the rich and poor worlds, as illustrated for hydropower in figure 1.1 and water storage in figure 1.2.

The battle royal that was unleashed has been described in detail in chapter 13 of Sebastian Mallaby's landmark history *The World's Banker.*[10] For the purposes of this chapter, there are a few salient observations. First, there was hostility to the idea of Bank reengagement with major infrastructure from almost all Bank senior managers, including the president, and from virtually all of the rich owners of the Bank. Second, not once was the hostility presented as a disagreement on substance—always it was because of "political realities." Third, "political realities" meant that the rich countries, pressured by single-issue NGOs, used blackmail when necessary. In one indicative instance, after a board meeting where developing countries had strongly supported Bank reengagement with dams, the representative of one of the Bank's biggest shareholders, who had not said a word in open session, telephoned the responsible vice president and explained that "if this is the position taken by the Bank, you should realize that it will be very difficult for our govern-

10. Mallaby, *The World's Banker*.

Figure 1.2 Water Storage Capacity in the Rich and Poor Worlds (cubic meters per capita)



Source: World Bank data.

ment to support the next round of IDA." The IDA, or International Development Association, is the Bank's soft-loan window that depends on donations from rich countries and underwrites, together with donor-directed trust funds, a major portion of the Bank's budget. As Devesh Kapur has documented,[11] the Bank has become addicted to the constantly-under-negotiation overhead associated with its soft-loan window—the soft-loan IDA tail has come to wag the hard-loan IBRD (International Bank for Reconstruction and Development) dog. Fourth, recently the political balance of power has changed as the rapidly growing middle income countries (MICs)—including China, India, and Brazil—finally decided (emboldened by their economic success and massive foreign exchange reserves) that enough was enough. "Infrastructure is essential for development and the Bank must reengage" was the message in an unprecedented joint message from the Chinese and Indian executive directors, in the board discussion of the water strategy, in 2003.[12]

And so the Bank has wiggled toward reengagement with infrastructure (figure 1.3). "Wiggled" is the operative word because nothing has been done to dismantle the ever-expanding set of "safeguards" and "operational policies" that, when taken in their entirety, make virtually any practical operation of any complexity and controversy impossible.

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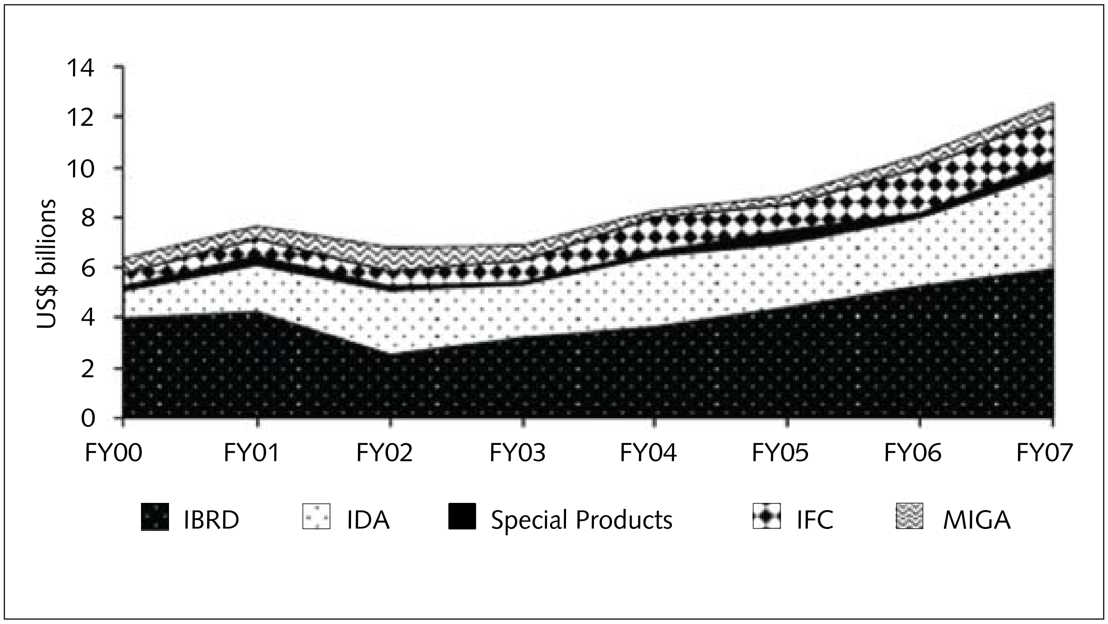
11. Devesh Kapur, *Do as I Say, Not as I Do: A Critique of G-7 Proposals on Reforming the MDBs,* Center for Global Development Working Paper Number 16 (Washington, D.C.: Center for Global Development, 2002).

12. World Bank, Statement by Chander Mohan Vasudev and Guangyao Zhu (executive directors for India and China), Infrastructure Business: Key Trends and Issues (World Bank, 2003).

Figure 1.3 World Bank Reengagement with Infrastructure



Source: World Bank data.

Devesh Kapur has argued that the much greater density of mandatory safeguard policies in the World Bank (compared with other development banks, as shown in table 1.1)[13] is a direct result of the dependence of the World Bank budget on IDA and thus the whims of the Bank's rich country owners. This dense fabric of mandatory "safeguards" gives single-issue NGOs (supported by many donors, who, as discussed in more detail later, share many of their views, and by the internal Bank groups who live to protect "their safeguard") easy targets in any project they do not like, because they can invoke the specter of the "Inspection Panel," which has the mandate to investigate any project where there is an allegation of violation of an operational policy. Vice presidents and country directors have necessarily developed antennae that tell them which types of projects are likely to lead to engagement of the Inspection Panel, a draconian institution without effective oversight and riddled with conflicts of interests that rides roughshod over due process and national law and that imposes huge monetary and reputational costs on Bank operations.[14]

In this environment, the Bank's clients divide into two distinct groups. First are the middle-income "countries with choices" that have adequate resources to do the big things themselves and thus refuse to incur the enormous uncertainty and costs that come with "following Bank procedures." The perspective of the Brazilian deputy minister of finance—"I would much rather pay a couple more percentage points of interest than have to incur the lack of predictability and transactions costs emanating from the Bank's rules on a controversial infrastructure project"—is universal. There have been endless analyses of "the cost of doing business" with the Bank,[15] but not one of the "safeguard" and other operational policies that underlie these costs have been repealed. Second is the more difficult case of the poorer "countries without choices," who live at the whim

13. Kapur, *Do as I Say, Not as I Do*.

14. Robert Wade, "Accountability Gone Wrong: The World Bank, NGOs and the U.S. Government in a Fight over China," *New Political Economy* 14, no. 1 (2009).

15. World Bank, *Cost of Doing Business Report* (Washington, D.C.: World Bank, 2000).

Table 1.1 World Bank and Other Multilateral Development Bank Policies

Safeguard Area	AfDB	AsDB	EBRD	IDB	IBRD/IDA
Environmental assessment	Guideline	Policy	Policy	Guideline	Policy
Forestry	Policy	Policy	NR	Policy	Policy
Involuntary resettlement	NR	Policy	NR	Policy	Policy
Indigenous peoples	Policy	Policy	NR	Guideline	Policy
International waterways	NR	NR	NR	NR	Policy
Dam safety	Guideline	Guideline	NR	NR	Policy
Natural habitats	NR	Guideline	NR	NR	Policy
Pest management	Guideline	NR	NR	NR	Policy
Cutural resources	Guideline	Guideline	NR	NR	OPN
Projects in disputed areas	NR	NR	NR	NR	Policy

Note: NR: no requirement; OPN: operational policy note (in process of being converted into a policy).

AfDB = African Development Bank; AsDB = Asian Development Bank; EBRD = European Bank for Reconstruction and Development; IDB = International Development Bank; and IBRD/IDA = International Bank for Reconstruction and Development/International Development Association.

Source: Devesh Kapur, *Do as I Say, Not as I Do: A Critique of G-7 Proposals on Reforming the MDBs*, Center for Global Development Working Paper Number 16 (Washington, D.C.: Center for Global Development, 2002), 8.

of the donors and who have to basically take what they are given. A few controversial projects have, indeed, recently been approved by the Bank, and this is a good thing. But this approval has been after processes of mind-boggling complexity and duration. The two "poster cases" for Bank reengagement are the Nam Theun hydropower project in Laos, where *The Economist*[16] reported that one villager had been interviewed by 14 different independent "Bank missions" to solicit his views, and the Bujagali hydropower project in Uganda, which took more than a decade before the Bank was able to make a decision and which led President Yoweri Museveni to bemoan, "I am ashamed to even come here . . . all this hullabaloo has been a waste of time and a lack of seriousness . . . this was a circus."[17]

The good news is that just as the political reality on the board at the Bank has now changed, so too the situation in the poor countries is changing. The big MICs have massive resources. (Brazil's National Development Bank, for example, disburses about $70 billion a year,[18] more than twice the size of all disbursements by the World Bank.) Now the MICs are offering new lines of financing to poor countries, lines that are a boon to poor countries, because they do not impose impossible-to-meet conditions and bring results in reasonable periods of time. The major positive result is that developing countries now have ways of financing key development needs; a secondary value is the recognition that the World Bank and others risk becoming irrelevant unless they change their ways.[19] The current global crisis has shown how the shoe is now on the other foot: "Who would have imagined that the IMF would come to Brazil, begging for a loan," noted Brazilian president Lula.

16. "Laos: Damned If You Do," *The Economist,* November 29, 2003, http://www.economist.com/world/asia/displaystory.cfm?story_id=2251859.

17. Reuters, "Peeved Museveni launches $550 million Uganda dam," January 24, 2002.

18. Valor Economico, "BNDES preve desembolsar ate Rs 130 bi este ano" (Sao Paulo: Valor Economico, January 26, 2009).

19. "Istanbul: Sin Aqua Non—Dams Are Making a Comeback," *The Economist,* March 21, 2009, http://www.economist.com/world/international/displaystory.cfm?story_id=13349220.

2. Addressing the Daunting Challenges of Agriculture and Water in South Asia

After succeeding in putting infrastructure—albeit imperfectly—back on the Bank's agenda, I wanted to help translate the new water policy into action. So I spent the next few years living in South Asia and focusing on the water challenges (and associated agricultural and energy challenges) of India and Pakistan. Working closely with local experts and with the governments, and supported by the Bank's vice president for South Asia (one of the few senior Bank officials willing to swim against the current), we produced a new approach, published in two Oxford University Press books: *India's Water Economy: Facing a Turbulent Future*[20] and *Pakistan's Water Economy: Running Dry*.[21]

The books were welcomed by the countries' leaders—for example, in India[22] and in Pakistan[23]— not least because they meant a reengagement of the Bank as a full-service partner and meant that the Bank recognized the need for "high-risk/high-reward" projects. The India and Pakistan reports, which have had some role in motivating the large and absolutely essential investments in infrastructure in both countries, also played a role in initiating fundamental reforms in the vital issue of water entitlements in the Punjab in Pakistan[24] and Maharashtra in India.[25]

Two points in this discussion on water, agriculture, and development deserve elaboration.

- Lesson One: The Need for Major Infrastructure

Large water projects became unpopular with the donor community in part because of the NGO critique that "they benefit the rich and not the poor." At first glance this accusation is irrefutable—for example, water from the Bhakra-Beas complex in Northwest India, which underpins irrigation in the breadbasket states of Punjab and Haryana, goes to those who have land.[26] And those who have land are the rich. Therefore, Bhakra-Beas is an anti-poor project. A deeper dig shows some interesting findings: irrigated districts have poverty rates of 26 percent and unirrigated districts poverty rates of 69 percent;[27] the returns to education in irrigated districts are 32 percent and in unirrigated districts 0 percent.[28] A recent study by Ramesh Bhatia and colleagues shows why this is so.[29] The study uses a computerized general equilibrium model to estimate the

20. John Briscoe and R.P.S. Malik, *India's Water Economy: Facing a Turbulent Future* (New Delhi: Oxford University Press, 2006).

21. John Briscoe and Usman Qamar, *Pakistan's Water Economy: Running Dry* (Karachi: Oxford University Press, 2005).

22. Shankar Acharya, "India's Water Troubles," *Business Standard,* New Delhi, October 25, 2005, http://www.business-standard.com/india/news/shankar-acharya-india%5Cs-water-troubles/226837/.

23. Pervez Musharraf, "Full text of President Musharraf's address to the nation," BBC, January 18, 2006.

24. Irrigation and Power Department of the Government of the Punjab, http://irrigation.punjab.gov.pk/entitlement.aspx entitlements.

25. Maharashtra Water Resources Regulatory Authority (MWRRA), http://www.mwrra.org/.

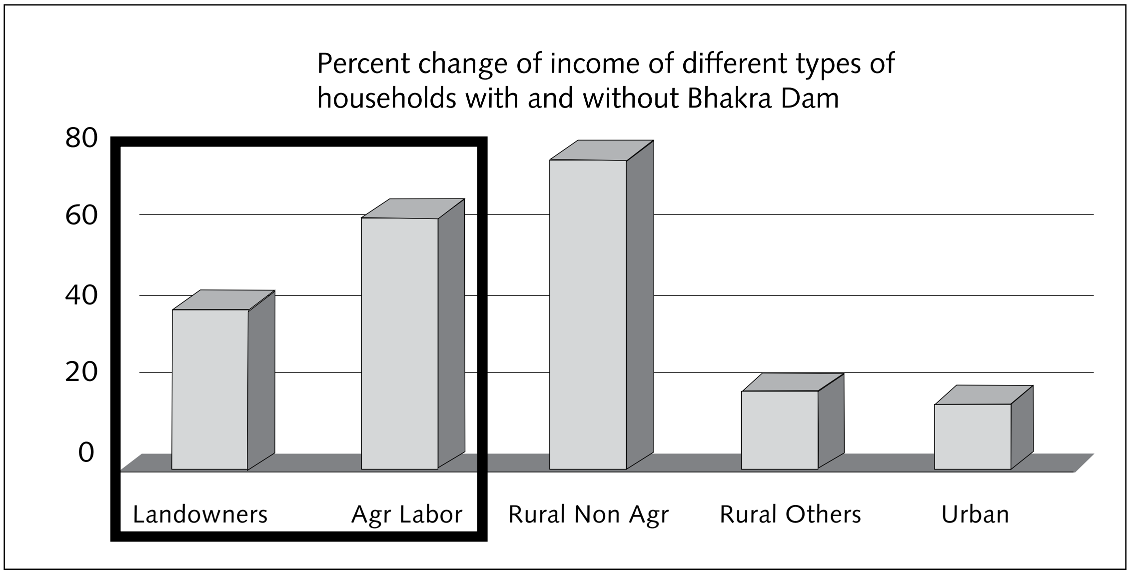
26. Shripad Dharmadhikary, *Unravelling Bhakra: Assessing the temple of resurgent India* (Madhya Pradesh, India: Manthan, 2005).

27. World Bank, *India Irrigation Sector Review* (Washington, D.C.: World Bank, 1991).

28. Lant Pritchett, "Where Has All the Education Gone?" *World Bank Economic Review* 15 (Oxford University Press, 2001), 367–391.

29. Ramesh Bhatia and R.P.S. Malik, "Bhakra Multipurpose Dam System," in *Indirect Economic Impacts of Dams: Case Studies from India, Egypt and Brazil* (New Delhi: Academic Foundation and World Bank, 2008), 133–192.

Figure 1.4 The Benefits of Bhakra Dam



Source: Ramesh Bhatia and R.P.S. Malik, "Bhakra Multipurpose Dam System," in *Indirect Economic Impacts of Dams: Case Studies from India, Egypt and Brazil* (New Delhi: Academic Foundation and World Bank, 2008).

multipliers (arising both from backward linkages, such as to those providing agricultural inputs, and forward linkages, such as food processing industries) and a social accounting matrix to tease out how different socioeconomic groups benefit from both these indirect effects. The conclusion is remarkable—indirect benefits are as large as the direct benefits (a finding consistent for similar studies in Malaysia,[30] Egypt,[31] the United States,[32] and Brazil[33]); and, as illustrated in figure 1.4, it is actually the poor who are the greatest beneficiaries of such projects because of the massive increase in the demand for labor. No wonder those who built such projects in India—Sir Arthur Cotton and K.L. Rao in the Krishna Delta and Mr. Pennyquick in Tamil Nadu—have been turned, by the local population, into de facto saints! No wonder Nehru described such projects as "the temples of modern India."

But why, the informed reader will reasonably ask, is the Sardar Sarovar Project on the Narmada so deeply unpopular? The answer is complex, but goes to the heart of the argument. First, there is no question that government at various levels in India has done a poor job on the complex task of resettlement in a densely populated country. Second, as shown in a study by the University

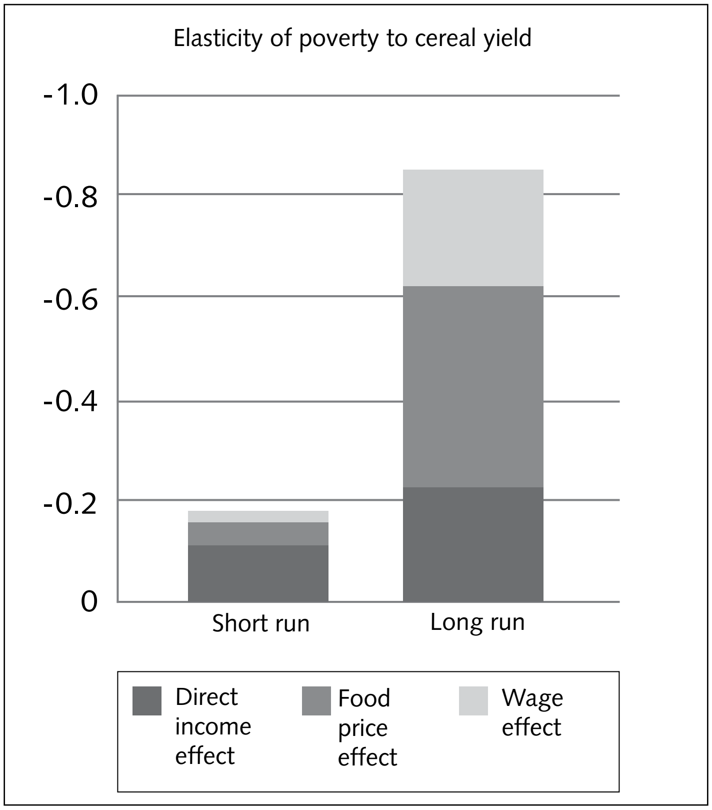
30. Clive Bell, Peter Hazell, Roger Slade, and Shantayanan Devarajan, *Project Evaluation in Regional Perspective–A Study of an Irrigation Project in Northwest Malaysia* (Baltimore: Johns Hopkins University Press, 1982).

31. Sherman Robinson, Ken Strzepek, Moataz El-Said, and Hans Lofgren, "The Aswan High Dam," in *Indirect Economic Impacts of Dams: Case Studies from India, Egypt and Brazil* (New Delhi: Academic Foundation and World Bank, 2008), 227–274.

32. Leonard Ortolano and Katherine Kao Cushing, "Grand Coulee Dam 70 Years Later: What Can We Learn," *Water Resources Development* 18, no. 3 (Routledge, 2002): 373–390.

33. Monica Scatasta, "Sobradinho Dam and the Cascade of Reservoirs on the Sub-Medio Sao Francisco River, Brazil," in *Indirect Economic Impacts of Dams: Case Studies from India, Egypt and Brazil* (New Delhi: Academic Foundation and World Bank, 2008), 275–350.

Figure 1.5 The Impact of Productivity on Poverty in India, 1958–1994



Source: World Bank, *World Development Report 2008: Agriculture for Development.*

of Sussex on the media and development,[34] opposition to the Narmada projects is almost universal in the English-language media in India but support almost universal in the vernacular-language media (which constitutes 95 percent of all readership in the country). Third is the issue of who can legitimately claim to be "the voice of the people." The leading anti-Narmada NGO campaigners have sometimes hinted that they will run for election,[35] and at other times they have said that electoral politics is not a personal option.[36] What is clear is that most activists and activist organizations have chosen to not submit their ideas for a vote by the people whom they claim to represent. These (often very eloquent) activists eulogize leaders such as Mandela and Lula when they are in opposition and then—as in the case of Arundhati Roy[37]—trash the same leaders once they take office and have to assume responsibility for the development of their countries. Meanwhile, support for transformational projects such as the Narmada dams—warts and all, just like the embankment in Bangladesh—is so widespread that it is inconceivable that any politician who opposed the Narmada projects could be elected governor of Gujarat or Madhya Pradesh.

The limitations of the narrow, "is it getting to the poor?" approach favored by donors is similarly fallacious in the related area of agricultural productivity. As documented in the World Bank's *World Development Report 2008: Agriculture for Development,*[38] the poor only benefit modestly from the direct, short-term income effect of productivity gains. But the long-run gains to the poor, acting mostly through the (indirect) price and wage effects, are huge (figure 1.5).

34. Graham Chapman et al., *Environmentalism and the Mass Media: The North-South Divide*, Indian Institute of Advanced Study (London: Routledge, 1997).

35. "Medha Patkar calls for political movement," *The Hindu*, February 4, 2003, and "Q & A: Medha Patkar," *The Hindu*, March 28, 2004.

36. J.M. Athyal, "Her Life Is Her Message," Medha Patkar at MIT, March 23, 2009, http://www.aidboston.org/medhapatkar2009/medha_patkar_indeptharticle_mar232009.pdf.

37. Arundhati Roy, "The New American Century," *The Nation,* February 9, 2004, http://www.thirdworldtraveler.com/Arundhati_Roy/NewAmericanCentury_ARoy.html.

38. World Bank, *World Development Report 2008: Agriculture for Development*.

- Lesson Two: The Desperate Need for a Revitalized State

The foundation for water-driven agricultural growth in the Indian subcontinent was laid down in the extensive canal networks built by the British in the nineteenth century. The contiguous irrigated area of Pakistan is 22 million hectares—10 times the size of the state of Massachusetts. Along with the infrastructure, the British built institutions for distributing and sharing the water—each canal had its allocation, and each farmer, through the famed warabandi system, had an assigned time to water his crops.

In the early decades after Partition, India and, even more, Pakistan faced massive challenges. The first challenge was a consequence of Sir Cyril Radcliffe's hasty scratch on the map, defining what would be India and what would be Pakistan. The line went right across the Ravi, Beas, Sutlej, Chenab, Jhelum, and Indus rivers, leaving the major irrigated areas in Pakistan and the headwaters in India. Fortunately that was the heroic era of the World Bank,[39] where more attention was paid to the sins of omission than those of commission. After ten years, the Indus Waters Treaty was signed in Karachi by Nehru, Ayub Khan, and the representative of the World Bank. The heart of the investment program that stitched "Pakistan's rivers" (the Chenab, Jhelum, and Indus) to its major irrigated areas (in the basins of "India's rivers"—the Ravi, Beas and Sutlej) was a series of massive link canals and two major dams, Mangla and Tarbela (figure 1.6). These "replacement works" were funded by donors, by Pakistan (including via a World Bank loan), and, most remarkably, by India. The Indus Waters Treaty, which has held over the subsequent six decades, is widely considered to be one of the great achievements of the World Bank. (It has often been remarked, and correctly so, that the contemporary World Bank, hamstrung by a spaghetti of internal regulations and focusing on sins of commission, could not possibly engage in such a heroic enterprise.)

The second great challenge in the subcontinent was a consequence of the technologies of distribution (leaky earth-lined canals) and irrigation (flooded fields). Over decades there were massive accumulations of water that leaked into the aquifers of Punjab and Sindh. By the early 1960s (figure 1.7), the water table intersected with the land in many areas rendered uncultivable by the combination of waterlogging and salt accumulation in the root zone. And so when President John Kennedy asked President Ayub Khan, "What can the United States do for Pakistan?" it was help with this daunting problem that was requested. And there started another round of true development cooperation, again facing squarely the disastrous consequences of doing nothing or of being overly cautious. A team of innovative hydrologists, agronomists, and economists from Harvard (where else?) studied the problem with their world-class Pakistani counterparts.[40] They concluded that the obvious "solution" ("line the canals to stem the leakage") was the wrong one and advocated a counterintuitive response—think of the canals as recharge structures as much as delivery structures, let them leak, and then intensify the circulation of the groundwater for irrigation. They advocated that this "increased circulation" be done through batteries of large, government-run tube wells that would pump water into the canal system. The technical solution was brilliantly correct; the institutional one was a failure, primarily because at just that time there was a technological revolution in the form of the availability of the humble low-cost submersible pump, powered initially by diesel generators and later by electricity. Over the next 40 years the number of pump sets in Pakistan increased from close to zero to more than 700,000 (figure 1.8).

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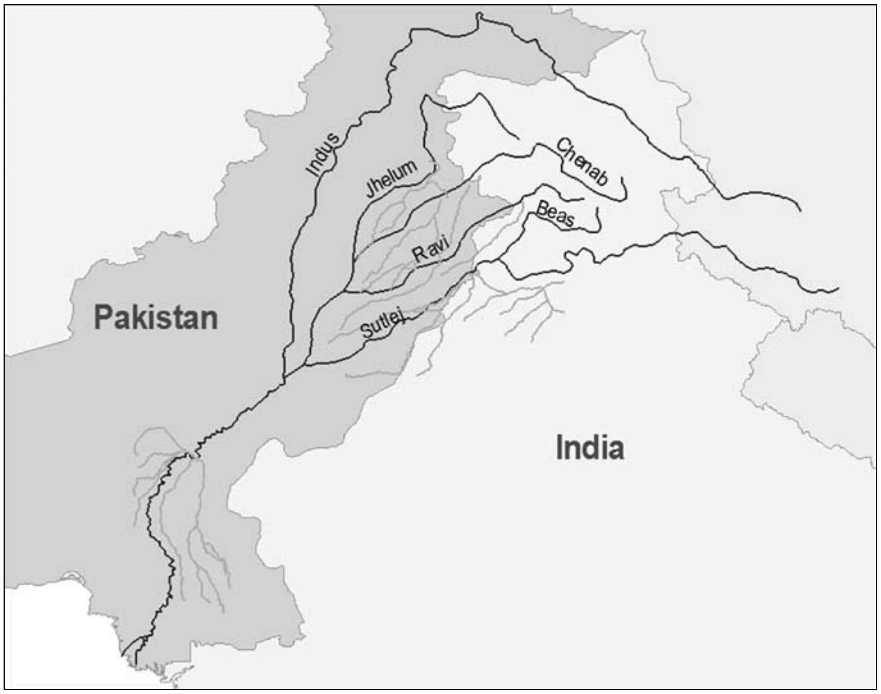
39. Shri N.D. Gulhati, *Indus Waters Treaty: An Exercise in International Mediation* (New Delhi: Allied Publishers, 1973).

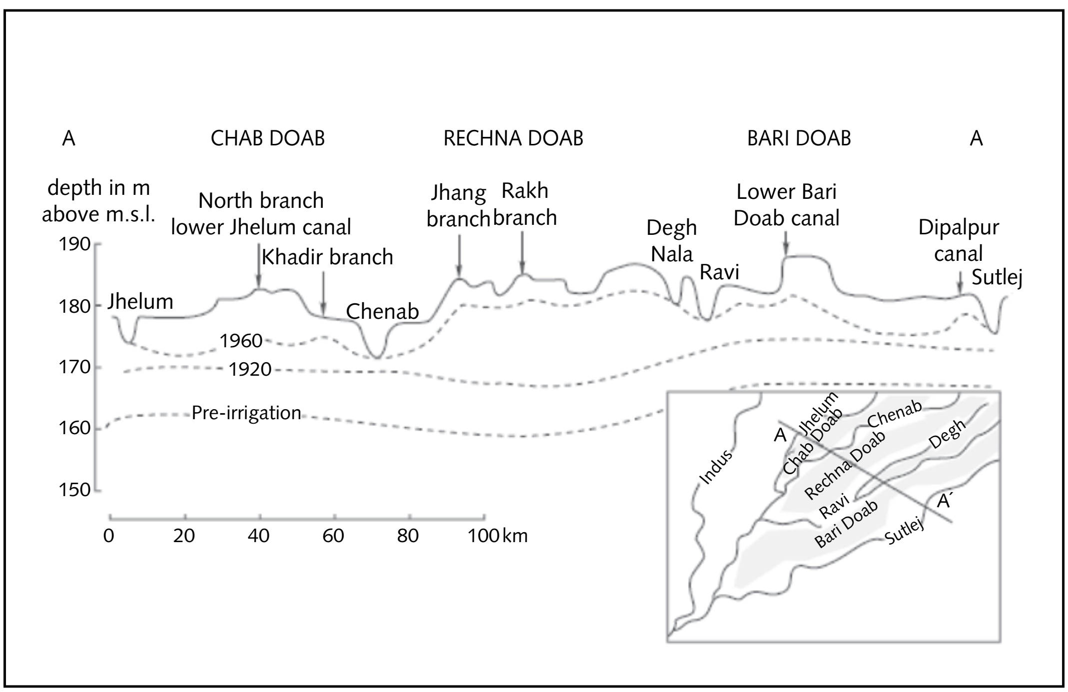
40. Aloys A. Michel, *The Indus Rivers: Study of the Effects of Partition* (New Haven: Yale University Press, 1967).

Figure 1.6 Partition and the Indus Basin



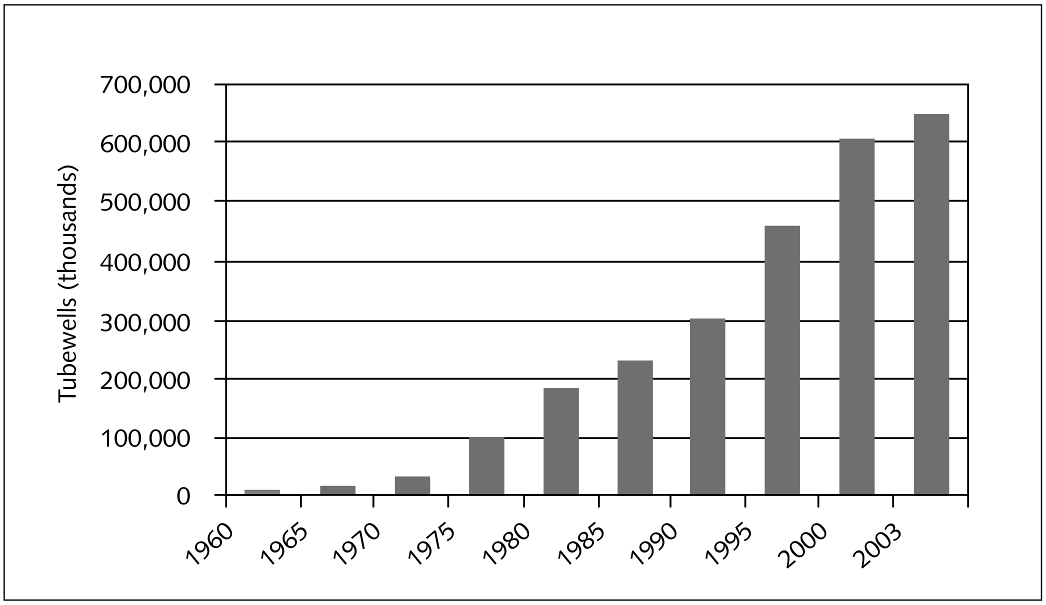
Source: John Briscoe and Usman Qamar, *Pakistan's Water Economy: Running Dry* (Karachi: Oxford University Press, 2005).

Figure 1.7 Rising Water Table in Punjab over Last 100 Years



Source: Briscoe and Qamar, *Pakistan's Water Economy*.

Figure 1.8 Number of Pump Sets in Pakistan



Source: Briscoe and Qamar, *Pakistan's Water Economy*.

The results were spectacular, in both agricultural and environmental terms. More than 70 percent of production (figure 1.9) now came from groundwater irrigation (controlled by the farmer and available just when needed). Canal irrigation slipped into a subsidiary role and the institutions for managing them descended into corruption and inefficiency. And with increased leaching the groundwater fell—today the area seriously affected by waterlogging and salinity is just 20 percent of the area in the 1960s.[41]

But water management is not a linear but a dialectic process—every success gives rise to a new set of challenges. (In the words of David Blackbourn's history of water and land management in Germany, "the state of art is always provisional—something that historians know well, but hydrological engineers found it hard to accept.")[42] Now the major challenge facing irrigated agriculture in both India and Pakistan is the falling water table (figure 1.10). In India, where the response of governments has been to subsidize electricity for pumping, accelerating the vicious cycle, the situation has reached catastrophic proportions throughout the breadbasket of Northwest and Western India. It is estimated that about 10 percent of India's foodgrains come from unsustainable groundwater use.[43] In Rajasthan over the past decade, the percentage of blocks where groundwater is overexploited has grown from 17 percent to 60 percent.[44] Pakistan, to its credit, has not subsidized electricity and thus not entered into this Faustian bargain.[45]

41. Briscoe and Qamar, *Pakistan's Water Economy*.

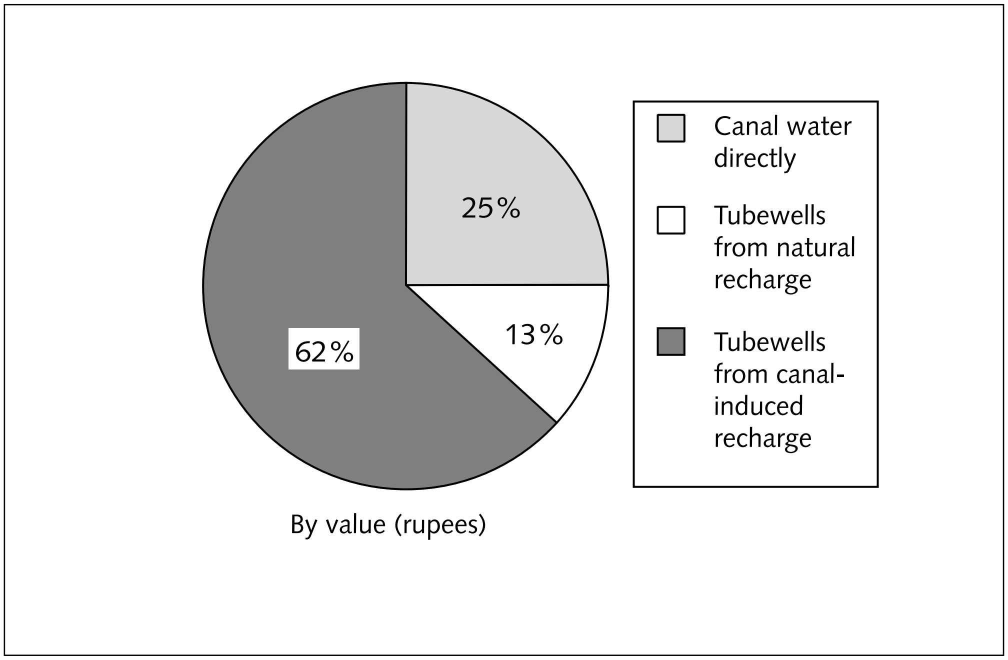
42. David Blackbourn, *The Conquest of Nature: Water, Landscape, and the Making of Modern Germany* (New York: W.W. Norton, 2007).

43. Briscoe and Qamar, *Pakistan's Water Economy*.

44. Briscoe and Malik, *India's Water Economy*.

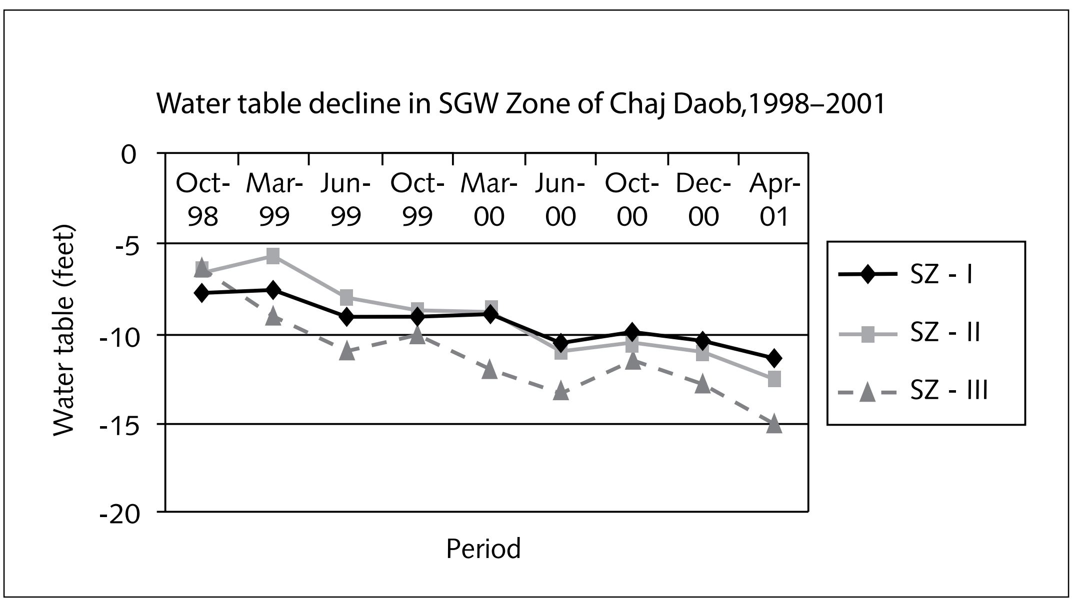
45. Briscoe and Qamar, *Pakistan's Water Economy*.

Figure 1.9 Water Source and Production in the Punjab



Source: Briscoe and Qamar, *Pakistan's Water Economy*.

Figure 1.10 Declining Water Table in the Pakistan Punjab



Source: Briscoe and Qamar, *Pakistan's Water Economy*.

For the past four decades the "exit" option, in Albert Hirschman's terms,[46] has worked brilliantly for the people of South Asia. But as is always the case with water management, processes are dialectic, and solutions are provisional. The countries of the region face a set of new challenges: they have to simultaneously reinvigorate the public networked surface water supply institutions and develop instruments and policies for restoring groundwater equilibrium. What is clear is that the core of these tasks is the reconstruction of a modern, accountable set of public water management institutions for regulating and providing networked services.

There is a growing understanding of the seriousness of these problems at the highest levels of government—by Pervez Musharraf[47] when he was president of Pakistan, and by the deputy chairman of the Planning Commission in India.[48] And there have been two important initial reform efforts—focusing on the central issue of water entitlements—in the Pakistan state of Punjab[49] and the Indian state of Maharashtra.[50] Acknowledging that every journey begins with the first steps, it is an open question whether the scale and pace of response will be fast enough, deep enough, or sustained enough to meet the daunting challenge of sustainable agricultural water management in South Asia.

3. Learning from Brazil, an Agricultural Superpower

Brazilian agriculture is a remarkable development success story. Agricultural output in Brazil today is four times its level of 30 years ago.[51] Brazil, which exports more than $20 billion a year in agricultural products, is now the world's largest exporter of beef, coffee, orange juice, sugar, and ethanol and is closing fast on the leaders in soya, poultry, and pork. It is, in the words of *The Economist,* "an agriculture superpower."[52] Equally remarkable (figure 1.11), increased inputs of land, capital, and labor account for only 10 percent of growth in output—90 percent is from increased productivity. The key is not (as the environmental and development NGOs would suggest) "cutting down the Amazon." Rather, this extraordinary, prolonged success has two main ingredients. First was large and sustained public (see figure 1.12) and private investment in agricultural research. It is widely acknowledged that Brazil's EMBRAPA is without peer in tropical agricultural technology. Second was the adoption of an agricultural model that invested in technology, knowledge, economies of scale, and integration of small farmers with agribusiness.

Without this Brazilian success story and without these high levels of Brazilian exports, the global price increases in 2008 would obviously have been worse.

So what, then, did the aid community—rich country donors, the World Bank and the regional development banks, and the advocacy NGOs—do for agriculture over the past several decades? Figure 1.12 showed how Brazil had maintained a large and consistent level of investment in agricultural research. Over the same period, in the words of the World Bank's *World Development Re-*

46. Albert Hirschman, *Exit, Voice, and Loyalty: Responses to Decline in Firms, Organizations, and States* (Cambridge: Harvard University Press, 1970).

47. Pervez Musharraf, "Full text of President Musharraf's address to the nation," BBC, January 18, 2006.

48. "Ahluwalia for Imposing Cess on Groundwater Resources," *The Hindu,* November 15, 2006.

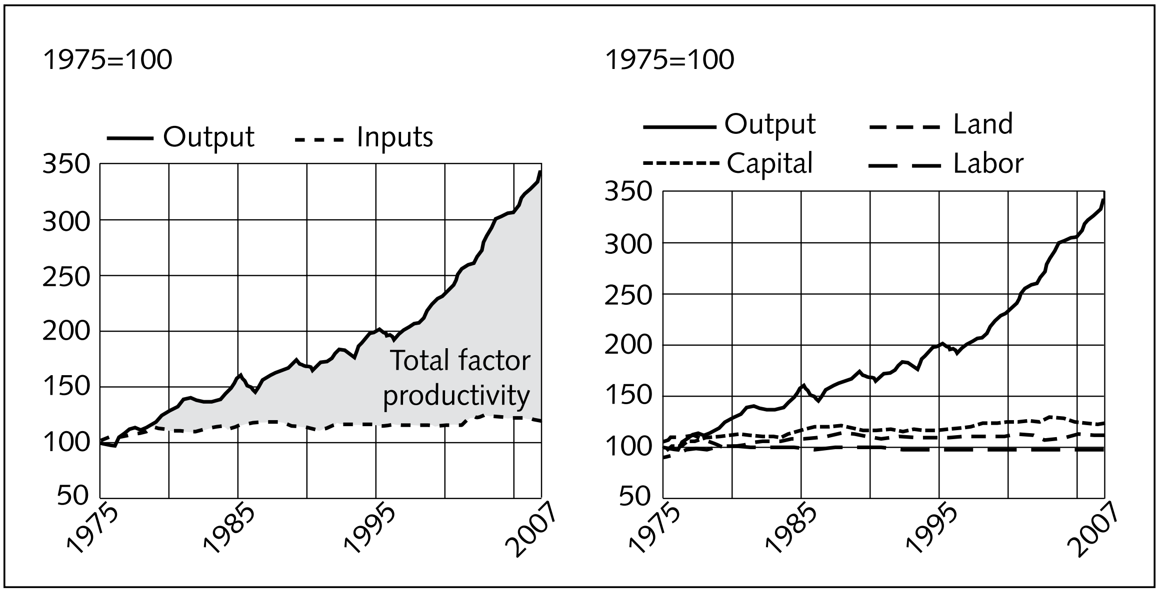
49. Irrigation and Power Department of the Government of the Punjab, entitlements, http://irrigation.punjab.gov.pk/entitlement.aspx.

50. Maharashtra Water Resources Regulatory Authority (MWRRA), http://www.mwrra.org/.

51. Delphin Netto, "Vivas a Produtividade" (Sao Paulo: Valor Economico, May 20, 2008).

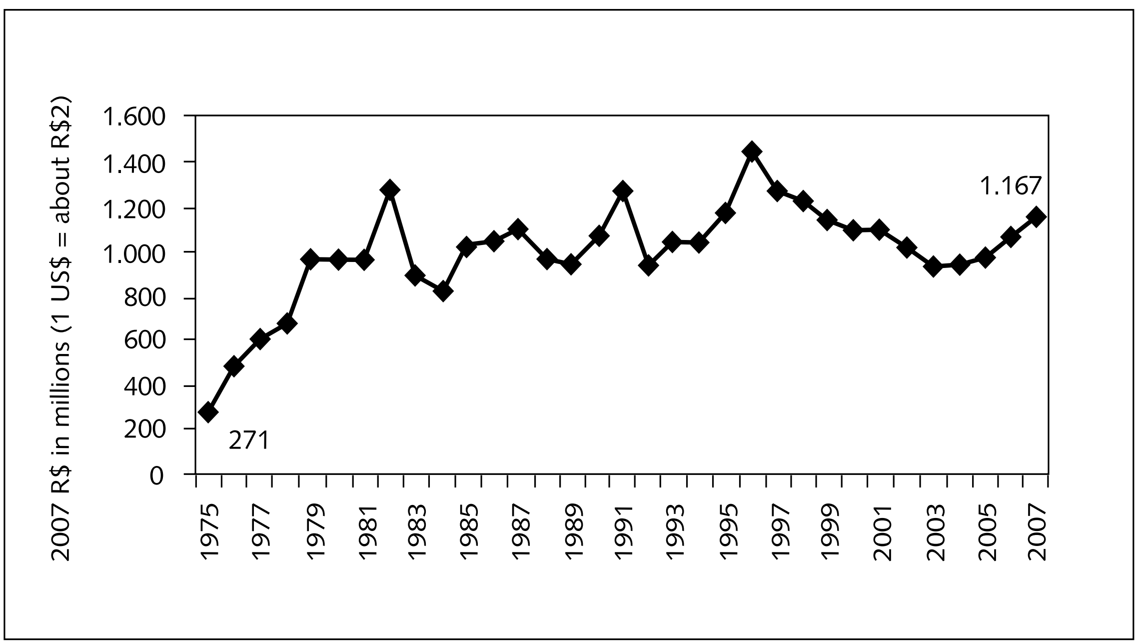
52. "Brazilian Agriculture: The Harnessing of Nature's Bounty," *The Economist*, November 3, 2005, http://www.economist.com/displaystory.cfm?story_id=5107849.

Figure 1.11 Productivity Growth in Brazilian Agriculture, 1975–2007



Source: Delphin Netto, "Vivas a Produtividade" (Sao Paulo: Valor Economico, May 20, 2008).

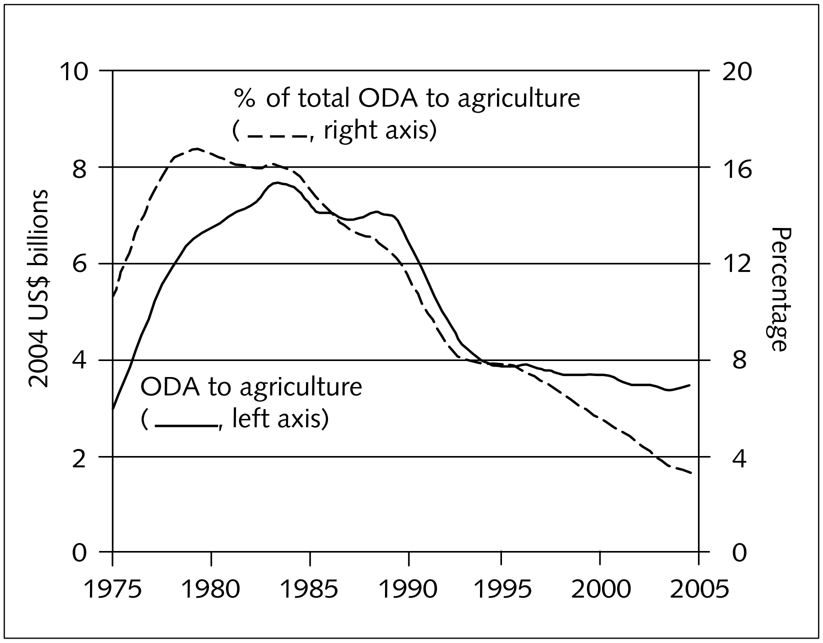
Figure 1.12 Federal Expenditures on Agricultural Research in Brazil



Note: R$ = *reais*.

Source: Netto, "Vivas a Produtividade."

Figure 1.13 How Donors Abandoned Agriculture



Source: World Bank, *World Development Report 2008: Agriculture for Development.*

port 2008,[53] "The share of agriculture in Official Development Assistance (ODA) declined sharply from a high of about 18 percent in 1979 to 3.5 percent in 2004 [figure 1.13]," with "a bigger decline from the World Bank."

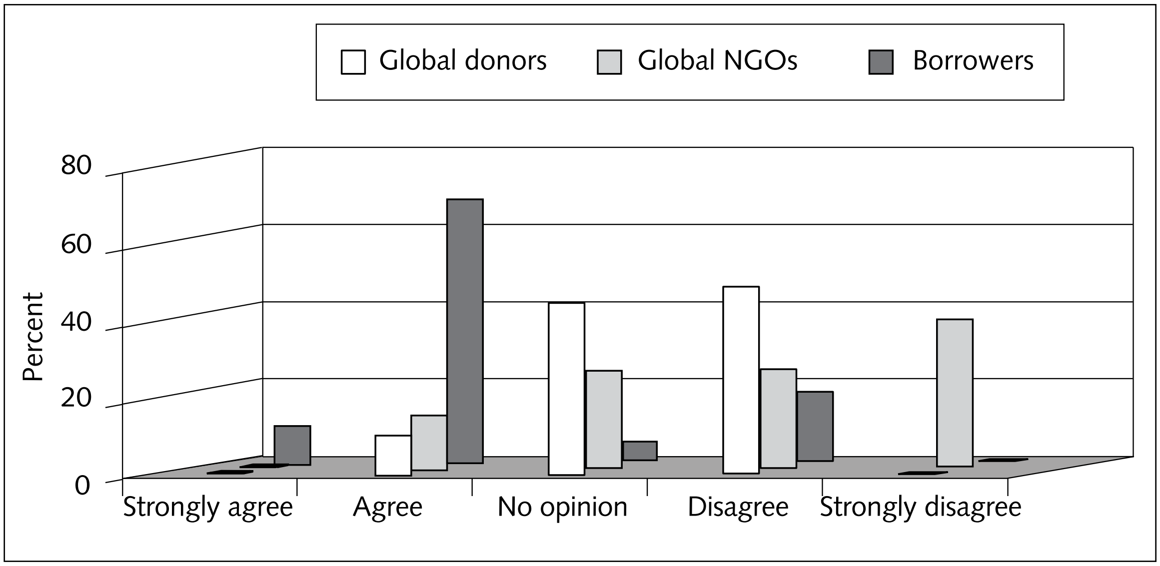
The *World Development Report,* in examining the reasons for this decline, includes "increased competition for ODA, especially from social sectors . . . and opposition from environmental groups that saw agriculture as a contributor to natural resource destruction and environmental pollution." On matters like these, the views of aid officials are (see figure 1.14) closely aligned with those of rich-country NGOs and are quite different from those of developing country governments, developing country academics, and developing country NGOs.[54] In short, northern NGOs and like-minded aid officials from rich countries have driven the World Bank and other development agencies away from engagement with "the basics" such as infrastructure and agriculture. The same groups prevented some of the poorest countries of the world from using water, pesticide, and fertilizer-saving GMOs (genetically modified organisms).[55] The more pragmatic and self-determined MICs, no longer dependent on the charity of the rich world—like the major rich-country agricultural producers—showed no such compunction (figure 1.15).

53. World Bank, *Agriculture for Development: World Development Report 2008*, http://www.worldbank.org/wdr2008.pdf.

54. World Bank, "External Views on the World Bank Group's Draft Water Resources Sector Strategy: How They Were Elicited, What They Are, and How They Will be Addressed" (Washington, D.C.: World Bank, 2002), http://siteresources.worldbank.org/EXTWAT/Resources/4602122-1209139051098/WBG_Water_Resources_Sector_Strategy_External_Views_Main_Report.pdf.

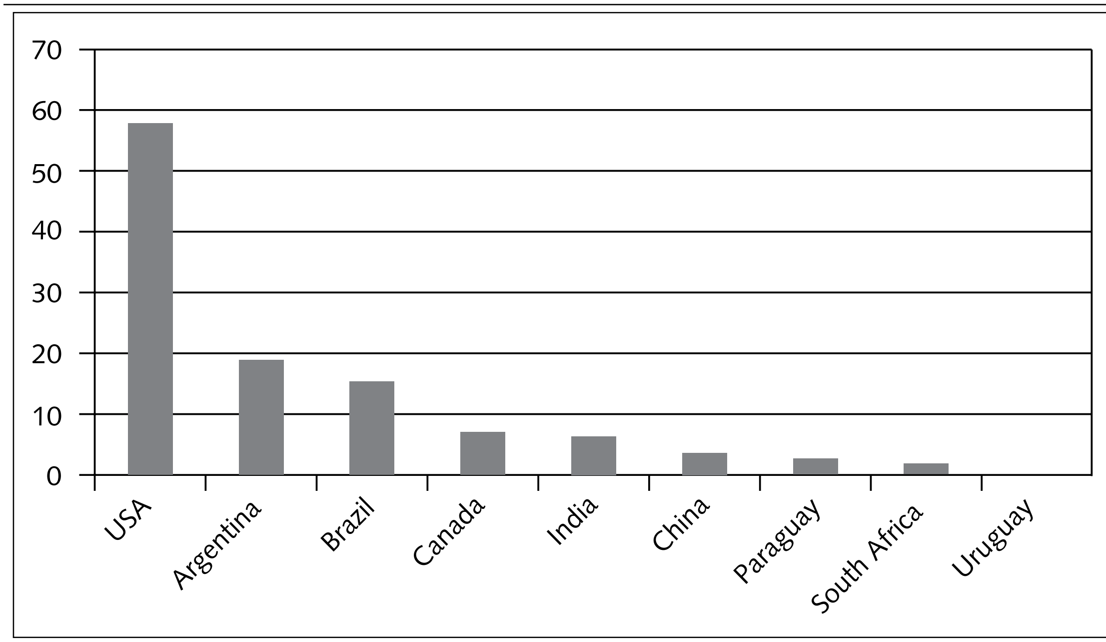
55. Paul Collier, "Comments on Martin Wolf: Food crisis is a chance to reform global agriculture," *Financial Times,* May 9, 2008.

Figure 1.14 How Views of Donors Align with Views of Rich Country NGOs and Differ from Views of Developing Country Borrowers



Source: World Bank data.

Figure 1.15 Eight of the Top Ten Users of GMOs Are Middle Income Countries
(millions of hectares)



Source: Clive James, *Global Status of Commercialized Biotech/GM Crops 2008,* International Service for the Acquisition of Agri-Biotech Applications (ISAAA), http://www.isaaa.org.

One would have expected the global community, then, when confronted with the food price crisis of 2008, to have asked two questions—first, what role have we played in the evolution of this crisis, and, second, what can we learn from others, such as Brazil—who had greater foresight?

What actually happened—as so often in the Humpty Dumpty world of development polemic—was just the opposite. The loudest voices proscribing "recipes" for dealing with the latest crisis (as they do for all other crises) comes from the aid agencies, the development banks, and the advocacy NGOs. And what did they say? A massive, multi-agency World Bank–managed effort, the "International Assessment of Agricultural Knowledge, Science and Technology for Development,"[56] condemned biotechnology, excoriated the Brazilian model of new technology and scale, and urged developing countries to pursue a "small and organic is beautiful" path to happiness. (So extreme was the position on this multimillion-dollar effort that scientists from the biotech companies withdrew, the United States and China formally objected to "the lack of balance" on the issue of biotechnology, the major food-exporting countries refused to sign the overall report, and independent scientists[57] lamented the report's "negative attitude toward technology, compounded by a visceral dislike of international capitalism." Reputable journals—including *Nature*[58] and *Science*[59]—similarly decried the lack of objectivity of the report.) "And what," I asked Washington, "do I tell the irate Brazilian Minister of Agriculture?" who had asked me to explain how the Bank could have produced such a report. "Tell him it was not the Bank's report" was the helpful reply from Washington!

A similarly bizarre air permeates the discussion of biofuels and food. As an integral part of its agricultural innovation, Brazil has become by far the world's lowest–cost producer of sugar cane and ethanol. And as part of associated industrial innovation Brazilian engineers invented the flex-fuel car. For a marginal cost of a few hundred dollars, cars can use either gasoline or ethanol, or any combination of the two. Flex-fuel cars now comprise 80 percent of the new fleet in Brazil, and over 50 percent of transportation fuel is clean, climate-friendly ethanol.[60] While developing country officials and companies have flooded Brazil to study this remarkable success, the attitude of the rich countries has been quite different. Again with advocacy environmental NGOs defining the debate, the cry has been that Brazil ethanol is coming at the expense of food production and deforestation in the Amazon. As so often in the development business, assertions have little factual basis.

Fact one is that Brazil's ethanol industry has arisen in parallel with, and from the same roots as, the rest of the Brazilian agriculture industry. Fact two is that the total area under sugar cane in Brazil comprises just 3 percent of the country's arable land and that practically no sugar cane is grown in the Amazon, nor is a single ethanol plant. Fact three is that Brazil could provide all of the ethanol for the whole world—see figure 1.16—without infringing on the Amazon.[61]

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56. International Assessment of Agricultural Knowledge, Science and Technology for Development, http://www.agassessment.org/ International Assessment of Agricultural Knowledge, Science and Technology for Development.

57. J.A. Heinemann, "Editorial: Off the Rails or on the Mark?" *Nature Biotechnology* 26, no. 5 (2008): 499–500.

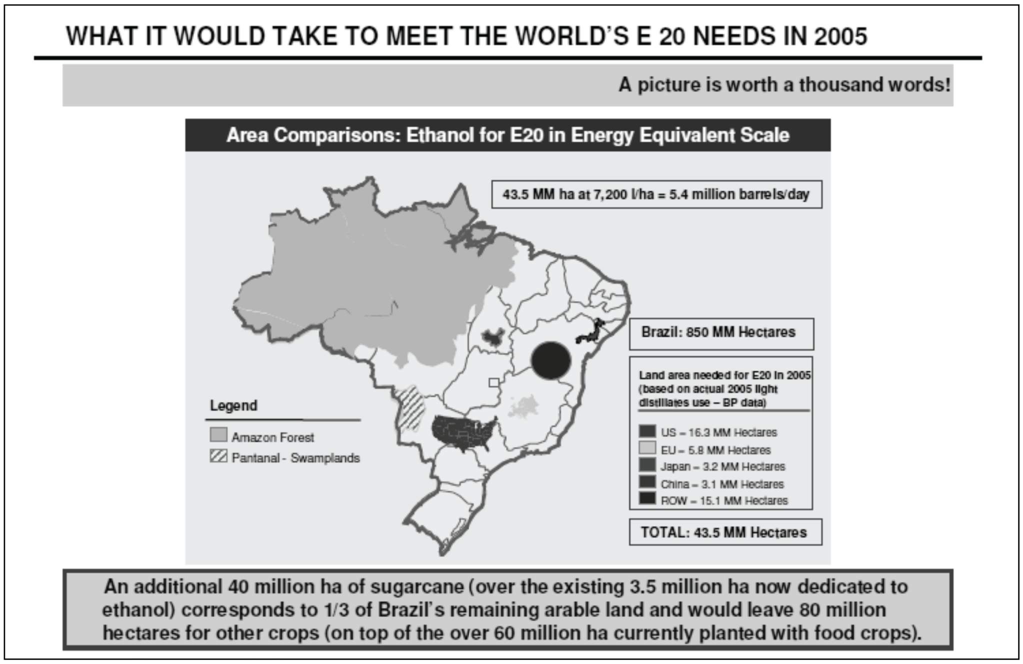
58. Ibid.

59. Erik Stokstad, "Dueling Visions for a Hungry World," *Science* 319, no. 5869 (March 14, 2008): 1474–1476.

60. John Briscoe, "Brazil Is Part of the Solution to the Crisis" (Rio de Janeiro: O Globo, May 1, 2008).

61. Gordian Bioenergy, "Biofuels: Great Expectations or Much Ado about Nothing?" October 2007.

Figure 1.16 Area Required If Brazil Alone Supplied the World's Entire Demand for Ethanol



Note: E20, the fuel mixture used in Brazil, contains 20 percent ethanol.
Source: Diomedes Christodoulou, "Biofuels: Great Expectations or Much Ado about Nothing?" Gordian Bioenergy, October 2007.

It was my privilege to have to address this strange interface between development ideology and fact as the World Bank's country director for Brazil for the last three years. Fortunately I was often able to temper the "make them do it!" enthusiasm emanating from Washington, London, and Berlin by pointing out that while Brazil was, indeed, the largest hard-currency borrower from the World Bank, our $2 billion a year did not really give us much leverage in a country where the Brazilian Development Bank, the BNDES, lends around $70 billion a year.[62] It was also fortunate that the Bank presidents were not always aware of the silliness of many of these messages and, during my time in Brazil, gave sensible messages to the government of Brazil on the sensitive issues of climate change and energy (in the case of Paul Wolfowitz)[63] and biofuels (in the case of Robert Zoellick).[64]

During the past decade there has also been a seismic shift in the world's economic geography. The current financial crisis will accelerate this process, for it is now the BRICs (Brazil, Russia, India, and China) who have their fiscal houses in order, who have massive reserves, and who have greatly improved their position in the real economy.

The consequences of these changes are now being felt in institutions like the World Bank. Executive directors from China, India, and other developing countries took the lead in changing—against the wishes of many of the rich country owners of the Bank and most World Bank senior

62. Valor Economico, "BNDES preve desembolsar ate Rs 130 bi este ano" (Sao Paulo, January 26, 2009).

63. Paul Wolfowitz, "Environment and Development: Reaching for a Double Dividend," at the Special Session of the Sao Paulo Forum on Climate Change, Sao Paulo, Brazil (Sao Paulo: World Bank Group, December 20, 2005), http://siteresources.worldbank.org/ESSDNETWORK/Resources/EnvironmentandDevelopmentReachingforaDoubleDividend.pdf.

64. Robert Zoellick, "Remarks to Brazil Climate Change Forum" (Brasilia: World Bank Group, February 21, 2008), http://www.docstoc.com/docs/1002799/World-Bank-President--Video-Message.

managers—the absurd position that infrastructure was not necessary for development.[65] And the Brazil Country *Partnership* Strategy (not Country *Assistance* Strategy, as had been the paternalistic norm) lays out principles—acclaimed by the executive directors of other developing countries—that, *inter alia*, defined the Bank's niche in Brazil as follows:[66]

- "The Bank Group should not be engaging in areas where Brazil has the knowledge and capacity to manage by itself;
- The Bank Group cannot act as though it is a "shadow government" in Brazil, attempting to respond to every challenge that Brazil faces;
- The Bank Group should be engaging primarily with the long-run, path-setting challenges where Brazil has not yet devised solutions and where international experience can be of particular value."

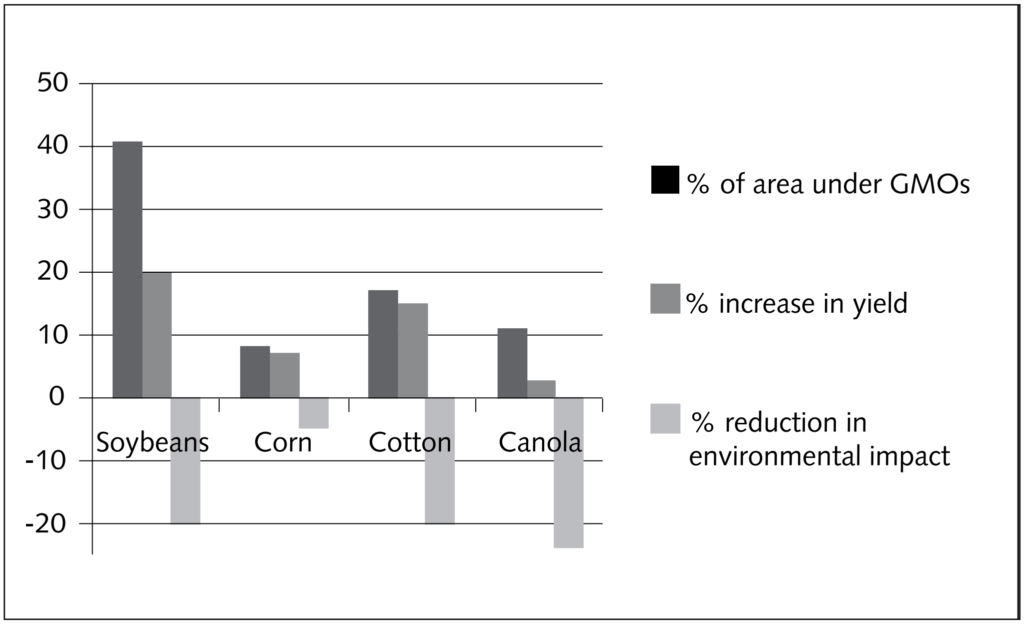
Water, Agriculture, and Development: Conclusions for Developing Countries

Developing countries face major challenges in managing their water resources so that they can provide their people with the energy and food essential for a better life. Developing country leaders should be careful to avoid the following myths on water and agriculture:

- *Myth 1: Agriculture can solve the problem of rural poverty*. There is a fundamental arithmetic inconsistency between the notion that (1) agricultural productivity can be high and (2) 80 percent of the population of a country can depend on agriculture. Every country that has become rich has urbanized and industrialized. The striking contemporary example is China, which has focused on creating productive nonagricultural jobs and helping people get out of the brutal job of traditional, low-productivity agriculture.
- *Myth 2: Small is beautiful*. A modern, productive agriculture is one that necessarily depends on information, technology, and sophisticated management. It is inconceivable that autonomous, small, poor farmers can compete effectively in such an economy. In some cases—and again Brazil provides some interesting examples both in the Southeast and Northeast—smaller farmers can flourish in close cooperation with, and "in the wake of," larger farmers who are able to solve the credit, technology, information, and market challenges. The water dimension of this challenge is well illustrated by the example of Mexico, where the number of jobs produced per unit of water by modern farmers is twice that of the traditional *ejido* farmers.[67]
- *Myth 3: Developing countries should not use GMOs*. New varieties of crops that use water and land more effectively and are resistant to changing temperatures, seasons, and incidence of drought have a central role to play in addressing diminishing water supplies and climate change.[68] There is abundant evidence (see figure 1.17) that GMO crops use smaller inputs of

65. Mallaby, *The World's Banker.*
66. World Bank, *Country Partnership Strategy Brazil 2008–2011,* 10.
67. World Bank, "Mexico: Policy Options for Aquifer Stabilization" (Washington, D.C.: World Bank, 1999).
68. Chris Somerville and John Briscoe, "Genetic Engineering and Water," *Science* 292, no. 5525 (June 22, 2001): 2217, http://www.sciencemag.org/cgi/content/long/292/5525/2217.

Figure 1.17 Market Share and Yield and Environmental Impact of Major GMOs



Source: Graham Brookes and Peter Barfoot, "Global impact of biotech crops: Socio-economic and environmental effects, 1996–2006," *AgBioForum* 11, no. 1 (2008).

water, fertilizer, and pesticides and are thus beneficial for the environment.[69] Developing countries "with choices" (the MICs) have understood this and account for 8 of the 10 major GMO-using countries. Developing countries "with fewer choices" would be well advised to listen more to China and Brazil and less to Prince Charles and Greenpeace (and the aid agencies who find that logic similarly compelling).

- *Myth 4: Research and higher education are luxuries that are not for developing countries*. Developing countries that have successful agricultural systems have done so because they have invested in higher education and in research (as illustrated for the case of EMBRAPA in Brazil). Developing countries have, indeed, to develop better basic education systems, but they also have to develop scientists and scientific institutions to address their challenges.
- *Myth 5: Poor countries do not need infrastructure and should follow "the soft path."* In recent decades, aid agencies and development agencies largely withdrew from financing major infrastructure in developing countries. Dams, highways, irrigation systems all became branded as "bad" by the development community, despite abundant evidence to the contrary.[70] Once again, MICs never fell for this line and continued to invest (with those investing most doing best). Poor, aid-dependent countries suffered most. They had no choice but to accept recipes such as the "Millennium Development Goals," which put the social cart before the development horse. The MDGs, which make no mention of employment, agriculture, industry, energy, transportation, or infrastructure, implicitly assume that the priorities of post-affluent societies

69. Graham Brookes and Peter Barfoot, "Global impact of biotech crops: Socio-economic and environmental effects, 1996–2006," *AgBioForum* 11, no. 1 (2008): 21–38.

70. Peter Hazell and C. Ramasamy, eds., *The Green Revolution Reconsidered: The Impact of High-Yielding Rice Varieties in South India* (Baltimore: Johns Hopkins University Press, 1991).

were those that would (without one iota of evidence) lead to economic development and poverty reduction. What is now painfully obvious is that almost all of the gains in reducing poverty were reaped in countries that essentially ignored the MDG path.

- *Myth 6: Treat water as a social, not economic, resource*. Water is becoming a scarce resource in much of the developing world and looming as a constraint to human well-being in many countries. Although there are variations across the globe, it is clear that climate change is going to exacerbate water scarcity in many countries.[71] Water-scarce regions of all rich countries (the western United States, Australia, Spain) have water rights systems that ensure that scarce water is voluntarily reallocated from low-value to high-value uses. These systems have shown that economic productivity can be maintained in the face of major reductions in water availability.[72] Southeastern Australia provides a salutary example. An active and well-regulated water trading system has meant that although water entitlements have declined by more than 70 percent as a result of an unprecedented, decade-long drought, the aggregate value of agricultural production has changed very little.[73] Some developing areas (Chile, for nearly 30 years,[74] Mexico for the past 15 years, and now Punjab in Pakistan[75] and Maharashtra in India[76]) are starting to put in place similar systems to motivate more crops, more rupees, and more jobs per drop of water.
- *Myth 7: Follow the agenda set by the rich countries*. Development is not a business for the impatient. And yet the priorities of development agencies are highly unstable, lurching—as described for agriculture in this paper—from one "flavor-of-the-month" to next, with little attention to prioritizing and sequencing. One encouraging reality is the emergence of development financing agencies from the BRICs—including China, Brazil, and India—which recognize that developing countries need infrastructure and need it fast and which are not tied down by long lists of "operational policies" that make development institutions such unreliable and costly partners for developing countries. A second encouraging sign is that developing countries, led by the BRICs, are playing a much more affirmative role in the governance of global institutions like the World Bank. They are saying "enough is enough" and insisting that there be more consistent support and more reasonable standards for building agriculture, infrastructure, and other time-tested, basic building blocks.

There are encouraging signs that the World Bank could, again, become (in the words of a partner in Brazil) "the indispensable partner" to developing countries. The MICs are appropriately pushing for major changes in an outdated governance structure (in which Belgium and Switzerland have the same voice as China). If the countries that are successfully grappling with the

71. "IPCC: Summary for Policymakers," in *Climate Change 2007: Impacts, Adaptation and Vulnerability. Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, ed. M.L. Parry, O.F. Canziani, J.P. Palutikof, P.J. van der Linden, and C.E. Hanson (Cambridge: Cambridge University Press, 2007), 7–22.

72. Richard Howitt, "Initiating Option and Spot Price Water Markets: Some Examples from California," University of California at Davis, 1996.

73. Wendy Craick, Don Blackmore, and John Langford, personal communication, 2008.

74. Robert R. Hearne and K. William Easter, *Water Allocation and Water Markets: An Analysis of Gains-from-Trade in Chile*, World Bank Technical Paper Number 315 (Washington, D.C., World Bank, 1995).

75. Irrigation and Power Department of the Government of the Punjab, entitlements, http://irrigation.punjab.gov.pk/entitlement.aspx.

76. Maharashtra Water Resources Regulatory Authority (MWRRA), http://www.mwrra.org/.

problem of economic growth and poverty can also reorder the priorities and processes,[77] then the World Bank's still-formidable human and reputational assets can again make it (in the words of a Brazilian official) "the indispensable development partner."

77. John Briscoe, "Reforming the World Bank: Not So Easy," *Business Standard*, New Delhi (June 10, 2009).

2 CHILDREN'S SAFE DRINKING WATER
PROCTER & GAMBLE'S PROGRAM TO ADDRESS THE GLOBAL CRISIS

Greg Allgood

The world is thirsty. Major bodies of water like the Aral and Dead Seas are drying up; large rivers like the Colorado, Yellow, and Ganges are no longer regularly reaching the ocean; and nearly 1 billion people do not have access to clean drinking water. The world is sick. Many rivers no longer support a healthy aquatic life, and about half of the hospital beds in the developing world are occupied by people suffering from preventable waterborne diseases. Perhaps the paramount issue of the global water crisis is the impact that water is having on human health—particularly on the health of our children. The cholera, dysentery, typhoid fever, and other infectious diseases primarily carried in our drinking water supply are taking more lives of children—about 1.8 million each year—than HIV/AIDS, malaria, and tuberculosis combined.

The vast majority of sicknesses and deaths in the developing world caused by waterborne illness can be eliminated by improved water quality, hygiene, and sanitation. In particular, public health efforts have largely ignored water quality during the last two decades, but research has shown that water purification technologies used at the household level can save a huge number of lives. Of all the issues of the global water crisis, sickness and death from drinking water is perhaps the most easily addressed and one for which there should be a clear mandate. A policy shift toward household water treatment can provide a rapid, scalable, and cost-effective way to prevent the 4,000 deaths of children that occur every day.

The majority of efforts in the water and sanitation sector during the last several decades were focused on providing water access to reduce the burden of collecting water, building latrines to prevent the contamination of water sources by human feces, and promoting hand-washing after defecation and other hygiene measures to prevent the spread of infectious diarrhea. A review by S.A. Esrey et al. showed that interventions of improved water quality provided less diarrhea reduction than improved water access, sanitation, and hygiene.[1] However, the Esrey review examined improved water quality based on the point of collection, such as provision of standpipes, and did not examine the impact of improving water quality at the point that it is used, such as in the home, school, or clinic.

During the last decade, more than 30 randomized controlled health intervention studies involving more than 53,000 people have been conducted with a variety of interventions that improve water quality at the point-of-use or household level. A review of these studies by Thomas Clasen et al. demonstrated conclusively that improving water quality at the household level dramatically

1. S.A. Esrey, R.G. Feachem, and J.M. Hughes, "Interventions for the control of diarrheal diseases among young children: Improving water supplies and excreta disposal facilities," *Bulletin of the World Health Organization* 63, no. 4 (1985): 757–772.

reduces diarrheal illness and therefore can save lives.[2] The four types of proven interventions include (1) solar disinfection or SODIS, (2) chlorination disinfection, (3) ceramic or biosand filtration, and (4) combined coagulation-disinfection through a Procter & Gamble (P&G) product called PUR Purifier of Water. A variety of technologies are needed, given the different living conditions and water sources of more than a billion people without safe drinking water. Point-of-use technologies, which are relatively low cost, are being provided inclusive of education, training, and the technology at a cost of less than $0.01 per liter of clean water.

The PUR packets were developed in collaboration with the U.S. Centers for Disease Control and Prevention (CDC). PUR is a powdered product that quickly and simply turns contaminated drinking water into clear and clean water that meets World Health Organization (WHO) standards for potable water. PUR uses the same ingredients used in municipal water treatment so essentially it is a mini–water treatment plant in a small four-gram packet. The coagulant and flocculants in PUR make it effective at turning dirty water into clear water while removing pollutants like arsenic and more than 99.9 percent of parasites like Giardia and Cryptosporidium. The chlorine disinfectant in PUR kills greater than 99.9999 percent of the bacteria and greater than 99.99 percent of the viruses that cause cholera, typhoid fever, and dysentery.[3] Results of five randomized controlled health intervention trials conducted by the CDC and Johns Hopkins show that PUR reduces diarrheal illness by an average of 50 percent, with up to 90 percent reduction among particularly vulnerable people.[4]

To provide the PUR packets in a not-for-profit effort, P&G created, in 2004, the Children's Safe Drinking Water Program, the signature program of P&G's global cause—*Live, Learn and Thrive™*—aimed at improving life for children in need. P&G has committed to provide 4 billion liters of safe drinking water via the Children's Safe Drinking Water Program between 2007 and 2012.

Also in 2004, a number of organizations joined together under the leadership of the World Health Organization to create the International Network to Promote Household Water Treatment and Safe Storage.[5] This network focuses on research, implementation, communication, and advocacy for household water treatment. P&G and Johns Hopkins were founding members of the network and have played a leading role in advocating these new technologies.

P&G and the Johns Hopkins Bloomberg School of Public Health/Center for Communication Programs (CCP) created a strategic alliance in 2002 to improve health with safe drinking water. An outcome of the P&G and Johns Hopkins alliance was creation of a "Safe Drinking Water Alliance" with USAID, CARE, and Population Services International. This public-private partnership provided the PUR packets in three different countries and through this work determined the most effective strategies for providing PUR to reduce diarrheal illness—namely, emergency relief provision and sustained social marketing to reach the most vulnerable.

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2. T. Clasen, I. Roberts, T. Rabi, W. Schmidt, and S. Cairncross, "Interventions to improve water quality for preventing diarrhea," *Cochrane Database of Systemic Reviews* 3 (2007).
3. P.F. Souter and G.D. Cruickshank et al., "Evaluation of a new water treatment for point-of-use household applications to remove microorganisms and arsenic from drinking water," *Journal of Water Health* 1, no. 2 (2003): 73–84.
4. S. Doocy and G. Burnham, "Point of Use water treatment and diarrhea reduction is the emergency context: an effectiveness trial in Liberia," *Tropical Medicine and International Health* 11 (2006): 1542–1552.
5. See http://www.who.int/household_water.

Careful monitoring of the initial distribution of PUR packets during emergencies showed that it was used correctly following simple training sessions, was well accepted, and reduced diarrheal illness.[6] Because the packets are lightweight, can be airshipped as nonhazardous, and turn even heavily contaminated water into clean drinking water, they can be rapidly deployed for emergency relief. Given these results, PUR has been used during most of the major disasters of the last 5 years including the Southeast Asia tsunami, the Pakistan and Indonesian earthquakes, hurricanes in the Caribbean, and cholera outbreaks throughout Africa. More than 86 million PUR packets have been used in more than 50 countries to respond to emergencies.

We have also established sustained programs in about a dozen countries, mostly in sub-Saharan Africa, to provide PUR to people on a sustained basis. Through these programs, we have distributed another 77 million PUR packets and have learned the most effective communication strategies to enable the habit change necessary to have a public health impact. Specifically, we focus on education of mothers at health clinics during immunization days, provision of safe drinking water to people living with HIV/AIDS, education of school children as positive catalysts for community change, and provision of safe drinking water to malnourished children.

Infants and malnourished children are particularly vulnerable to the pathogens in contaminated drinking water. The period from weaning to development of a full immune system is the time when ensuring safe drinking water provides the greatest benefit. Because of this, reaching the caregivers of children at health clinics during immunization days and well baby visits is one of the most effective strategies to adoption of household water treatment.

Similar to an infant, people with HIV/AIDS are particularly vulnerable to pathogens in drinking water and frequently have severe and persistent diarrhea. Waterborne parasitic infections caused by Cryptosporidium and Giardia are a particular problem; these infections, though generally self-limiting in healthy individuals, are frequently fatal in people with HIV/AIDS. In collaboration with the CDC, P&G began providing the PUR packets to people with HIV/AIDS in 2003 and began reporting anecdotally a Lazarus-type of recovery. Based on these reports and more careful documentation of the quality of life improvement by the CDC when people with HIV/AIDS disinfected their water with chlorine bleach,[7] P&G began scaling-up provision of PUR packets to people with HIV/AIDS and have seen dramatic impacts in health through implementation programs with many partners.

Provision of safe drinking water for people with HIV/AIDS is a critical intervention since the absorption of antiretroviral drugs will be impaired if there is persistent diarrhea. Recent research in Tanzania showed that diarrhea was the leading cause of death among people with HIV/AIDS and recommended provision of safe drinking water as a critical intervention. The President's Emergency Plan for AIDS Relief (PEPFAR) is starting to address this by helping provide 20 million PUR packets to people with HIV/AIDS in Ethiopia, Nigeria, Cote d'Ivoire, and Tanzania through Population Services International, CARE, Academy for Educational Development, P&G, and a number of other partners. Because PUR packets can provide safe drinking water to a person

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6. R.E. Colindres, S. Jain, A. Bowen, P. Domond, and E. Mintz, "After the Flood: An evaluation of in-home drinking water treatment with combined flocculent-disinfectant following Tropical Storm Jeanne—Gonaives, Haiti, 2004," *Journal of Water and Health* 5, no. 3 (2006): 367–374.

7. J. R. Lule and J. Mermin et al., "Effect of home-based water chlorination and safe storage on diarrhea among persons with HIV in Uganda," *American Journal of Tropical Medicine and Hygiene* 73, no. 5 (2005): 926–933.

with HIV/AIDS for less than $0.02 per day, it is essential that this effort be scaled up in areas where people drink contaminated water.

More public support is needed to scale up the proven household water treatment technologies. One specific mechanism to do this is to support the Paul Simon Water for the World Act and to advocate that some of these public funds go to scale up household water treatment. Grassroots-level advocacy to raise awareness of the safe drinking water crisis along with the proven solutions is also needed. P&G and the PUR Water Filtration Brand is pleased to partner with *Summit on the Summit: Kilimanjaro* in an effort to raise awareness and inspire action for the global water crisis by involving celebrities such as Jessica Biel, educators such as Alexandra Cousteau, and water experts such as the author (http://www.csdw.org). This effort will raise funds from the public, and each $1 donated will provide clean water to a child for 50 days using the PUR packets. In addition, a P&G-funded program during 2008–2010 reaches more than 57 million U.S. households each year with information about the program and, through coupon redemption for P&G products, raises significant additional funds for safe drinking water.

Through public-private partnerships, household water treatment is being scaled up to save thousands of lives. There is great urgency to do more to ensure that children and other vulnerable people do not die needlessly from a lack of something as simple as a drink of clean water. Providing safe drinking water to prevent human suffering and death is perhaps the most pressing—and one of the most easily addressed—issues of the global water crisis.

3 THE POLITICAL ECONOMY OF WATER AND AGRICULTURE

Jason Clay

You can't wake a person who's pretending to sleep.
—Oromo (Ethiopia) Proverb

The world has finally awakened to the fact that we live on a finite planet—a fact brought home to many when recent global economic growth led to spikes in commodity prices. While it should have been obvious that *nonrenewable* resources are finite, even many *renewable* resources are now clearly being used at unsustainable rates. These renewables include seafood from poorly managed marine fisheries as well as wood and pulp from poorly managed natural forests and food produced on agricultural lands that lose more soil and organic matter each year than they replace.

Living on a Finite Planet

The World Wildlife Fund (WWF) has developed a peer-reviewed methodology, the Living Planet Index (LPI), that examines whether the Earth's resources are being consumed sustainably. WWF publishes this information every two years in the *Living Planet Report*. What is clearer perhaps than ever before, however, is that the following equation holds:

Population x *Consumption* = Planet

Unfortunately, the *Living Planet Report* suggests that we are currently living at the rate of 1.3 planets—well beyond the carrying capacity of Earth. Just as we are finally realizing that we are not using the planet's resources sustainably and that we must find ways to produce more with less, we now acknowledge that we have to go even farther and reduce our overall use of resources, both renewable and nonrenewable.[1]

Many now understand that climate change poses a threat to every living thing on the planet. Unfortunately, many of us are still asleep to many other environmental threats that are perhaps even more serious in the short term.

Although the LPI calculations suggest where we are today with regard to the overall carrying capacity of the planet, they do not give insights into where we are headed, particularly if the "business-as-usual" case prevails. While the precise numbers are not certain, the trends are. An increasing consensus among scientists points to a global population peak at between 9 and 10

1. Sarah Humphrey, Jonathan Loh, and Steven Goldfinger, eds., *Living Planet Report 2008* (Washington, D.C.: World Wildlife Fund, 2008), http://assets.panda.org/downloads/living_planet_report_2008.pdf.

billion by 2050. This estimate translates into some 3 billion more people than we have today or 50 percent more than in 2000. In addition, by 2050 some 70 percent of all people are expected to live in cities, and their per capita income is expected to increase 2.8 times. Put another way, in 2050 more people will be living in cities than are alive today. Given these factors, global consumption will likely double. What is less well understood is that with increasing income, many of the world's poorest will in all likelihood more than double their food consumption. In short, while many of us are beginning to understand that we are living beyond the carrying capacity of the planet, few are pondering the broad impact of such increases in consumption.

The situation with water is particularly illustrative. Currently, a billion people lack adequate water. By 2025, water consumption is likely to increase by 13 percent,[2] and 2.8 billion people in 48 countries will face a scarcity.[3] By 2050, an estimated 7 billion people in 60 countries are expected to face water scarcity if something is not done before then.[4] In short, the lack of water in an increasing number of places appears to pose a more urgent, short-term threat to people and biodiversity alike than climate change itself. But the two are related—climate change will intensify the issues surrounding water scarcity.

Agriculture's Environmental Footprint

The impacts of human activities are not equal. Nowhere is this clearer than with agriculture—the human activity with the single-greatest impact on the planet bar none. The use of land for food production (farming or ranching) is the single-largest cause of habitat loss. Agriculture is also the single-largest source of ecosystem loss from the decline in forests to the draining of wetlands and alteration of local hydrology to the altering of rivers and river flows. Food production is the single-largest user of chemicals globally (including herbicides, insecticides, and fungicides as well as fertilizers and other nutrient supplements). Many scientists view agriculture as one of the largest, if not the largest, sources of the greenhouse gasses (GHGs) that contribute to climate change—and that is without instruments to measure or even adequately estimate impacts of food production on soil, rangeland, wetlands, and other ecosystems.

Agricultural land use (crops and pasture, for example) accounts for 33 percent of the land on the planet. However, if one eliminates uninhabitable areas—deserts, mountains, lakes, rivers, and so forth—then the land used for food production represents 55 percent of the planet. After 1960 with the advent of the green revolution, the amount of land cleared for food production increased about 0.4 percent per year. Over the past 10 years, however, the natural habitat lost to food production has increased to 0.6 percent per year. The increased encroachment of food production on natural habitat is probably caused by three factors—increased demand for food due to increased consumption, an overall decline in productivity gains through plant breeding and genetics, and the incorporation of poorer soils for farming—that is, soils are cleared, farmed, and more quickly abandoned. In the past 150 years, for example, farmers on the planet have lost more than half of

2. Mark W. Rosengrant, Ximing Cai, and Sarah A. Cline, *World Water and Food to 2025: Dealing with Scarcity and Global Water Outlook to 2025—Averting the Impending Crisis* (Washington, D.C.: International Food Policy Research Institute, 2002).

3. United Nations Environmental Program, "Vital Water Graphics" (New York: UNEP, 2002), http://www.unep.org/dewa/assessments/ecosystems/water/vitalwater/.

4. United Nations World Water Assessment Program, *Water for People, Water for Life* (Paris: UNESCO, 2003).

all topsoil from farmed areas. Such losses mean that farmed areas are losing organic matter faster than they are replacing it.

One message is clear: we are running out of land to produce food precisely at the time when we need to be producing more to meet increasing global demand. And that is just land.

Agriculture and Water—Why Does It Matter?

Arguably, agriculture makes its biggest environmental impact on water. Of any human activity, agriculture is both the single-largest user of water and the single-largest polluter of water on the planet. Water scarcity is now common in many parts of the world, and scarcity is increasing at alarming rates. More than a dozen major rivers are dry for at least part of the year with devastating impacts on downstream communities and biodiversity alike. The decline in the flow of the Colorado River in the United States, for example, began around 1900 and reached the point of virtually no flow by 1960. Global food and food-processing companies are attempting to predict where water will be more abundant or scarce in the future to guide their investments in production, infrastructure, and processing. And, of course, climate change will make the availability of freshwater even more variable from year to year and harder to predict.

Unfortunately, as with the changes in land use outlined above, all water-use projections are headed in the wrong direction. In 1900, agriculture accounted for some 90 percent of all water used by humans; by 2000, agriculture accounted for 69 percent. Total water use, however, had increased by more than five times. By 2025, total water use by humans is expected to increase by an additional 13 percent. The question is, where will all this water come from, and what effect will such demand have on the planet's biodiversity and ecosystems?

Some might argue that not all water matters equally. Most experts, for example, would agree that blue water—lakes, ponds, rivers, aquifers, groundwater, and the like—is more important than green water, or rainfall. A significant blue-water issue is dams. Dams that prevent year-round stream flows can devastate downstream biodiversity. However, pumping waters from ossified aquifers, or from places where water is withdrawn more quickly than underground water tables can be replenished, is clearly not sustainable either.

But even rainfall is more complicated than it may appear. In the natural cycle, water falls from the sky and is absorbed by the soil and taken up by plants; and then it evaporates. Does it really matter whether rain falls on natural habitat or on cultivated fields? Often, probably not. But if the farmers' crops are "thirsty"—that is, they require more water than the natural vegetation—then the crops are likely to take up more of the rainfall or moisture and leave less for nature. Or if crops do not take up the rainfall or hold the water in the soil as previous habitat did and water runs off, then the downstream flow will be more variable than before and could affect downstream marine and freshwater ecosystems and the biodiversity that depends on them. While nature tends to be resilient, very minor changes can disrupt balances that have evolved over millennia.

Who Is Responsible for Water Use in Agriculture?

Since water is becoming increasingly scarce, we might want to understand better how much water is currently required to deliver the food and fiber that we depend on each day. How can we possibly manage water use if we do not measure it? The question quickly becomes, how do we measure water use in a value chain? Do we limit it to the production or processing of the food item, or do we also include the production of the raw material itself? Do we include both green and blue water? We need consensus on the key water impacts but also on the methodologies for measuring them.

The amount of water that it takes anywhere along the value chain to deliver a final product is often referred to as "embedded water." Calculating embedded water is as much an art as a science. We do not currently have a science-based consensus about what methodologies are acceptable for calculating embedded water. But at some level, if it takes a certain amount of water to produce and deliver a product, then the company that sells that product must be responsible, at least to some degree, for the embedded water required.

Two examples illustrate this point—a grande latte and a soda. More than 200 liters of water go into making one grande latte—and the amount of water used to make the shot of coffee is less than 0.05 liters. In fact, the average latte bar uses more water to rinse the spoons used for foam or to flush their public toilets than they use to make the espresso shots for the latte. About 5 percent of the remaining "embedded" water in the latte is found in the plastic lid, the paper cup and sleeve, and the sugar; the milk accounts for 25 percent; and the coffee itself accounts for 70 percent. If a company wants to sell lattes with less embedded water, then it would do well to work with coffee and milk producers to help them reduce their overall water use. All uses of resources have impacts—the challenge is defining which are acceptable. It will always take water to make lattes, but maybe we can cut it by 10 percent, then 25, and finally, perhaps, 50.

Similarly, soda companies generally use 2.5 to 3.5 liters of water for every liter of soda they produce. To increase their efficiency, many companies have set targets of 2.2 liters of water for each liter of soda. This effort is good: companies should strive to become more efficient. They should also be strategic, however. If soda is sweetened with cane sugar, then it takes 150–250 liters of water to grow the sugar to sweeten each liter. If a company worked with its sugar suppliers to reduce water use by 10 percent, embedded water could be reduced by 12–20 times as much as if that company were simply more efficient itself.

The most significant issue, however, is water use in areas of scarcity. For soda, then, it may in fact matter whether water is scarcer where the sugarcane is being grown or where the bottling plant is located. Without baseline information, though, it is very difficult to become strategic. Still, most agree that companies should encourage efficiency throughout their value chain—in those areas that they control directly as well as in those controlled by someone else. But where water is scarce special efforts are called for.

In the food industry, retailers and brands are associated with both their products and their embedded impacts. Such companies have direct contact with consumers who see them as responsible for their products even if the companies do not control most of the impacts in question. In fact, most retailers and brands control less than 15 percent of the embedded environmental impacts of their products. The two examples above suggest that some brands control considerably less than 1 percent of the water embedded in a latte or soda. Wal-Mart recently reported that it controls only 8 percent of the GHGs embedded in the products it sells. In short, life-cycle analyses suggest that more than 85 percent of environmental impacts embedded in products fall outside the control of retailers or brands. If such brands and retailers do not take some responsibility for embedded impacts, however, consumers can easily assume that the companies are indifferent to those impacts.

What Does Agricultural Water Efficiency Mean and How Do We Achieve It?

Not counting the water from rainfall, agriculture currently accounts for 69 percent of all water used by humans. Without increased irrigation efficiency, experts suggest that agriculture could require 50 percent more water by 2050 to meet food needs. As it will be impossible to increase the total amount of water used for irrigation in absolute terms, it is imperative that we find more efficient techniques. Fortunately, we already know a lot about improving the efficiency of irrigation. There are several forms of irrigation, including, from least to most efficient, flood, furrow, alternate furrow, center pivot, modified center pivot, drip, and underground drip. Each of these forms of irrigation provides an efficiency of 25–50 percent over the previous method. The difference between the least and the most efficient irrigation may be as much as 10–100 times, depending on the method of implementation.

Selected Products, Water Use, and Farmer Income

While we know how to improve irrigation efficiency, however, the technology required is usually more expensive than water, since water is notoriously undervalued throughout the world. Table 3.1 suggests the problem. No matter what price a farmer receives for the raw materials that he or she produces and sells, that price does not cover the real cost of the water; even with heavy subsidies, that cost is only barely covered. In fact, in the case of many raw materials, the price paid to the farmer does not adequately cover the price even for the water, much less any other costs of production. A few examples in table 3.1 illustrate the point.

Even when producers use the same technology, though, they sometimes achieve very different results. Some results are many times better than others. In fact, if we could simply shift the global norm to equal that of the average performance of the top 50 percent of producers, we could have a huge impact on global efficiency. Table 3.2 shows which countries on average use the least water and which the most water to produce seed cotton, cotton lint, and final textiles. In those instances where the difference between the worst and the best countries of production are closest, the average is still four times better for the most water-efficient producing countries than for their poorer-performing counterparts. In some cases, where only irrigated production is being compared, the difference is as much as 120 times.[5]

In addition to improved irrigation efficiency, there are other ways to increase the efficiency of water use in agriculture. Perhaps the most important is to increase organic matter (or soil carbon) both in and on the soil. Studies have shown that increased soil carbon can reduce water needs by as much as 50 percent, where soil carbon acts as a sponge, soaking up the water and making it available over time, and surface carbon acts as a mulch that reduces evapotranspiration.

Soil organic matter can be increased by such practices as growing crops with high biomass or growing cover crops to add additional biomass and then leaving the biomass in the field. Organic matter can also be increased through no-till or conservation tillage practices. Another way to increase soil organic matter is to eliminate burning either in the land-clearing phase (swidden

5. A.K. Chapagain, A.Y. Hoekstra, H.H.G. Savenije, and R. Gautam, *Water Footprint of Cotton Consumption,* Value of Water Research Report Series 18 (Delft, The Netherlands: UNESCO–Institute for Water Education, September 2005), http://www.waterfootprint.org/Reports/Report18.pdf.

Table 3.1 Selected Products, Water Use, and Farmer Income

Item	Raw Material Input	Water to Produce Input	Farm Gate Price
1 cotton T-shirt	4 oz. ginned	500 to 2,000 liters	US$0.20 (Aust.)
1 liter of soda	6 T. sugar	175 to 250 liters	US$0.006 (Brazil)
1-oz. slice of cheese	6 oz. milk	40 liters	US$0.03 (US)
1 double quarter pounder	8 oz. of hamburger	3,000 to 15,000 liters	US$0.25 (US)

Source: Data from author's interviews with farmers and from various other sources.

Table 3.2 Global Water Use in Cotton Production

	Global Average	Lowest	Highest
Seed cotton	3,544 l/kg (I & R)	2,018 l/kg (China)	8,663 l/kg (India)
	1,818 l/kg (I only)	46 l/kg (Brazil)	5,602 l/kg (Turkm)
Cotton lint	8,506 l/kg (I & R)	4,710 l/kg (China)	20,217 l/kg (India)
	4,242 (I only)	107 l/kg (Brazil)	13,077 l/kg (Turkm)
Final textile	9,359 l/kg (I & R)	5,404 l/kg (China)	21,563 l/kg (India)
	4,917 l/kg (I only)	608 l/kg (Brazil)	14,122 l/kg (Turkm)

Note: I & R = irrigated and rainfed; I = Irrigated only.

Source: Chapagain et al., *Water Footprint of Cotton Consumption,* from tables 3.4 and 3.5.

agriculture, for example), or before harvest (sugarcane, for example), or postharvest (such as for wheat or rice straw). Perennial crops tend to build up organic matter faster than annual crops, and soils in temperate areas tend to retain organic matter longer than tropical soils.

Better agricultural practices can also improve water-use efficiency. Keeping irrigation equipment in good repair, for example, enhances efficiency as does enclosing or covering water-delivery systems. Watering based on soil moisture and plant needs rather than on a fixed calendar system can improve water use as well.

Not all water efficiency in food production is related to crop or plant production, however. The Brazilian poultry industry, for example, is attempting to reduce the water used to raise and process a single bird from 32 liters to 16. The industry's challenge is to achieve that target within 10 years, and it is well on the way to achieving it by 2015.

In some cases, efficiency of water use can actually be improved by using more water—at least during parts of the year. For example, it is now understood that many cacao pods fall off the trees when the trees are stressed during the dry season. If water is provided during the two–three month dry period, total production can be doubled. This approach, in effect, reduces the amount of water required to produce a kilogram of cacao.

Another way to reduce water use or increase efficiency per ton of output is through plant breeding and drought tolerance. While this work is now commercially viable only for some crops, plant-breeding programs that identify and select drought-resistant genes will clearly increase productivity or reduce overall water use significantly, perhaps by as much as 50 percent or more.

With water, as with most things in life, there is no free lunch. To improve global diets by 2050, we will have to use both green and blue water much more efficiently. Irrigation is currently practiced on only 16 percent of total cropland; yet it provides more than a third of global calories. Those calories can come at a high price, however. For example, rice, which is the second-largest source of calories globally (after wheat), requires nearly 14 percent of the water used by humans for all activities. Still, companies now know that by mechanically or aerially planting rice (rather than setting out seedlings by hand in flooded paddies), they can reduce total water use by about 50 percent.

Bundled Values—Including Externalities—in Commodity Pricing

One way to force the issue of water pricing is to internalize the cost and start paying for water as a "bundled value" or as an attribute of an existing commodity. While this approach may sound far-fetched, virtually every commodity today represents a number of traits that include verifiable, physical traits as well as nonphysical values or traits that can be credibly claimed only through third-party certification.

What is interesting about commodity trading systems is that they were, without exception, started by the private sector rather than by the government. Governments stepped in only 30–50 years later to regulate trade. The driving force behind commodity markets was the private sector's need for a way to buy and sell products globally. The "traits" were the characteristics of the product that were required by the user to ensure product quality and substitutability—a kilo of sugar needed to be substitutable for a kilo of sugar anywhere in the world. More recently, intangible values have been added to the list of descriptors (organic, non-genetically modified organism, hazard analysis and critical control points, and the like, for example). These traits are not physical and therefore cannot be differentiated simply by looking at or in many cases even testing products (see table 3.3).

Some companies are now beginning to bundle additional values—carbon-free products, for example. Domino sells a brand of sugar that is carbon neutral or "free." Other companies are looking at bundled values to differentiate their products in the market place, to address their own carbon footprints, to comply with post-Kyoto carbon requirements, or to comply with internal targets related to water, poverty, or other issues that are key to a company or its markets. It is likely that carbon will be "bundled" into products, particularly agricultural and food commodities, more quickly than other values. But some companies are already beginning to see if water can be bundled into the raw materials they buy as well.

Table 3.3 Values That Are or Could Be "Bundled" with Commodity Prices

Current Physical Values	Current Intangible Values	Potential Future Values
Weights and measures	Organic	Carbon
Quality	Non-GMO	Water
Color	Fair trade	Biodiversity
Foreign matter	Origin	Child labor
Health and safety	HACCP	Poverty alleviation

Source: Author.

2050 Vision for a Sustainable Agriculture

If we are to achieve the vision of sustainable supply chains by 2050, five key principles need to guide agriculture:

- Zero loss of natural habitat
- 50 percent increase in overall productivity ("crop per drop," for example)
- Zero loss of soil carbon through erosion
- Zero waste and pollution
- Reduce, reuse, and recycle

Most approaches to making agriculture more sustainable over the past century have focused on increasing productivity and producing more with less. This approach includes plant and animal breeding and genetic selection as well as improved management practices and the delivery and use of key inputs such as water, fertilizer, and pesticides. No-till farming and conservation tillage have certainly made it possible to achieve more with less. We will have to redouble those efforts, but even so the pursuit of productivity gains and management practices alone will probably not achieve the results needed to meet consumer demand from agriculture by 2050. In addition to those activities, we need to rehabilitate degraded and abandoned land through existing technologies, such as no-till or perennial crops, or develop new technologies to address those issues. We will also have to reduce postharvest losses and, as important, postconsumer losses. The average person in developed countries throws away from 20 to 40 percent of the food he or she purchases. That waste cannot continue. We cannot squander the Earth's limited resources if we are to meet projected 2050 consumption levels.

Should consumers have choice? Should they be able to buy foods that are produced unsustainably in a world with finite resources, or should everything on the shelf be produced with more sustainable raw materials and manufacturing processes? And, if consumers shouldn't have "choice," should companies have the option of manufacturing and selling unsustainable products?

In the end, however, the real challenge is not about efficiency, or making more with less but about changing consumption patterns—using less more responsibly. Some estimates suggest that there are twice as many overweight people on the planet as there are malnourished ones. That imbalance, too, will have to change.

4 PROTECTING WATER
SUSTAINABLE PRODUCTION AND EFFICIENT IRRIGATION IN OAXACA´S CENTRAL VALLEYS

Juan José Consejo

The Stage

The Central Valleys region of Oaxaca, Mexico, lacks an adequate water supply in both quantity and quality for several reasons. In the city, the current water collection and distribution system is inefficient, and the treatment system for human waste is inadequate, allowing raw sewage to be released into the rivers. The city of Oaxaca is experiencing rapid population growth, and current zoning laws do not control development at the city limits. The resulting expansion and uncontrolled deforestation of previously rural lands have significantly impacted Oaxaca´s Central Valleys by reducing the water catchment area.[1] Current government policies do not adequately address the city's water problems, and furthermore, recently proposed policies focus more on large infrastructure development to bring water from distant water basins than on protection and conservation of the city's watershed.

In the surrounding rural areas, farmers use up to 1 cubic meter per second (m^3/second) of water, just as much as is being used by urban residents. As local peasants, who are used to times of more abundance, have weakened in traditional knowledge, farmers now irrigate their crops very inefficiently. This is more than a local issue: in Mexico as well as the rest of the world, irrigation for agriculture accounts for the greatest percentage of water used by society. It also represents the biggest contribution to wastewater.[2] If we really aim at solving the water crisis, it is imperative to improve the efficiency of irrigation systems and the sustainability of agriculture in general.

The Project

In 2004, the Institute for Nature and Society of Oaxaca launched a project called *Aguaxaca* to design a comprehensive strategy for the ecological regulation of the watershed that will conserve its natural processes and develop opportunities for the social and economic improvement of its inhabitants.[3] Our strategy is fivefold. The first component, "the photo," focuses on researching and compiling ecological, hydrological, and demographic information for each micro-basin in the watershed, undertaken with the participation of communities. Our second strategy, "the table," has resulted in the formation of the Oaxacan Water Forum, which brings together a diverse group of

1. Juan José Consejo and Laura López, "El Agua en Oaxaca," in *Voces de la Transición en Oaxaca,* comp., Claudia Sanchez, Instituto de la Naturaleza y la Sociedad de Oaxaca (Oaxaca, Mexico: Carteles Editores, 2004), 151–157.
2. World Commission on Dams, *The Report of the World Commission on Dams* (London: November 2000), 320, http://www.dams.org/report/.
3. Consejo and López, "El Agua en Oaxaca," 151–157.

stakeholders from communities, the government, nonprofit organizations, and academic institutions to discuss solutions, models for watershed management, and plans for conservation projects. The third strategy, "the plan," aims to design a new urban development plan. It also assists communities to create new zoning plans and conservation projects. In our fourth strategy, "the tools," we conduct concrete activities that help save water, prevent contamination, avert deforestation, and promote sustainable agriculture. The last strategic line, "the voice," aims to improve the education, participation, and responsibility of all water consumers.

Within this framework, the specific initiative for sustainable agriculture and efficient irrigation started three years ago in collaboration with Ashoka and other funding agencies. One of the main components was to create a private trust fund to finance organic production and efficient irrigation projects. This can be seen as a pilot phase for a broader scheme: in the Water Forum, we are laying the cornerstones of a financial mechanism that charges a just price for water to urban consumers and compensates upper watershed communities for the provision of hydrological ecosystem services (PES).[4]

The fund, which started one year ago, has allowed small producers to obtain greenhouses and irrigation systems that enable them to save water, raise and diversify their production, and improve their environment. We are also implementing social and technical innovations in irrigation systems and low-cost greenhouses. The systems are installed by means of a three-part contribution of government funds, producers (especially in kind), and private funding. As part of the project, our organization is also providing technical support for sustainable production and forestry. All these experiences are being spread at the local, regional, and national level.

Currently we are supporting 17 irrigation and greenhouse projects in which organic production and water saving are the key elements. We have also developed a collaborative reforestation plan for the whole watershed, and nine local governments are engaged in producing and planting trees. Approximately 60,000 plants have been produced under our scheme, and more than 50 hectares have so far been reforested. To strengthen training and dissemination activities, we established a Permaculture Demonstration Center and also carried out several workshops on soil conservation, fuel-saving stoves, water storage, irrigation, and organic farming.

All these activities have been accomplished within a scheme of a threefold partnership: local communities and authorities, government, and private national and international funding.

Some Innovations

Our solution is unique in combining contrasting principles precisely to create a new ecological regulation of the watershed. Often we find ourselves seeking a balance between two seemingly opposing ideas. For example, we do not believe that privatization or economic valuation of water will sufficiently solve water problems, yet we propose the use of an economic tool as part of the solution, distinguishing between *value* of water (which cannot be priced) and the cost of some water services (which should help us to compensate social inequity). Similarly, we are using modern scientific knowledge as an essential part of our analysis and in the technologies we suggest, yet we also value traditional and indigenous knowledge as a necessary part of the solution. We conduct

4. Within the background of the dramatic water crisis worldwide, in Mexico and many other parts of the world there is mounting interest in the schemes of payment or compensation for ecosystem services (PES). As part of our project, several theses have been produced.

projects at a local level, but we find it equally important to keep in mind the whole watershed. We postulate that the root of the problem is our current social attitude toward water; therefore we propose a shift in the social paradigm. Yet, at the same time we also approach communities with respect for their autonomy and their right to decide their level of involvement. We see it most important to bring communities together and engage them in a discussion toward collaboration. We understand that by combining seemingly contradictory ideas, we will produce the best ecological planning possible.

We contribute in many ways to transferring technology to communities. We have produced a 130-page manual of technologies for ecological defense, which we distribute to those communities who show interest.[5] This manual was written after years of consultation with communities, universities, and technical experts. The technologies we promote generally combine modern knowledge with traditional knowledge. For example, we contend that the modern concept of drainage and a sewer system is not the most efficient use of our water resources. We promote dry composting toilets that can be constructed in a way to appear modern and to be odorless. A bacteria added to the mix aids in decomposition, and the compost can eventually be used as a fertilizer. In another example, we also promote soil erosion prevention practices that are also suggested by Conafor (the National Forest Commission). To capture water and allow it to slowly infiltrate the soil on mountainsides, we build trenches along the contour of hillsides, a traditional practice, and, using a modern science-based restoration technique, reinforce them with vetiver grass, a hardy, nonintrusive plant from India.

As mentioned earlier, we hold several workshops to teach alternative technology and farming techniques. During the wet season, we have hosted community service reforestation days on weekends on a mountain close to the center of the city as well as at other sites. Community members who come with their children to plant trees are also able to view the irrigation and conservation technologies that we have installed. Our permaculture/alternative technology demonstration project is a center for technology transfer. During its development, we have invited interested people to visit and/or work for the day, and at its completion we will hold workshops and tours. Also, we offer our administrative, collaborative, technical, and financial assistance to actualize new technical projects in communities.

Our fivefold strategy of "the photo," "the table," "the plan," "the tools," and "the voice" has proven to be innovative and very attractive and has started to be reproduced by other organizations in other contexts. We have found this breakdown particularly useful in guiding our simultaneous work and in maintaining a balance between several necessary activities. Other organizations and communities have adopted the idea of addressing water problems from several different angles at the same time and viewing the issue holistically.

Many projects in Mexico and other parts of the world attempt to bring water from other watersheds through expensive engineering feats. When people think of having clean water in their community, they may imagine the prevailing modern concept of having water treatment plants and an elaborate sewer system. Alternatively, we suggest that water problems can be solved locally, through small, simple daily practices and with the help of alternative technologies and local education.

In the area of irrigation and agriculture, we have focused on a sector often forgotten by both market and government—small steep-slope producers. Within this sector, we promote food self-

5. Juan José Consejo and Laura López et al., *Manual de Técnicas de Defensa Ecológica,* 2nd ed. (Oaxaca, Mexico: Instituto de la Naturaleza y la Sociedad de Oaxaca y Fundación Frederich Evert, 1998), 130.

sufficiency and productive diversification. The central element here is a microcredit scheme, but we also include technical support for production and selling. The project has also a strategic value: to create a productive green belt around Oaxaca city that will act as a buffer to prevent urban growth and will protect its water sources. Such a private fund can be used to experiment with different mechanisms to develop an effective PES system as well.

The foundations of our relationship with water and nature must be built on the cornerstones of respect and common sense. We believe that our initiative contributes to this process.

5 MANAGEMENT OF IRRIGATION WATER IN RURAL CHINA

Qiuqiong Huang

Impact of Irrigation on Agricultural Production and Rural Income

My colleagues and I have assessed the impact that irrigation in China has had on grain production and incomes in general and on income and poverty alleviation in poor areas in particular.[1] Our studies use the 2000 China National Rural Survey data that include a random sample of 1,200 households in 60 rural villages in six provinces (Hebei, Liaoning, Shanxi, Zhejiang, Hubei, and Sichuan) to show that irrigation contributes to increases in yields for almost all crops. For example, irrigation increases the yields of wheat by 17.7 percent, those of maize by 29.4 percent, and those of cotton by 28.4 percent. Irrigation also contributes to increases in income for farmers in all areas. Increasing irrigated land per capita by one hectare will lead to an increase of 3,082 yuan in annual cropping income per capita, holding other household characteristics constant. Given the importance of crop income in poor areas (34 percent of total income), the strong and positive relationship between crop revenue and irrigation provides evidence of the importance of irrigation in past and future poverty alleviation in China.

To uncover the effect of irrigation on the income distribution, we decompose inequality by source of income, by group according to access to irrigation, and by estimated income flows due to specific household characteristics. Our results show that irrigation reduces inequality. For example, a 1 percent increase in cropping income from irrigated land for all households would decrease the Gini coefficient for total income by 0.1 percent, a marginal effect on lowering inequality that is higher than those of other sources of income. We also show that, in the majority of the villages that invested in new irrigation, returns are positive even after accounting for increases in capital and production costs. Hence, irrigation investment in rural China appears to be one that can lead to both growth and equity.

Water Management Institutions

To study the institution of water management in rural China, my colleagues and I collected two sets of survey data. The first survey, the China Water Institutions and Management Panel, was conducted in 2001, 2004, and 2007. Enumerators interviewed village leaders, surface and groundwater irrigation managers, and farmers in 80 villages in Hebei, Ningxia, and Henan provinces. The second survey, the North China Water Resource Survey, was conducted in January 2005 and

1. Qiuqiong Huang et al., "Irrigation, Poverty and Inequality in Rural China," *Australian Journal of Agricultural and Resource Economics* 49, no. 2 (June 2005): 159–175, and Qiuqiong Huang et al., "Irrigation, Agricultural Performance and Poverty Reduction in China," *Food Policy* 31, no. 1 (2006): 30.

randomly sampled 401 villages in six provinces (Inner Mongolia, Hebei, Henan, Liaoning, Shaanxi, and Shanxi). In that survey, we interviewed only village leaders owing to limitations of time and budget. We collected data on most variables for two years, 2004 and 1995. The scopes of both surveys, which were quite broad, included sections on the nature of water resources in the villages, the condition of village irrigation infrastructure, irrigation management practices, government policies, adoption of water-saving technology, and household agricultural production activities.

Changes in Water Management Institutions over Time and across Places

Two studies provide information on the reform of water management in China.[2] They show that reforms have spread steadily: in the period between 1995 and 2004, between 20 percent and 30 percent of villages that use surface water in northern China had shifted away from traditional forms of management, i.e., collective management. In their place, some villages are hiring individual contractors; others are adopting water user associations. While China's new forms of water governance are not very participatory (from the farmer's point of view), water managers—especially contractors—are increasingly being given more incentives to save water and to manage their village's water more effectively. In groundwater-using areas, the ownership of wells shifted sharply from collective ownership to private ownership. In 1995, collective ownership accounted for 58 percent of wells in groundwater-using villages. By 2004, the share of privately owned wells rose sharply to 70 percent, shifting the decisionmaking of groundwater management largely into the hands of private individuals.

The Driving Force behind Changes in Water Management Institutions

In another study, my colleagues and I identify factors that lead to the creation of reform-oriented irrigation institutions (water user associations or contracting) in one place but not in another.[3] Our study indicates that the managerial form of water resources (collective management, WUA, or contracting) depends on the relative abilities of the leader and the potential candidates for managers within the village, the design of the cultivated land, the characteristics of the canal system, the opportunity costs of the leader, and the pool of managerial candidates. Water scarcity and policies implemented by local and regional government water officials are also among the main drivers of water management reform.

The Effects of Different Water Management Institutions

My colleagues and I also compared different approaches to community-based groundwater management: *collective well management*, under which wells are collectively owned and the community leader allocates water among households, and *private well management,* under which wells are

2. Qiuqiong Huang et al., "Efficient Use of Data in Building Policy Models—Trading Off Precision and Heterogeneity," Working Paper (Department of Applied Economics, University of Minnesota, 2008), http://www.apec.umn.edu/faculty/qhuang/research.html; and Jinxia Wang et al., "Agriculture and Groundwater Development in Northern China: Trends, Institutional Responses, and Policy Options," *Water Policy* 9, no. 1 (2007): 61–74.

3. Qiuqiong Huang et al., "Water Management Reform and the Choice of Contractual Form in China," *Environment and Development Economics* 13, no. 2 (2008): 171–200.

privately owned and households make their own pumping decisions.[4] Unlike previous studies, the nature of the aquifer is taken into account by distinguishing between *connected communities* whose aquifers are connected to neighboring communities and *isolated communities* that are hydrologically isolated. Empirical analysis shows that households located in isolated communities use less water than households in connected communities, controlling for the type of well management. Furthermore, results show that in isolated communities households under collective well management use 20 percent less water than households under private well management. In connected communities, however, no difference in water use is observed between collective well management and private well management. Our study shows that community-based management of groundwater resources has the potential to succeed in resource conservation but that its success depends crucially on the nature of the aquifer.

Water Pricing Policy

Two studies—Huang et al. and Lohmar et al.—focus on the potential of water pricing policy as a policy tool for dealing with the rising water scarcity in China.[5] We first develop an approach to estimating water demand that can use limited micro-level data sets most efficiently to estimate parameters of production function.[6] In that article, we develop a series of quantitative metrics of both precision and heterogeneity to compare model performance. We also propose a new alternative to estimate technical inefficiency and frontier parameters simultaneously. Both sets of parameters are needed to estimate water demand.

Huang et al. and Lohmar et al. then analyze the responsiveness of household water users and assess the magnitudes of the water price increments that are required to achieve the water-saving targets of policymakers.[7] Household-level water demands are estimated so that adjustments at both the intensive and extensive margins are captured. The results show that there is a large gap between the cost of water and the value of water to producers. We then examine the effects of two different water-pricing policies, a value-based policy that takes into account the gap between the cost and the value of water and a cost-based policy that ignores this gap. Simulation analysis shows that reforming water pricing can induce water savings. The price of water, however, needs to be raised to a relatively high level. We also find that the value-based policy is more effective than the cost-based policy, since it generates larger water savings given the same increase in the average price of water. While raising the price of water negatively affects crop production and crop income, higher water prices do not adversely affect the distribution of household income.

4. Qiuqiong Huang et al., "The Effects of Well Management and the Nature of the Aquifer on Groundwater Resources," Working Paper (Department of Applied Economics, University of Minnesota, 2009), http://www.apec.umn.edu/faculty/qhuang/research.html.

5. Huang et al., "Water Management Reform and the Choice of Contractual Form in China"; Qiuqiong Huang et al., "Irrigation Water Pricing Policy in Rural China," Working Paper (Department of Applied Economics, University of Minnesota, 2009); and Bryan Lohmar et al., "Water Pricing Policies and Recent Reforms in China: The Conflict between Conservation and Other Policy Goals," in *Irrigation Water Pricing: The Gap between Theory and Practice,* ed. François Molle and Jeremy Berkoff (Wallingford, UK: CAB International, 2008).

6. Huang et al., "Water Management Reform and the Choice of Contractual Form in China."

7. Huang et al., "Irrigation Water Pricing Policy in Rural China"; Lohmar et al., "Water Pricing Policies and Recent Reforms in China."

6 SUSTAINABILITY ISSUES OF WATER AND AGRICULTURE IN CHINA

Mei Xurong

Agricultural production, particularly for cereal, depends largely upon cultivated acreage, yield, and farmers' practices. Furthermore, arable land and water availability as well as their allocation for agriculture are the main constraints to not only cultivated acreage, but also the yield. Besides land and water resources, additional constraints to agricultural production include climatic conditions, land management scale, and agricultural policy. Such issues and their interactions thus form the matrix of agricultural sustainability.

Agriculture in China: Growth and Development

In China, agriculture plays a fundamental role in food security and socioeconomic development. Strategically, its multifunctional role has been to ensure food security, protect and restore agro-ecosystem health, and reduce rural poverty as well as promote urbanization and modernization. Nowadays, China's agriculture, with only 8 percent of the world's arable land and 6 percent of renewable water resources, produces 19 percent of the world's cereal, 30 percent of meat, and 38 percent of fruits and vegetables[1]—serving 20 percent of the world's population, but consuming 32 percent of the world's chemical fertilizer. However, such a situation has constraints to agricultural sustainability, raising such issues as arable land shortages, water scarcity, variable climate, and agro-ecosystem fragility (natural aspects) as well as socioeconomic aspects like smallholder farmers and scale of agriculture operation.

Production of grain (defined as cereal, soybean, and tuber crops) in China has been the most important agricultural function for a country with a huge population. In the past 60 years (1949–2008), grain production has grown from 113.2 million tons to 528.5 million tons (see figure 6.1).[2] During this time period, significant changes in agriculture have occurred—in 1978 the reform and open strategy was adopted that brought changes in land management patterns, rural economy growth, and diversified food demand and supply. In terms of the factors that drive grain production, the last 60 years of agriculture in China may be separated into three phases—1949–1978, 1979–1998, and 1999–2008. The major growth characteristics of each phase are shown in table 6.1.

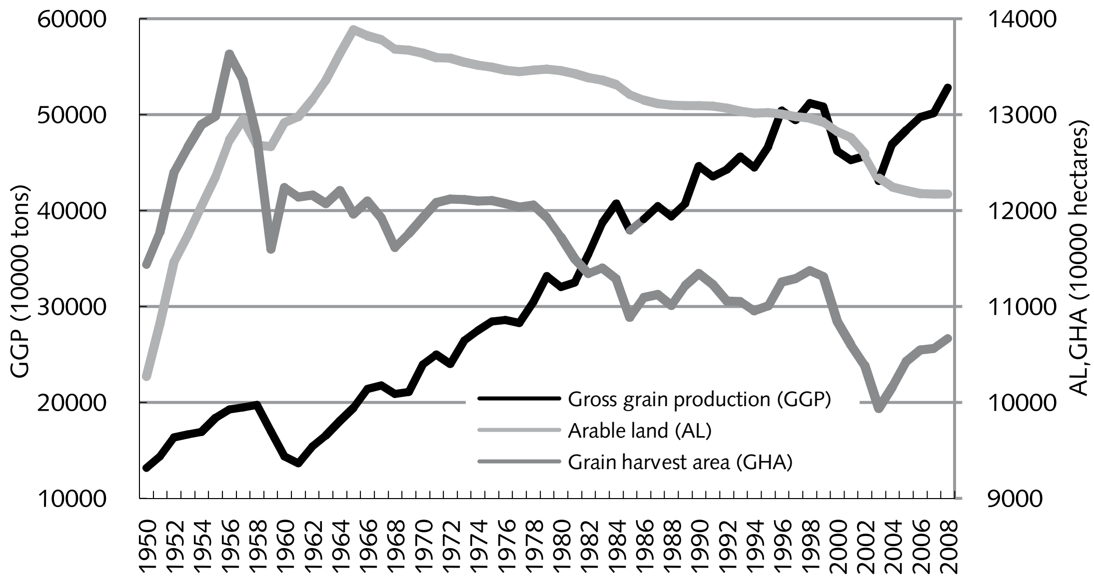
China's national food development outline to serve 1.55 billion people by 2030 promotes grain self-sufficiency until 2030 at 95 percent and cereal self-sufficiency at 100 percent.[3] China's

1. United Nations, Food and Agriculture Organization (FAO), FAO Statistics, World and China Food Production 2007, http://faostat.fao.org/site/399/default.aspx.

2. National Bureau of Statistics China (NBSC), *National Statistics Bulletin* (Beijing: China Statistics Press, 2006).

3. "Middle and long term planning outline of national food security," http://www.gov.cn/jrzg/2008-11/13/content_114841.

Figure 6.1 Changes in Gross Grain Production, Arable Land, and Grain Harvest Area in China, 1950–2008



Source: Data from National Bureau of Statistics of China (NBSC), *National Statistics Bulletin* (Beijing: National Statistics Press) and from China's Ministry of Agricutlure (MOA), *China Agricultural Bulletin* (Beijing: China Agriculture Press).

Table 6.1 Agriculture Growth in China during 1949–2008 (in percent)

	1949–1978 (30 years)	**1979–1998** (20 years)	**1999–2008** (10 years)
Annual increment of gross grain production	3.47	2.63	0.31
Annual increment of yield	3.15	2.93	0.96
Annual increment of arable land	0.97	-0.19	-0.63
Annual increment of grain harvest area	0.32	-0.29	-0.64
Annual increment of irrigation area	3.95	1.37	0.33
Major contributing factors	Farmland infrastructure, irrigation	Policy, chemical fertilizer, variety	Policy, low profit, technologies

most challenging issue in agricultural sustainability is thus how to ensure food security under the land and water shortage.

Land and Agriculture

Since 1949, the arable land acreage for China's agriculture has been decreasing while gross grain production has been increasing due to yield improvement. During the statistical period, the annual increase rate of gross grain production and yield are 2.42 percent and 2.54 percent respectively, while arable land and grain harvest area suggest 0.29 percent and –0.12 percent respectively.[4]

Besides the arable land and harvest area, land quality and soil fertility are degrading gradually. The significance of the degradation may be suggested by tillage depth. The survey data from the Chinese Ministry of Agriculture showed that tillage depth decreased from 22.0 centimeters (cm) in 1949 to 16.5 cm in 2000, a reduction mainly caused by small power tractors and smallholder operations in agricultural practices. In addition, if invested organic nutrition is viewed against total nutrition, the organic nutrition rate decreased from 99 percent (1949) to 49 percent (1980) and 30 percent (2000). The overutilization of chemical fertilizer (more than 50 million tons of pure nutrition) creates a nutrition imbalance that contributes to such degradation.

Water and Agriculture

Water and agriculture in China are considered in terms of water availability and grain productivity, water allocation/reallocation and rural economy, and water quality and rural environment. These relationships can also be summarized in terms of water scarcity and food security, water shift-off agriculture and rural poor, and water pollution and food safety.

Currently, grain production in China consumes 570 billion cubic meters (BCM) of water. Statistical research and geological studies have shown that this quantity of water consists, very roughly, of 170 BCM of irrigated water and 400 BCM of rainwater.[5] The research also determined water use efficiency in grain production as follows: irrigation water use ratio at 45 percent, rainwater use ratio at 55 percent, and water use efficiency at 0.9 kilogram per cubic meter (1100 cubic meters of water for each ton of grain). Food security in 2030 predicts the gross grain production to be 620 million tons. If assuming that water use efficiency maintains the current level, the water requirement for grain production is estimated at 680 BCM. Therefore, a water shortage of 110 BCM could challenge grain production growth.[6]

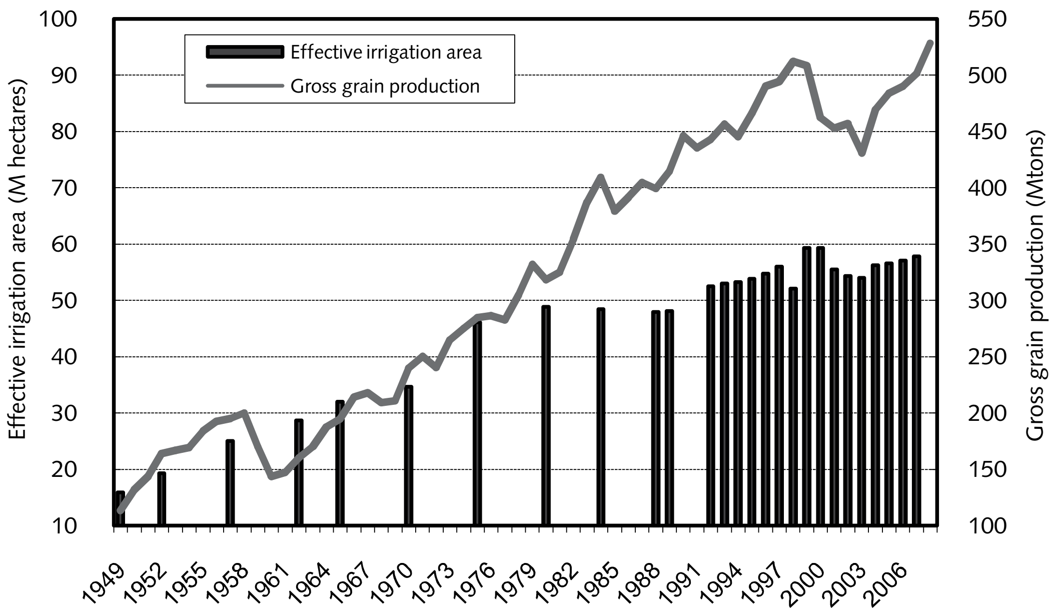
On the other hand, the water for agriculture will not increase according to a water resource allocation program. Currently, 400 BCM of water is allocated and limited for agriculture, of which about 350 BCM is for irrigation. Irrigation water for incremental grain production should not exceed that amount and may be less.

4. NBSC, *National Statistics Bulletin*.

5. Xurong Mei, Weiping Hao, and Qingsuo Wang, *Technologies of Water-saving Agriculture* (Beijing: China Agricultural SciTech Press, 2007).

6. Xue Liang, Ye Zhenqin, Peng Shiqi, and Mei Xurong, *Theory and Practice of Water Saving Agriculture in China* (Beijing: China Agricultural Press, 2002).

Figure 6.2 Comparison between Gross Grain Production and Effective Irrigation Area in China, 1949–2008



Source: Data from *National Agricultural Bulletin* and the *National Water Bulletin*.

Table 6.2 Increment Comparison between Gross Grain Production and Irrigation Acreage, 1949–2008 (in percent)

	1978–1949	1998–1979	2008–1999	2008–1949
Gross grain production increment	169.3	68.1	3.2	367.0
Irrigation acreage increment	207.2	14.6	3.0	263.0

Furthermore, the contribution of irrigation to grain production is reduced. This may be comprehensive, because of the difficulty of expanding irrigation acreage and the shifting of water away from grain production, due to low profit and water productivity (figure 6.2). The incremental comparison between gross grain production and irrigation acreage are available in table 6.2.[7]

In addition, the constraints and limitations for water shortage and grain production, which are numerous, are simplified as follows:

- **Climate change and agriculture**. Numerous studies show that climate change, which induces increased temperatures and decreased precipitation, differs from region to region. Even though uncertainty remains, extreme weather events such as drought and heat waves are increasing in China and consequently reducing agricultural productivity. The latest scenarios study of

7. Ministry of Agriculture, *China Agricultural Bulletin* (Beijing: China Agriculture Press, 2008); Ministry of Water Resource, *China Water Bulletin* (Beijing: China Water Conservancy Press, 2007).

climate change[8] showed that gross cereal productivity in China can decrease 5 percent to 10 percent if no action is taken by 2030. By the second half of the twenty-first century, climate change can cause a yield reduction in rice, maize, and wheat of up to 37 percent.

- **Domestic grain production and trade patterns**. About 50 percent of irrigated farmland grows paddy rice, mainly in southern China—a region that does not suffer from water shortages. But the north's delivery of cereal to the south converts to 15 BCM of water from the dry north to the wet south, which is one-third of the annual Yellow River discharge. Thus the region with the most water-saving potential does not contribute to solving the national water shortage.
- **Economic water transfer.** Within agriculture, fruits, vegetables, and livestock compete with grain production for land and water use. Competitive water utilization induces limited water transferring from agriculture to industry and urbanization (non-farming transfer). Even though agriculture is paid for by non-farming water transfers as compensation for infrastructure construction, particularly for irrigation improvement, the payment is under value.
- **Commodity and water pricing.** Cereal prices are controlled at a low level, which encourages inflation but also affects the farmer's income. Prices for water as well as fertilizer, pesticide, gasoline, and machinery are controlled and maintained at a low level, which may encourage nonpoint source pollution.
- **The national target and farmers' livelihoods.** The national target for ensuring food security, water availability, and ecological safety is not very often consistent with the livelihood needs of farmers (such as income). Farmers' willingness to produce grain responds to market need but often at a delay.
- **The smallholder farmer and technical extension.** With smallholder and individual farmers, it is difficult to achieve uniform practices in grain production for crop varieties, tillage, and irrigation, etc. Technical transfers are also difficult under different scales of operation and educational backgrounds. The rural poor in both regions still lack the latest information.

Toward Sustainability

Land shortage, water scarcity, climate change, and economic competition have a severe environmental impact on agriculture, particularly grain production, in China. The effects on China's agriculture, which consists of smallholder farms and a huge number of farmers (about 0.2 billion), are as follows:

- Farmers do not receive a sufficient and timely amount of clean water;
- They suffer from severe drought and/or heat waves;
- They experience reduced willingness to engage in cereal production for economic reasons; and
- Nonpoint source pollution is produced.

The solution to such issues should be comprehensive but also integrated. The estimation of water balance for agriculture in China suggests that to effectively improve water use ratios, water

8. W. Xiong et al., "Future cereal production in China: The interaction of climate change, water availability and socio-economic scenarios," *Global Environmental Change* 19 (2009): 34-44.

use efficiency can be addressed when the environmental aspects are ready.[9] The conclusions are as follows:

- **Enhance investment for infrastructure improvement.** The "building of a new socialist countryside" policy highlights improving the irrigation and water harvesting systems, launching a program for soil fertility enhancement, and equipping the machinery and technical service facility in the main agricultural region.
- **Strengthen technique extension and application.** Carry out research and development, pilot demonstrations, and on-site trainings (such as the "technique goes to farmer" project). Popularizing education and knowledge is highly recommended and promoted.
- **Perfect strategies and policies.** Reducing taxes and fees on agriculture, increasing subsidies for grain production, improving the cereal pricing system, and providing compensation for resource-saving and environmentally sound practices are helpful for promoting smallholder farmer willingness to engage in grain production and thus address water scarcity and ensure food security.
- **Promote socioeconomic supports.** The government should balance the benefit between the urban rich and rural poor, consumer and producer, government investments and commercial insurance, etc. It is highly recommended that the pattern be changed whereby the poor (agriculture) help the rich (industry). To reduce the impact of disaster, commercial insurance should speed up efforts to protect farmers from risks.

9. Mei et al., *Technologies of Water-saving Agriculture*.

7 WASTEWATER TREATMENT FOR AGRICULTURAL IRRIGATION IN MEXICO

Susan E. Murcott, Andy Dunn, and Donald R.F. Harleman

Chemically enhanced primary treatment (CEPT) is a technology well suited to wastewater reuse for agricultural irrigation, especially in areas coping with water scarcity, demographic stress, and agricultural and food supply demands. In bench and pilot-scale tests of Mexico City's raw wastewater, CEPT obtained helminth egg counts of one to five per liter compared to activated sludge, which obtained one to three helminth eggs per liter.* Only tertiary treatment would meet current WHO helminth guidelines of less than 1 helminth egg per liter. Not only are these secondary and tertiary treatment levels prohibitively expensive, especially in cash-strapped developing countries, but they also remove higher levels of beneficial substances. CEPT removed only one-third of the organic matter and nutrients, allowing the remaining two-thirds to be available as fertilizer in lieu of expensive artificial fertilizers. CEPT-treated wastewater enables effective chlorination or UV disinfection with medium-pressure mercury lamps to meet WHO bacterial guidelines. Drawing on epidemiological studies in Hidalgo, Mexico, the authors conclude that a helminth count of fewer than five eggs per liter is sufficient to adequately protect public health and that current WHO guidelines may be overly strict and not in the public's best interest.

With half the world's population now living in urban areas, the water resource problems of the largest and fastest-growing cities have become test cases for sustainable use and reuse of wastewater in the twenty-first century. Mexico City is such a test case. Greater Mexico City (*Zona Metropolitana del Valle de México*), which incorporates 59 adjacent municipalities of the state of Mexico and 29 municipalities of the state of Hidalgo, has a population exceeding 19 million

*Ninety percent of the developing world has no wastewater treatment. Although Mexico City began a planning process to institute wastewater treatment more than one decade ago, almost no progress has been made. This is symptomatic of the larger global problem of indifference to wastewater pollution's impacts on the environment and human health. Precisely because Mexico City's residents and those of the neighboring state of Hidalgo remain unprotected from untreated wastewater (only about 10 percent of wastewater is treated in Mexico City today in about 23 small-capacity wastewater treatment plants), the research reported on in this 1996 International Association of Water Quality biennial conference presentation remains current. In this article, we describe the efficacy of chemically enhanced primary treatment (CEPT) in its ability to remove helminth eggs from Mexico City's raw wastewater and the disinfection options that can be combined with CEPT to achieve the appropriate log reductions of pathogens. Action to implement wastewater treatment in Mexico City was needed decades ago, and this remains true today.

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people, making it the second-largest metropolitan area in the Americas and the third-largest city in the world. In 2009, approximately 90 percent of Mexico City's wastewater remains untreated, a situation largely unchanged from the previous decade. The only current wastewater treatment in existence is at 23 small-capacity wastewater treatment plants in the central city that use the treated water primarily for green space irrigation. The bulk of Mexico City's untreated wastewater is routed through drainage canals to agricultural districts in the adjacent state of Hidalgo. Here it is used as a resource in the irrigation of farmland. Due to poor soils and low rainfall, Hidalgo had been a depressed district. The application of the raw wastewater, however, has dramatically changed the agricultural potential of the region by fertilizing previously infertile areas, without the use of expensive inorganic chemicals. The local economy and the standard of living have increased substantially.

While this scheme for reusing wastewater has improved crop productivity and the local economy, it has also caused a serious public health problem—the infection of agricultural workers and their families with helminth eggs. A study sponsored by the National Institute of Public Health and the National Institute of Nutrition has determined that the incidence of sewage-transmitted disease is higher in the area of Hidalgo called Tula, where raw wastewater is applied to crops, than in the area of Alfajayucan further east, where local lake water is used for irrigation. As a result, restrictions have been enforced that limit the farmers' production of cash crops, thus slowing economic growth in the region. Given this sanitation and economic problem, the Comision Nacional del Aqua (CNA) has stated its goal: "The disinfection of wastewater with the object of eliminating pathogens," using a treatment technology that "should remove as little of the organic material and nutrients as possible in order that the treated wastewater can be used as fertilizer in agricultural production."[1]

The Project

The CNA has presented its drainage infrastructure and wastewater treatment plan in Saneamiento del Valle de México. At projected flows of 85 cubic meters per second, this plan would create the largest urban wastewater infrastructure project under way in the world. Three huge wastewater treatment plants were originally planned: Texcoco Norte, at 35 cubic meters per second; El Salto, at 25 cubic meters per second; and Bombeo, at 30 cubic meters per second. Significant work enclosing and rerouting open sections of the drainage canal network will take place. In addition, a number of smaller wastewater treatment plants will be constructed, and sludge drying beds are planned on 500 hectares of the site of the former Texcoco Lake.

Currently, in 2009, six wastewater treatment plants are planned. All would give secondary treatment except for Zumpango, which would have a module for tertiary treatment with recirculated water. The capacity of the individual plants has been reduced from the original 1994 plan, the only remaining one being Atotonilco (El Salto). The six plants are as follows:

1. Guadalupe: 0.5 cubic meters per second
2. Berriozabel: 2.0 cubic meters per second

1. Comision Nacional del Agua (CNA), "Saneamiento del Valle de México: Informe de Avance Del Proyecto" (Mexico City: Comision Nacional del Agua, 1994), 3.

3. Nextlalpan: 9.0 cubic meters per second
4. Zumpango: 1.5, and Zumpango 2.5, cubic meters per second (tertiary treatment with recirculated water)
5. Vaso El Cristo: 4.0 cubic meters per second
6. Atotonilco (El Salto): 23.0 cubic meters per second.[2]

Because the treated wastewater will be used in agricultural irrigation, the ideal effluent for wastewater treatment for Mexico City would have several specific characteristics:

- Low in pathogens
- High in organic content
- High in nutrient content (nitrogen and phosphorus)
- Low in toxic substances (heavy metals and organics)
- Low in salinity

Pathogenicity is evaluated in the World Health Organization (WHO) Guidelines for the Safe Use of Wastewater, Excreta and Greywater. According to the guidelines, wastewater effluent used for agricultural irrigation should contain less than one helminth egg per liter and a 6–7 $\log_{10}$ pathogen reduction.[3] These were deliberately set forth as *guidelines*, not *standards*, to ensure that best efforts to achieve lower levels of pathogens be made, despite any technical or financial obstacles.

Chemically Enhanced Primary Treatment

Various wastewater treatment technologies should be under consideration for reaching CAN's multiple objectives. The most promising may be chemically enhanced primary treatment (CEPT). CEPT is an appropriate wastewater treatment technology preceding reuse in irrigation because it achieves the desired compromise between public health protection (i.e., high helminth egg removal) and fertilizing ability (i.e., relatively low organic and nutrient removal). CEPT may be used in a single-stage process or as the first stage of a two-stage CEPT plus biological process, depending on the treatment objectives. In the CEPT process, the dosage and type of coagulants can be optimized to achieve high total suspended solids (TSS) removal and, at the same time, comparatively low removal of organic material, measured as biochemical oxygen demand (BOD) or chemical oxygen demand (COD). The soluble organic material in the CEPT effluent provides a natural fertilizer, thereby minimizing or eliminating the need for costly petrochemical fertilizers.

CEPT could be used as a single-stage treatment process in Mexico City, and, if so, advantage should be taken of the increased overflow rate provided by CEPT. (The overflow rate is the flow rate divided by the surface area of the tank and is a measure of the efficiency of the treatment.) A typical overflow rate for CEPT is about 60 meters per day in contrast to the conventional design

2. Personal communication, José Antonio Correa Ibarguengoitia, October 10, 2009.

3. World Health Organization (WHO), *Guidelines for the Safe Use of Wastewater, Excreta and Greywater,* Vol. 2: *Wastewater Use in Agriculture* (Geneva: WHO, 2006).

overflow rate of 40 meters per day for nonchemical primary plants.[4] This greater efficiency of the CEPT plant allows one to reduce the size and cost of the single-stage CEPT plant for an equivalent level of throughput. The construction of single-stage CEPT plants in Mexico City would not foreclose future options for upgrading them to a higher level of treatment, should effluent objectives change. In addition, CEPT allows for effective disinfection using either chlorination or ultraviolet (UV) light. That CEPT is a simple and inexpensive treatment method makes it particularly attractive for areas such as Mexico City and elsewhere that are coping with financial constraints, scarce water resources, demographic stress, and agricultural and food supply demands.

Approach

To establish the suitability of CEPT for the Valley of Mexico Wastewater Treatment Scheme, the CNA commissioned bench (laboratory-based) and pilot-scale testing, coordinated by Agua de Mexico (a jointly owned company of Gupta Construction in Mexico and North West Water International in the United Kingdom) with technical advice provided by the Massachusetts Institute of Technology.

In the winter of 1994–1995, a 75-liters-per-second pilot plant was built at an existing activated sludge plant in Ecatepec, Mexico, to test the ability of CEPT to meet the CNA objectives. The raw water feeding the plant came directly from the Gran Canal, one of the major drainage canals serving Mexico City. The pilot plant comprised the following unit processes:

- A pre-aeration tank
- A flash mixer
- Three flocculation tanks
- An existing rectangular primary settlement tank

Metal salt and polymer dosing capability was available for any stage in this process. Disinfection capability was not included. Sampling was undertaken at the inlet and outlet of the pilot plant and was conducted with 24-hour composite samples. Spot samples were taken once a day to test for helminth eggs and fecal coliform.

The trial protocol consisted of four components: (1) a control trial; (2) a trial to establish the effect of the pre-aeration tank; (3) trials to establish the best metal salt coagulant with or without a polymer; and (4) trials to establish the best coagulant or polymer dosing location. The coagulants included ferric chloride at 40 and 50 milligrams per liter, aluminium sulfate at 50 milligrams per liter, and lime at 100 milligrams per liter. The anionic polymer was Nalcomex, from Nalco Inc., Mexico, and was dosed at 0.25 milligrams per liter and 0.4 milligrams per liter in some trials.

Results—Pilot Test

The results of the pilot plant trials are summarized in table 7.1.

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4. S.P. Morrissey and D.R.F. Harleman, "Retrofitting Conventional Primary Treatment Plants for Chemically Enhanced Primary Treatment in the USA," in *Chemical Water and Wastewater Treatment II. Proceedings of the 5th Gothenburg Symposium*, ed. R. Klute and H. Hahn (Berlin: Springer-Verlag, 1992), 401–416.

Table 7.1 Test Results of CEPT Pilot Plant

Parameter	Column 1 Control: no chemical coagulant	Column 2 Pre-aeration: no chemical coagulant	Column 3 50 mg/l FeCl3 + 0.4 mg/l anion	Column 4 50 mg/l Al2(SO4)3 + 0.4 mg/l anion	Column 5 100 mg/l lime
Helminth (# eggs/l)	n/r	15	4	4	1.5
TSS (% removal)	11	14	65	78	70
VSS (% removal)	8	10	63	81	75
tBOD (% removal)	6	8	45	18	30
sBOD (% removal)	1	2	13	0	4
tCOD (% removal)	11	1	45	36	33
sCOD (% removal)	0	0	26	0	5
TN (% removal)	3	2	25	32	n/r
NH3 (% removal)	1	1	4	0	n/r
TP (% removal)	4	n/r	43	17	n/r
Total coliform (% removal)	36	-124	-8	46	56
Fecal coliform (% removal)	17	-125	-38	38	42

- **Control trial** (column 1). The control trial (no chemical coagulant added) shows a very low removal of TSS (11 percent). This result was expected because the concentration of settleable solids was low.
- **Pre-aeration trial** (column 2). This trial had no chemical dosing but used the pre-aeration tank. It shows that the pre-aeration tank provides no improvement relative to the control.
- **Ferric chloride** (column 3). The ferric chloride results were obtained dosing 50 milligrams per liter of ferric chloride and 0.4 milligrams per liter of anionic polymer. This combination resulted in 65 percent TSS removal (100 milligrams per liter of effluent TSS) and a helminth egg removal of 96 percent (four eggs per liter). The removal of soluble BOD (sBOD) and soluble COD (sCOD) was low (13 percent and 26 percent), as was the removal of ammonia (4 percent).
- **Aluminium sulfate** (column 4). The aluminium sulfate results were obtained dosing 50 milligrams per liter of aluminium sulfate and 0.4 milligrams per liter of anion, giving higher TSS removal (78 percent) (50 milligrams per liter of effluent TSS) than in the ferric chloride trial,

although the concentration of helminth eggs was the same. An interesting result was the aluminium sulfate did not remove the soluble BOD or COD.

- **Lime** (column 5). These results show excellent helminth egg removal (1.5 eggs per liter of effluent). The total solids removal (70 percent), however, was lower than with aluminium sulfate. Visual evidence indicated lime deposits on the weir step and suggests that the lime dosing rate was too high, producing the somewhat higher results for effluent solids.

Results of the Jar Test

Concurrent jar tests took place during some of the pilot test trials. (Jar tests occur at the bench/laboratory scale and use 1–2 liter plastic or glass beakers and a mixing device called a flocculator, which typically comprises 4 to 6 paddles, like egg beaters, the speed of which can be precisely controlled.) A jar test protocol was developed to model the mixing times and speeds occurring in the pilot plant.[5] The purpose of concurrent jar testing was to determine if jar test results matched those of the pilot plant. If so, the jar test could be used to predict alternative treatment scenarios or to determine design specifications for a future CEPT plant. TSS and COD pilot and jar test results are presented in table 7.2.

In this set of tests, the same chemical coagulant dose applied was 50 milligrams per liter of aluminum sulfate [$Al_2(SO_{4)3}$] plus 0.4 milligram per liter of an anionic polymer. Table 7.2 shows that results of the pilot and jar tests are closely matched in concentration and percentage removal, which suggests that the jar test is a good model of full-plant performance. The TSS percent removal is typically greater than 70 percent, and COD percent removal is greater than 30 percent. These performance results are favorable, given the low concentration of settleable solids in the raw water because of the septicity and other effects of a long residence in the Gran Canal before CEPT treatment.

Discussion

The WHO guidelines define limits for coliform and helminth eggs. The coliform limit can be met with chlorination or UV disinfection. Whereas previously UV was considered for use only with a secondary or tertiary effluent, new developments in UV technology using medium-pressure mercury lamps allow for effective disinfection of a CEPT effluent.[6] Full-scale testing and application of this new CEPT plus UV disinfection process have already taken place in North America.

Because standard disinfection practices have no effect on removal of helminth eggs, the wastewater treatment technology itself becomes important. At Ecatapec, CEPT yielded helminth egg counts between one and five helminth eggs per liter; helminth egg removal was always above 95 percent when coagulants were dosed. Although this number falls short of the WHO guideline,

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5. Susan Murcott, "Chemical Upgrading of Wastewater Treatment Plants in Slovakia and Hungary," *IIASA Internal Document* (Laxenburg, Austria, 1993).

6. C. Comair and Ronald Gehr, "Pilot Studies of Ultraviolet Disinfection at the Montreal Wastewater Treatment Plant," *Prepared for the Montreal Urban Community and Quebec Ministry of the Environment by Trojan Industries Inc.* (Montreal: Montreal Urban Community and Quebec Ministry of the Environment, 1993).

Table 7.2 Comparison of Bench-Scale Jar Test Results and Pilot Scale Results

Date	Test	TSS Influent/ Effluent	TSS Removal (percent)	COD Influent/ Effluent	COD Removal (percent)
15/II	Pilot	189 / 61	68		
15/II	Jar	157 / 57	74		
16/II	Jar	200 / 54	73		
17/II	Pilot	199 / 53	73	469 / 333	29
17/II	Jar	235 / 70	70	528 / 372	30
20/II	Pilot	199 / 52	74	501 / 331	34
20/II	Jar	206 / 46	78	520 / 333	36
21/II	Pilot	199 / 59	70	471 / 292	38
21/II	Jar	180 / 50	72	491 / 320	35
22/II	Pilot	225 / 68	70		
23/II	Jar	186 / 46	75		

an activated sludge effluent is not likely to comply with the WHO guideline either.[7] This observation was confirmed at Ecatepec, where helminth egg contamination in the activated sludge effluent yielded one to three eggs per liter. This result indicates that a tertiary treatment process is necessary to achieve the WHO guidelines. Not only is such a high level of treatment prohibitively expensive, but also it would remove almost all the organic matter. The important objective of wastewater reuse for fertilizer is canceled by the stringent limit on helminth eggs.

Some are concerned that the number of helminth eggs in the effluent remains slightly above the WHO guidelines. Epidemiological studies directed specifically at establishing the increased incidence of disease due to irrigation with wastewater are few and extremely difficult to undertake. Two studies worth considering are those by Deborah Blum and Richard Feachem and by Ursula Blumenthal.[8] Both studies concentrate on the difference between "potential risk" and "actual risk"

7. Andy J. Dunn, "The Development of a Predictive Model for the Removal of Helminth Eggs during Rapid Sand Filtration" (PhD diss., University of Southampton 1991).

8. Deborah Blum and Richard G. Feachem,"Health Aspects of Nightsoil and Sludge Use in Agriculture and Aquaculture: An Epidemiological Perspective," *International Reference Centre for Waste Disposal,* Report No. 05/85 (Dubendorf, IRCWD,1985); Ursula Blumenthal, "Research Activities and Needs in Wastewater and Excreta Use in Agriculture and Aquaculture," *International Reference Centre for Waste Disposal News*, Report No. 24/25 (Dubendorf: IRCWD, 1988), 21–26.

of infection. The potential risk is that which may occur due to the reuse of wastewater in irrigation. The actual risk is the measurable increase in the incidence of disease directly attributable to a cause, in this case, the reuse of wastewater. It is this risk that needs to be carefully considered.

Health studies in Mexico have illustrated that the incidence of helminth diseases in areas where untreated wastewater is used in irrigation is approximately 10 percent.[9] By the time the wastewater reaches the fields, it is contaminated with up to 100 helminth eggs per liter. The 10 percent actual risk of helminth egg disease attributable to contamination from wastewater irrigation compares to an incidence of approximately 1 percent in areas where lake water is used in irrigation.

The CEPT process is currently achieving an effluent with fewer than five helminth eggs per liter. This is a 95 percent reduction, which, if applied to the current 10 percent incidence rate, equates to a reduction in helminth egg infection to 0.05 percent. This rate is lower than the 1 percent currently observed in areas of lake water irrigation and therefore suggests that, at this level of helminth egg contamination, other routes of disease transmission mask the transmission route due to the reuse of wastewater. This calculation suggests that the WHO guidelines are too strict and that a count of five eggs per liter would be acceptable. Research undertaken at Leeds University reached a similar conclusion.[10]

According to the results of the study, CEPT removes only a small amount of organics and nitrogen from this hard-to-treat wastewater, an ideal outcome for the reuse of wastewater for irrigation. In both the ferric chloride and the aluminium sulfate trials, some phosphorus was removed, but even that amount was not enough to become limiting. Therefore, CEPT could comply with all the criteria required for the reuse of wastewater in irrigation, as long as disinfection is provided downstream to meet the coliform guideline.

Finally, the jar tests results relate well to the results of the pilot plant test. Jar testing, therefore, would appear to be an inexpensive and reliable methodology for assessing CEPT.

Summary

Based on our discussion of the results of CEPT tests at Ecatepec and the ideal characteristics of a wastewater suitable for reuse in irrigation, table 7.3 compares the appropriateness of various levels of treatment for irrigation. Because CEPT results in substantial removal of helminth eggs and only a moderate removal of organic matter and nutrients, it is a good, affordable compromise for achieving an appropriate wastewater for irrigation.

Conclusions

For Mexico City, CEPT is expected to remove more than 70 percent of the TSS and more than 30 percent of COD in the raw water from the Gran Canal. Helminth removal with CEPT (one to five eggs per liter of effluent) is almost identical to helminth removal with activated sludge (one

9. CNA.

10. Kenneth R. Stott et al., "An Experimental Evaluation of Potential Risks to Human Health from Parasitic Nematodes in Wastewaters Treated in Waste Stabilization Ponds and Used for Crop Irrigation," *Research Monograph in Tropical Health Engineering* (Leeds: University of Leeds, 1994).

Table 7.3 Treatment Technologies for the Reuse of Wastewater

Treatment Process	Effluent Helminth Count* (# eggs/l)	Organic Matter Concentration	Nutrients Concentration	Approximate Cost
Influent	250	high	high	—
Primary sedimentation	40	high	high	low
CEPT	1–5	moderate	moderate	low–moderate
Activated sludge	1–3	low	moderate–low	high
Activated sludge + sand filtration	<1	low	low	extremely high

* Based on Ecatapec helminth analyses and Dunn, "The Development of a Predictive Model for the Removal of Helminth Eggs."

to three eggs per liter). In addition, removal of organic matter and nutrients is sufficiently low to enable the CEPT effluent to be a good fertilizer. Treating Mexico City's raw wastewater with CEPT will protect public health, restore farmers' ability to grow cash crops, and not require artificial fertilizers to maintain the region's fertility. Properly treated wastewater thus becomes not a waste product but a natural resource.

The following conclusions can be drawn from this work:

- CEPT is a highly appropriate process for treating Mexico City's wastewater before its reuse in the irrigation of agricultural land. TSS removal with CEPT (more than 70 percent) would allow for effective chlorination or the use of UV technology with medium-pressure mercury lamps.
- Helminth egg counts with CEPT are consistently at or below five eggs per liter. This ratio equates to a reduction of actual risk of helminth egg infection to lower than the 1 percent currently observed in areas irrigated with lake water.
- The current WHO guidelines for helminth eggs in wastewater may be overly strict, promoting more costly wastewater treatment processes where these are not necessary. A compromise is required that will achieve substantial public health protection but still allow wastewater to be reused as a resource.
- Jar tests of CEPT with Mexico City wastewater can be used to predict full-scale CEPT performance accurately.

8 DRIVING WATER FOR AGRICULTURE

Peter G. McCornick

The global population is projected to reach 9 billion within the next 50 years. It is expected to be wealthier and to demand a diet higher in animal products and fish.[1] The demand for non-food crops is also expected to increase, and the promotion of crops for bioenergy will further expand the agricultural sector.[2] The consequences and trade-offs of likely interventions in the sector have yet to be fully understood, however, especially with regard to water and, ultimately, to the environment.

With wise choices and timely action, it is estimated that global water use in the agricultural sector will increase by only 20 percent.[3] Without such preemptive measures, though, the water used by the agricultural sector could double—with potentially devastating effects on the environment. To secure the necessary agricultural production with less impact on water resources requires farsighted investments in research, bold policy, management changes, and, at least in some parts of South Asia and sub-Saharan Africa, prudent development of infrastructure. Even with these actions, the effect of key drivers in the countries, regions, and the water basins themselves will still be very significant, especially where water is already scarce and countries are relatively poor.

A complex, interlinked set of drivers has affected and will continue to affect the evolution of agricultural systems, their water management, and their capacity to produce. Responses to the recent food crisis have already been transforming the agricultural sector.[4] The effects of the global financial crisis on the agricultural and water sectors have yet to emerge fully.

A number of drivers are particularly important to the agricultural sector, including population and diets; availability and access to markets; policies, institutions, and power; water storage, delivery, and drainage infrastructure; urbanization; agricultural knowledge, science, and technology; global integration and trade; environmental and climate change; and energy production and use.[5]

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1. Charlotte de Fraiture et al., "Looking Ahead to 2050: Scenarios of Alternative Investment Approaches," in *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture,* ed. David Molden (London: Earthscan and International Water Management Institute, 2007), 91–145.
2. Petra Hellegers et al., "Interactions between Water, Energy, Food and Environment," in "Water-Energy-Food-Environment Interface: Synergies and Conflicts," special issue, *Water Policy Journal* 10, no. S1 (2008): 1–10.
3. David Molden, ed., *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture* (London: Earthscan and International Water Management Institute, 2007), 645.
4. Joachim von Braun, "The World Food Situation: New Driving Forces and Required Actions" (paper prepared for the Consultative Group on International Agricultural Research, Annual General Meeting, Beijing, December 3, 2007).
5. Molden, *Water for Food, Water for Life,* 645.

Transformations in Agriculture

The transformations that compel the agricultural sector to adjust to these new realities will differ according to region. Traditionally, the growth of the agricultural sector leads to more general economic development, and as the broader economy grows, the agriculture-based economy becomes less important to the overall national economy, although it usually continues to grow and remain politically important. Generally, agriculture continues to evolve with the emergence of value-added supply chains and a retail sector connected to national, regional, and even international markets and with access to credit, input markets, and improved resources, including water.[6] Agriculture, however, remains important to the poor as a source of inexpensive food and for those in rural areas, livelihoods, either directly or indirectly through the creation of jobs. In many regions, larger commercial agriculture and supermarkets are critical intermediaries for poorer farmers as they seek connection to value-added supply chains.

Urbanization

Rapid urbanization in the developing world, including rural-to-urban migration, influences farming practices and water demand. In the 1960s, two-thirds of the world's population lived in rural areas, and 60 percent of the economically active population worked in agriculture. Today, half of all humans live in rural areas, and just a little more than 40 percent of the economically active population depends directly on agriculture. In absolute terms, the rural population will start to decline in the next few years, and by 2050 two-thirds of the world's people are projected to live in cities. In many developing countries in South Asia and sub-Saharan Africa, though, the rural population will continue to grow until about 2030, and the absolute number of people depending on agriculture will continue to rise.

These demographic trends have several direct and indirect implications for water. Urban population growth increases the demand for drinking and industrial water in urban centers. As a result, more water is reallocated from agriculture, and more wastewater—treated and untreated—returns to surface water systems. When treated, these return flows are increasingly recognized as an important component of the overall water balance for agriculture, especially in water-short basins.[7] In the developing world, however, these expanding volumes of wastewater are rarely treated, even though they are an increasingly important water source for peri-urban farmers. This situation presents a particular set of health and environmental challenges and threatens the markets for high-value fruit and vegetables that are made available through the value-chain discussed above. Indirectly, urbanization can result in encroachment on wetlands and other ecosystems by spurring increased agricultural expansion to feed growing populations. This expansion, in turn, affects the hydrological functionality of wetlands and watersheds, including the provision of clean water services, and can constrain the capacity of the natural system to cope with adverse impacts, such as heightened intensity and frequency of storm surges, floods, and droughts as a result of climate change.

6. Peter Timmer, "Agriculture and Pro-Poor Growth: An Asian Perspective" (Working Paper 63, Center for Global Development, Washington, D.C., 2005).

7. Manzoor Qadir et al., "Agricultural Use of Marginal-Quality Water—Opportunities and Challenges," in *Water for Food, Water for Life: A Comprehensive Assessment of Water Management in Agriculture*, ed. David Molden (London: Earthscan and International Water Management Institute, 2007), 425–453.

Climate Change

The effect of climate change on the relationship between agriculture and water is likely to be significant over the medium to long term, because of a combination of several factors, including changes in water availability, increased demand for crop water resulting from higher temperatures and adjustments to growing seasons, and the loss of productive agricultural areas through more frequent flooding and higher sea levels.

While our understanding of the impact of climate change is still developing and the effects will vary from one region to the next, the direct effects on water for agriculture, including that supplied by direct precipitation, are already felt in many parts of the world: higher intensity and variability of precipitation events, changes in surface flow from snow and ice melt, and variations in precipitation and temperature characteristics that affect surface and groundwater volumes. In some regions, changes in water availability and temperatures will create new opportunities to intensify and expand agriculture. In much of the developing world, however, where the capacity to adapt is least, many agro-ecosystems will be adversely affected.

Improving water management is a basic prerequisite in adaptation to climate change. Where the capacities and resources are available, adaptations such as changing cropping patterns, revised reservoir operations, development of new storage and other infrastructure, and enhanced institutional arrangements such as drought and flood insurance will affect how water is used in the agricultural sector. Where the capacity for adaptation is not present, however, the agricultural sector is likely to remain risk averse and water productivity relatively low, therefore requiring the capture of more water to meet the basic needs of the population.

The specific challenges will range from ensuring the livelihoods and food security of households to regional and global food security, especially when combined with the other major drivers. In the case of the developing world, the rural poor are already particularly vulnerable to climate variation, and the capacity of governments either to improve water availability directly or to facilitate alternative opportunities for maintaining livelihoods and agricultural production is constrained.

Investment Trends

Investments in agricultural water management, in the form of large-scale public facilities, underpinned the green revolution in Asia. In much of South Asia, private and community-based irrigation systems, particularly groundwater pumping, have grown rapidly since the 1980s, propelled by the availability of cheap drilling technology, rural electrification, subsidized energy, and small, inexpensive pumps that farmers can afford themselves. Pumping enabled small-scale irrigation to develop within rain-fed systems and supplement other sources of irrigation water, and in many cases it overcame the head-tail inequities whereby farmers most distant from the source in surface irrigation systems had the least reliable water supply. In India, with 26 million pump owners, the area irrigated by groundwater now exceeds irrigation from surface water systems. As a consequence, however, groundwater has been declining at an accelerated rate,[8] and, when combined with other water-related investments made by many communities and smallholders, groundwater

8. Tushaar Shah, *Taming the Anarchy: Groundwater Governance in South Asia; Resources for the Future* (Washington, D.C.: International Water Management Institute, 2009).

pumping has had a significant impact on the hydrology of some basins[9] and has contributed to the disruption of downstream ecosystems.

The appropriate scale of investments in agricultural water management needs to be determined according to specific environmental, social, and economic conditions and goals. Large projects are often preferred because they generate political support, are important icons in state building, often allow for significant economies of scale, are major investments in poor regions, and allow for the development of water sources unattainable through smaller-scale investments.

Regional Overview: Asia and Africa

South Asia and India

In South Asia, further urbanization and increasing incomes in the emerging economies are expected to continue the trend of increasing food consumption, with diets shifting away from grain toward more animal products and higher-value products, such as fruit and vegetables. Even in largely vegetarian India, consumption of dairy products is already among the highest in the world. As the agricultural sector has continued to grow, it has moved from production of food grains grown in surface irrigation systems toward more diversified products with an increasing reliance on groundwater.[10]

Total annual water withdrawals in India, which are now around 700 billion cubic meters, are projected to increase by more than 20 percent by 2025, with approximately half the increase going to the agricultural sector.[11] According to recent trends, groundwater will continue to be the source of choice, because of its accessibility, reliability, and flexibility—assuming the resource can be sustained. The inherent improvement of water control that groundwater offers, combined with increased adoption of technologies such as micro-irrigation and the declining demand for grain, is expected to result in a gradual decline in demand for irrigation water after 2025.[12]

In the Krishna Basin in southern India, per capita renewable water availability is approximately two-thirds of that of the country as a whole, and the discharge into the lower basin has halved in the past five decades.[13] While large-scale dams and irrigation systems significantly affected the hydrology of the region in earlier decades, more recently declining flows have been attributed to widespread development of community tanks (reservoirs), groundwater, and changes in landscape. While some of the water has been diverted for nonagricultural uses, the vast majority has been used for agriculture and increasingly for higher-value dairy production and sugarcane. This trend has decreased reliability to users in the lower basin and disrupted environmental flows.

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9. Manohar Velpuri et al., *Methods for Mapping Irrigated Areas Using Landsat ETM+ 30 Meter, SRTM 90 Meter, and MODIS 500 Meter Time Series Data Taking Krishna River Basin India* (Colombo, Sri Lanka: International Water Management Institute, 2007).

10. Amarasinghe et al., "India's Water Futures: Business as Usual Scenario and Deviations," in *International Water Management Institute Research Report 123* (Colombo, Sri Lanka: International Water Management Institute, 2007), 41.

11. Ibid.

12. Ibid.

13. Jean-Philipe Venot et al., "Explaining Basin Closure through Shifting Waterscape in the Lower Krishna Basin," in *International Water Management Institute Research Report 121* (Colombo, Sri Lanka: International Water Management Institute, 2007), 50.

Africa

Sub-Saharan Africa is also experiencing growing populations and, in many cases, expanding economies, albeit from a lower base than its South Asian counterparts. While a number of countries continue to focus on achieving basic food security, the increasing demands for diversified products and improved connections to local, regional, and even international markets are all transforming the agricultural systems and driving agricultural water requirements.

Unlike in South Asia, investments in infrastructure for agricultural water management, especially large-scale systems, have been relatively modest, and in the past two decades investments in large systems have almost entirely lost favor.[14] Smaller-scale, community-based interventions in agricultural water management, both irrigated and rain fed, have been and continue to be an important part of rural development in the policies of many African countries.

Ethiopia, for example, is estimated to have renewable freshwater resources of approximately 1,500 cubic meters per capita, primarily from surface water but with some potential for groundwater development. While water is relatively abundant, water security is a major challenge for much of the population due to underinvestment in, among other things, water-related infrastructure and capacity. Without these assets, the shocks of periodic droughts continue to plague the population and strangle long-term economic growth, even beyond the agriculture sector.[15]

Apart from the Awash Valley, where both larger- and small-scale irrigation systems have been developed in the past, smallholdings dependent on rainfall have been the mainstay of the country's agriculture. Recognizing the importance of agricultural water management to Ethiopia's food security, to the broader economy, and to the creation of livelihoods in rural areas, both national and state policy makers have aimed at improving it through legislation in recent years. Such policies have included the expansion of small-scale systems for both surface water and groundwater and the development of a few larger-scale surface water systems in the less well developed basins of the country. Other policies include the intensification and expansion of existing systems in the Awash, particularly to meet national and regional demands for sugarcane. These expansions include linking to small-scale outgrowers in the immediate vicinity. Of course, as in India, the increasing pressure on water resources is creating conflict with downstream users.

One relatively significant change in Ethiopia has been the development of floriculture and horticulture for both export and national markets, taking advantage of, among other things, available water resources and the variety of microclimates in the country. Initially, these operations developed in the Awash and near the Rift Valley lakes, but they are expanding elsewhere. In addition to the export earnings, these specialized farms have been generating jobs in parts of the country where there have been few alternatives to subsistence agriculture. Concurrently, conflicts over water availability and pollution in the Rift Valley lakes have increased.

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14. Arlene Inocencio et al., "Costs and Performance of Irrigation Projects: A Comparison of Sub-Saharan Africa and Other Developing Regions," in *International Water Management Institute Research Report 109* (Colombo, Sri Lanka: International Water Management Institute, 2007), 71.

15. World Bank, *Ethiopia: Managing Water Resources to Maximize Sustainable Growth: Country Water Resources Assistance Strategy* (Washington, D.C.: World Bank, 2006).

Concluding Thoughts

The agricultural sector will be using more water in the next few decades. And while on the global scale some of the more optimistic scenarios project relatively modest increases, in many regions—where the demand for food and opportunities to access markets are expanding—water requirements are likely to be considerable.

Whatever the scale or approach (rain fed or irrigated), given the requirements discussed in this chapter, the effect on water systems will be profound. The major challenge lies in implementing interventions appropriate to the particular conditions, drawing on the lessons from the past, and designing systems with an eye toward adapting to changing conditions, including increased flexibility in agricultural policies, adaptive management, and innovative technologies for coping with greater urbanization, continued globalization, and climate changes.

While the nature of the impacts within a given region depends on how the various drivers play out and interact in that particular setting, including the decisions that are made regarding interventions, the major trade-offs will be between agriculture and the environment, even if the focus is on small-scale farming or enhancing rain-fed systems. The importance of carefully considering the environmental implications of these trade-offs cannot be overstated.

Finally, the most significant challenge in managing water for agriculture lies in ensuring sufficient capacity for decisionmaking, policy development, and implementation strategies tailored to particular conditions. While much is known about how to develop successful interventions in the sector, the major challenge is creating the necessary capacity at all levels—within communities, extension services, nongovernmental organizations, and national agencies—to make informed choices and implement and manage appropriate interventions.

9 SATELLITE-BASED ASSESSMENT OF WATER RESOURCES AND AGRICULTURAL PRODUCTIVITY

Christa D. Peters-Lidard, John D. Bolten, Molly E. Brown,
Chris Funk, Matthew Rodell, David L. Toll, and James P. Verdin

Advances in satellite remote-sensing technologies have enabled monitoring and measurement of Earth's land surface with unprecedented detail and frequency. Such observations provide a huge volume of valuable data in near–real time about conditions on the Earth's surface, including land cover type, vegetation type and health, precipitation, snow, soil moisture, water levels, and radiation. Observations of this sort combined with models and analysis enable satellite-based assessment of water resources and agricultural productivity. Such assessments can subsequently provide policymakers with the time-critical information they need to make more informed decisions on humanitarian and other issues, including early warnings of famine, disaster management, and food security.

NASA's Earth Science Research Program

The National Aeronautics and Space Administration (NASA) supports an Earth science research program that comprises approximately 7 percent of the total NASA budget. This program conducts and sponsors research, collects new observations from space, develops technologies, and promotes science and technology education. The focus of this program is to answer fundamental questions about the changes we observe in climate, weather, and natural hazards and to deliver sound science that informs decisionmakers. NASA satellites provide a global view of Earth's ecosystems from space, and the applied sciences program leverages this national investment in satellite technology to increase the benefits to society through the widest practical use of NASA research. The program works with other government agencies—e.g., the National Oceanic and Atmospheric Administration (NOAA), the Foreign Agricultural Service (FAS) of the U.S. Department of Agriculture (USDA), the U.S. Geological Survey (USGS), and the Air Force Weather Agency (AFWA)—and with universities and nonprofit, international, and private sector organizations to extend the benefits of this research in Earth science. In addition to water resources and agriculture, activities of the program include helping observe, understand, and predict forest fires, coastal environments, impacts of infectious diseases, aviation safety, and risks to public health and providing hurricane forecasting.

Satellite-based assessments of water resources and agricultural productivity focus on three broad areas: (1) water availability; (2) water use; and (3) crop health. Advances in our ability to monitor, understand, and predict water and agricultural status enable us to make integrated assessments, provide more accurate crop monitoring, and result in greater economic security for agriculture, improved warnings of food shortages, increased agricultural efficiency, and better decisions on policy and resource management.

Water Availability

Satellite-based assessments of water availability provide the foundation for evaluating current or potential stress affecting agricultural water. Key components of the hydrological cycle that can be estimated from satellites include precipitation, lake and reservoir heights, soil moisture, snow pack, and groundwater storage.

Precipitation

In many regions of the world, rain gauges are sparse and difficult to access and maintain because of both conflict and costs. Satellite-based measurement of precipitation thus provides a unique source of information about water availability for agriculture. Since 1997, NASA has been providing multisatellite rainfall estimates for most of the globe based on data from the Tropical Rainfall Measurement Mission satellite. As described in Funk et al. and Funk and Verdin,[1] researchers have combined these products with other climate and weather-related tools from NOAA as part of the Famine Early Warning System Network,[2] which is sponsored by the U.S. Agency for International Development (USAID). Similarly, the Air Force Weather Agency's agricultural meteorology system provides combined gauge and satellite-based estimates of precipitation for USDA-FAS. In 2013, NASA will launch the core satellite for a new global precipitation measurement mission, which will significantly advance our capabilities for monitoring precipitation in mid-to-high latitudes, including snowfall and light rain.

Lakes and Reservoirs

Data on water levels for many lakes and reservoirs can be difficult to obtain, given access and resource constraints. Before satellite-based monitoring of lake levels, information on water levels in remote lakes in Africa or Asia was usually possible only if a researcher happened to be passing by the area. Today, USDA-FAS, in cooperation with NASA and the University of Maryland, is routinely monitoring lake and reservoir height variations for approximately 100 lakes around the world. This project uses near-real-time radar altimeter data from the joint Topex/Poseidon and Jason-1/2 satellite missions of NASA and the French space agency (Le Centre National d'Etudes Spatiales), primarily over large inland water bodies (greater than 100 square kilometers).[3]

1. C. Funk, M. Dettinger, J. Michaelsen, J. Verdin, M. Brown, M. Barlow, and A. Hoell, "Warming of the Indian Ocean Threatens Eastern and Southern African Food Security but Could Be Mitigated by Agricultural Development," *Proceedings of the National Academy of Science* 105, no. 32 (2008): 11081–11086; and C. Funk and J. Verdin, "Real-Time Decision Support Systems: The Famine Early Warning System Network," in *Satellite Rainfall Applications for Surface Hydrology*, ed. Gebremichael Mekonnen and Faisal Hossein (New York: Springer, 2009).

2. J. Verdin, C. Funk, G. Senay, and R. Choularton, "Climate Science and Famine Early Warning," *Philosophical Transactions of the Royal Society B: Biological Science* 360 (2005): 2155–2168.

3. Time series of altimetric variations in lake levels are available from the USDA Reservoir Database at http://www.pecad.fas.usda.gov/cropexplorer/global_reservoir.

Soil Moisture

USDA-FAS provides information about important crops around the world. Its forecasts of crop yields allow crucial assessment of U.S. and global agriculture that in turn influences trade policy and food aid. As result, these data help shape decisions made by farmers, businesses, and governments by defining the fundamental conditions in commodity markets.

The accuracy of global crop estimates provided by FAS depends on the coverage, accuracy, and consistency of the data sources used—particularly soil moisture, which is a fundamental variable for crop calendar (growth stage) and crop stress (alarm) models. In the past, the estimates of soil moisture that FAS has used for predicting crop growth have been derived solely from a soil moisture model driven by spatially and temporally interpolated estimates of precipitation and temperature. The lack of direct observations of soil moisture has accounted for uncertain crop forecasts in data-poor regions.

To add to this effort, NASA has teamed with USDA-FAS to develop a global soil moisture product fashioned by integrating observations of soil moisture from its Earth Observing Satellite into the USDA-FAS soil moisture model. Tests of this approach over the continental United States show that this technique is able to compensate effectively for the impact of poorly observed rainfall patterns.[4]

Snow Pack

Snow pack properties important for joint water resource and agricultural productivity assessments include estimates of snow-covered areas as well as snow water equivalent. Today, instruments on two NASA satellites are able to sense these critical water quantities remotely: they can measure snow-covered areas globally at a spatial resolution of 500 meters. The instrument that measures soil moisture is also able to measure the snow water equivalent for snow-covered regions at a resolution of approximately 25 kilometers. As shown by Zaitchik and Rodell, assimilating snow-covered areas into a land surface model can produce more reasonable estimates of the snow water equivalent.[5]

Groundwater

In many regions of the world, water extracted from the ground is increasingly supplementing rain-fed agricultural systems. Similarly, groundwater wells are a critical source of potable water, particularly in drought-stressed regions. Because groundwater aquifers represent a scarce resource for sensitive areas, cross political boundaries, and reside underground, access to data on groundwater is generally much more difficult than access to data on precipitation. Recent work with data from another NASA system of satellites, however, has shown that information about gravity anomalies caused by variations in terrestrial water storage can be combined with advanced hydrological

4. John D. Bolten, Wade T. Crow, Xiwu Zhan, Curt A. Reynolds, and Thomas J. Jackson, "Assimilation of a Satellite-Based Soil Moisture Product into a Two-Layer Water Balance Model for a Global Crop Production Decision Support System," in *Data Assimilation for Atmospheric, Oceanic and Hydrologic Applications,* ed. Seon K. Park and Liang Xu (Berlin: Springer-Verlag, 2009), 449–464.

5. B.F. Zaitchik and M. Rodell, "Forward-Looking Assimilation of MODIS-Derived Snow-Covered Area into a Land Surface Model," *Journal of Hydrometeorology* 10 (2009): 130–148.

models to infer groundwater levels. Zaitchik et al. have shown that combining data on groundwater with a hydrological model using a process known as data assimilation yields improved estimates of terrestrial water storage, river flow, and groundwater levels for large (200,000–1,000,000 kilometer^2) river basins, such as the Mississippi River and its four major subbasins.[6]

Water Use

Remote monitoring of water use is the second important component of satellite-based assessment of water resources and agricultural productivity. Two important examples include detecting and estimating water used in irrigation and evaluating evapotranspiration (or water consumption) in agricultural areas.

Irrigation Detection and Modeling

Although irrigated areas currently cover a small fraction of total agricultural land, lower-cost irrigation technologies, access to groundwater from wells, and increasing climate variability and drought stress will tend to promote the practice of irrigated agriculture. Irrigation reporting is difficult to verify and sparse to nonexistent in many parts of the world. Therefore, satellite-based detection of irrigation is an important information source for integrated water-agriculture assessment. Recent work by Ozdogan and Gutman[7] demonstrates that irrigation mapping is possible for the first time using the specialized instrument designed for detection of snow-covered areas combined with globally available ancillary sources of gridded climate and agricultural data and an advanced image classification algorithm.

Currently, irrigation can be detected under dryland conditions—excluding irrigated pastures, paddy rice fields, and other semiaquatic crops—by detecting changes in the evolution of greenness between irrigated and nonirrigated crops along with moisture stress. Evaluation of the technique over the continental United States shows a strong correlation with a small bias and an estimated error of a little over 2 percent. Recent work by Ozdogan, Rodell, and Kato[8] has shown that this irrigation detection technique can be combined with a model to estimate the water used for irrigation, improve model temperatures, and estimate changes in evapotranspiration due to irrigation.

Evapotranspiration and Water Stress

In addition to the model-based approach related to irrigation, combining satellite-based estimates of solar and atmospheric radiation, surface temperature, and vegetation greenness yields independent estimates of evapotranspiration and water stress in agricultural areas. Many of these techniques are available, as described in two recent studies.[9] These analyses show that the technique is

6. B.F. Zaitchik, M. Rodell, and R.H. Reichle, "Assimilation of GRACE Terrestrial Water Storage Data into a Land Surface Model: Results for the Mississippi River Basin," *Journal of Hydrometeorology* 9 (2008): 535–548.

7. M. Ozdogan and G. Gutman, "A New Methodology to Map Irrigated Areas Using Multi-Temporal MODIS and Ancillary Data: An Application Example in the Continental US," *Remote Sensing of Environment* 112 (2008): 3520–3537.

8. Personal communication.

9. See G.B. Senay, J.P. Verdin, R. Lietzow, and A.M. Melesse, "Global Daily Reference Evapotranspiration Modeling and Validation," *Journal of the American Water Resources Association* 44, no. 4 (2008): 969–

accurate at daily timescales and even more so at 10-day timescales, which are common for yield analysis.

Crop Health

The third and final area of satellite-based assessment of water resources and agricultural productivity is that of crop health. The two major remotely sensed variables in this topic are type of land and leaf area (or green biomass). As Myneni et al. describe,[10] sensors can be used to determine land cover as well as vegetation leaf area. These vegetation products are typically derived from a commonly used index known as the normalized difference vegetation index, which is the difference of spectral reflectance measurements acquired in the near-infrared and red regions divided by the sum of the reflectances.

Recent work by Funk and Budde has shown that multiple seasonal estimates of vegetation type and leaf area from remote-sensing satellites can be used to monitor and predict crop production anomalies in Africa by country.

Future Directions

As Brown and Funk have stated, "Food insecurity is likely to increase under climate change, unless early warning systems and development programs are used more effectively."[11] Advances in remote sensing techniques, land surface modeling, and data assimilation for water resources and agricultural assessments must be fully and readily integrated into systems such as the Famine Early Warning System Network. Recognizing this need, NASA is working with its agency partners at USGS, USAID, AFWA, NOAA, and USDA to transition and integrate the techniques embodied in our Land Information System[12] with the Famine Early Warning System Network and USDA-FAS systems. By merging our efforts at satellite observation, modeling, and data assimilation, we can significantly advance our ability to understand, predict, and respond to stressed water resources and the associated impacts and feedbacks on agricultural productivity through a comprehensive and integrated approach.

979; and G.B. Senay, M.E. Budde, J.P. Verdin, and A.M. Melesse, "A Coupled Remote Sensing and Simplified Surface Energy Balance Approach to Estimate Actual Evapotranspiration from Irrigated Fields," *Sensors* 7 (2007): 979–1000.

10. R.B. Myneni, R.R. Nemani, and S.W. Running, "Algorithm for the Estimation of Global Land Cover," *IEEE Transactions on Geosciences and Remote Sensing* 35 (1997): 1380–1393; and R.B. Myneni, S. Hoffman, Y. Knyazikhin, J.L. Privette, J. Glassy, Y. Tian, Y. Wang, X. Song, Y. Zhang, G.R. Smith, A. Lotsch, M. Friedl, J.T. Morisette, P. Votava, R.R. Nemani, and S.W. Running, "Global Products of Vegetation Leaf Area and Fraction Absorbed PAR from Year One of MODIS Data," *Remote Sensing of the Environment* 83 (2002): 214–231.

11. M. E. Brown and C. Funk, "Food Security under Climate Change," *Science* 319 (2008): 580–581.

12. S.V. Kumar, C.D. Peters-Lidard, Y. Tian, J. Geiger, P.R. Houser, S. Olden, L. Lighty, J. L. Eastman, P. Dirmeyer, B. Doty, J. Adams, E. Wood, and J. Sheffield, "LIS—An Interoperable Framework for High Resolution Land Surface Modeling," *Environmental Modeling and Software* 21 (2006): 1402–1415; and C.D. Peters-Lidard, P. R. Houser, Y. Tian, S.V. Kumar, J. Geiger, S. Olden, L. Lighty, B. Doty, P. Dirmeyer, J. Adams, K. Mitchell, E.F. Wood, and J. Sheffield, "High Performance Earth System Modeling with NASA/GSFC's Land Information System," *Innovations in Systems and Software Engineering* 3, no. 3 (2007): 157–165.

10 IMPACT SYNERGIES AND INSTITUTIONAL ROLES
EMPIRICAL EVIDENCE FROM SRI LANKA

R. Maria Saleth

Two major gaps persist in the literature on development impact and institutional analysis: inadequate attention to the impact of synergies among closely related development programs and insufficient understanding of the roles that formal institutions play in generating and transmitting impact.[1] This chapter summarizes my recent attempt, with Ariel Dinar, to fill these gaps by both developing a methodology to capture the impact synergies and institutional roles within a unified framework and applying that methodology in the context of Kala Oya Basin in Sri Lanka to provide some empirical numerical evidence. We approach this task by taking food security as the development goal and then examining three development programs (system rehabilitation, bulk water delivery, and crop diversification) and 11 institutions (land tenure, water institutions, customs, farm inputs supply systems, rural markets, price regulations, wage legislations, and rural development, trade, farm subsidy, and poverty alleviation policies).

Methodological Framework

Despite their limitations in treating impact synergies and institutional roles, existing methods of impact assessment and institutional analysis have useful analytical components for building the proposed methodology.[2] For instance, the approach for evaluating multiple programs in the Method for Impact Assessment of Programs and Projects (MAPP)[3] can be combined with that of the Poverty and Social Impact Assessment (PSIA) method that details impact pathways and

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This chapter is a summary of a longer work: R.M. Saleth and Ariel Dinar, *Quantifying Institutional Impacts and Development Synergies in Water Resource Programs: A Methodology with Application to the Kala Oya Basin, Sri Lanka,* World Bank Policy Research Working Paper 4498 (Washington, D.C.: World Bank, 2008). Excerpts are used with permission of the International Bank for Reconstruction and Development, The World Bank.

1. Defined as systems of legal, policy, and organizational components affecting human behavior. See Douglass C. North, *Institutions, Institutional Change, and Economic Performance* (Cambridge, Mass.: Cambridge University Press, 1990); and Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge: Cambridge University Press, 1990).

2. For a review of these limitations, see Judy L. Baker, *Evaluating the Impact of Development Projects on Poverty: A Handbook for Practitioners,* Directions in Development Series (Washington, D.C.: World Bank, 2000); and R.M. Saleth and Ariel Dinar, *Quantifying Institutional Impacts and Development Synergies in Water Resource Programs: A Methodology with Application to the Kala Oya Basin, Sri Lanka*, World Bank Policy Research Working Paper 4498 (Washington, D.C.: World Bank, 2008).

3. In the MAPP method, stakeholders award points on criteria related to one or more programs and their impacts on development goal; for details, see Susanne Neubert, *Social Impact Analysis of Poverty Alleviation Programs and Projects* (Illford, Essex: Frank Cass, 2000).

institutions.[4] For building the institutional dimension of the proposed methodology, we adapt our own framework as defined by the institutional ecology principle, institutional decomposition and analysis, and adaptive instrumental evaluation.[5] By combining these analytical and empirical elements, we obtain a methodology centered on a system model of interactions between institutions and impacts that captures a set of well-defined impact pathways.[6]

Empirical Context and Model Specification

For empirical context, we selected the Kala Oya Basin in Sri Lanka, a small land area of 287,303 hectares with a population of 0.41 million. Owing to soil and water-related problems, only a third of the area is cultivated, and that is mostly for paddies (40 percent); 38 percent of the population is landless. With low rainfall (50 to 300 millimeters) and hard groundwater, water scarcity is serious. While basin water demand is 1,695 million cubic meters, its supply is only 823 million cubic meters. The poverty incidence remains high, with 20 percent of the population below the poverty line ($14 per capita per month), and many villages are quite vulnerable to food insecurity.

Food security is the major development challenge of the basin, while efficient water use and rural diversification are its main development needs. For specifying the system model, it is reasonable to take food security as the goal and system rehabilitation (completed), bulk water delivery (piloted), and crop diversification (planned) as candidate programs. With this choice, we can delineate the impact pathways and also identify the institutions influencing the generation of impact and operating in the process of impact transmission. Figure 10.1 depicts these impact pathways and their underlying institutions. There are 21 verifiable impact pathways, which can be formally characterized by using the appropriate chains of developmental, institutional, and impact variables listed in table 10.1.

While more details on the nature and definition of these variables are given in Saleth and Dinar,[7] here, it is sufficient to say that all the variables are defined essentially in a notional and qualitative sense to be evaluated on a 1–10 scale, where 1 is the lowest and 10 the highest value. Thus, each variable captures the overall evaluation of the status, change, and effectiveness of a developmental, institutional, or impact aspect. With these variables, the 21 impact pathways in figure 10.1 can be formalized as a system model:

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4. The PSIA method identifies impact pathways or channels such as prices and wages, employment, access to goods and services, assets, transfers and taxes, and authority. For details, see Aline Coudouel, Anis A. Dani, and Stefano Paternostro, eds., *Poverty and Social Impact Analysis of Reforms: Lessons and Examples from Implementation* (Washington, D.C.: World Bank, 2006).

5. The institutional ecology principle allows one to view regional and basin institutions as a nested system. The institutional decomposition analysis framework analytically unbundles both the impact transmission process and its underlying institutional configurations. The "adaptive instrumental evaluation" legitimizes the use of perception-based data. For details, see Daniel Kahneman and Amos Tversky, "Choices, Values, and Frames," *American Psychologist* 39, no. 4 (1984): 341–350.

6. These pathways capture the routes of impact transmission. For a water development program, for instance, there can be a production route (e.g., irrigation-cropping intensity-productivity-food supply), income route (irrigation-productivity-employment-income), and price routes (irrigation-production-food prices). These pathways can be characterized by a set of developmental, impact, and institutional variables.

7. Saleth and Dinar, *Quantifying Institutional Impacts and Development Synergies in Water Resource Programs*.

Figure 10.1 Institution-Impact Interactions with Three Development Programs

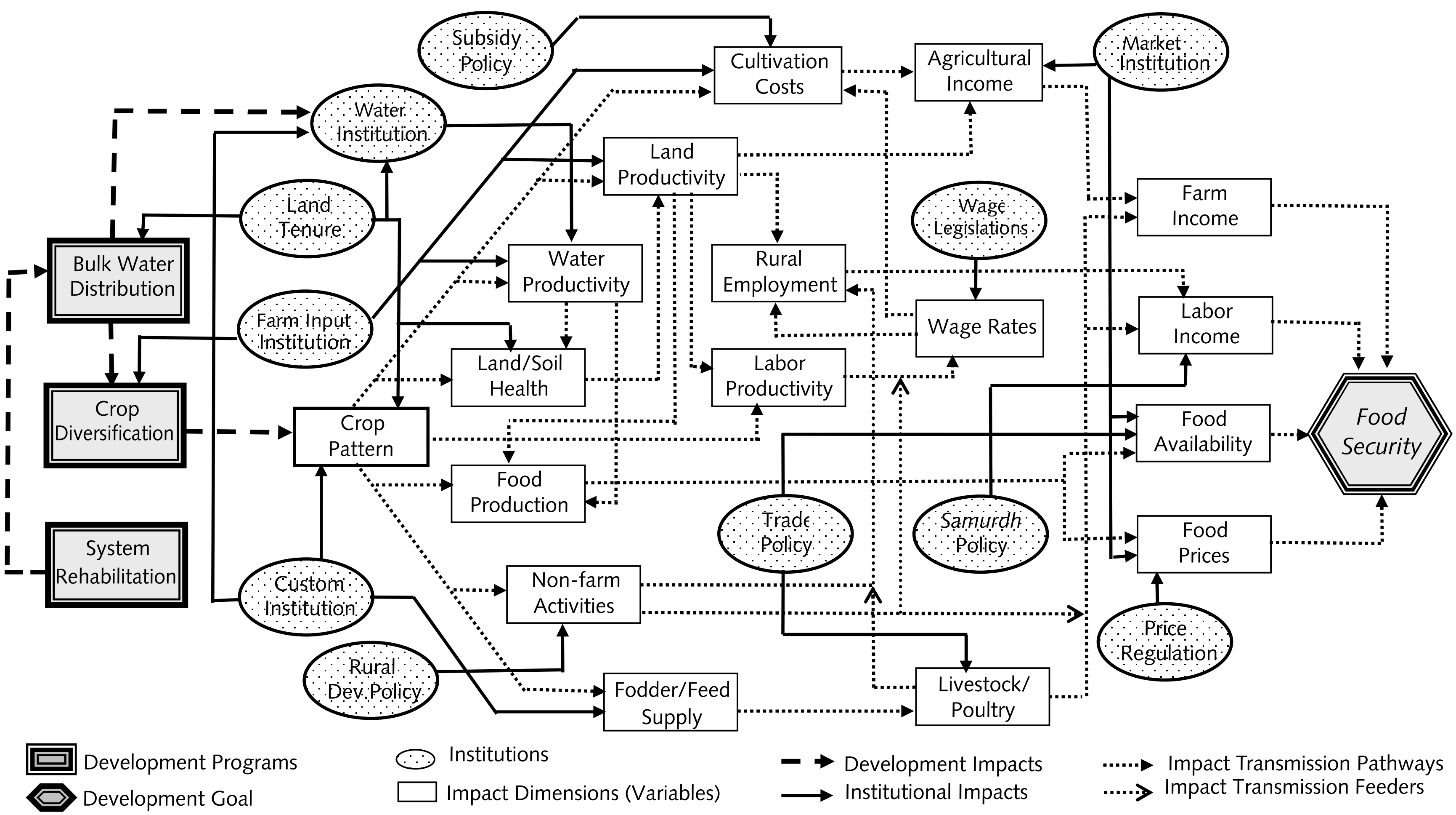

Table 10.1 Definition of Model Variables

Categories	Variable Names	Acronyms
Development Goal	Food Security	FOODSECT
Development Programs	System Rehabilitation	SYSREHAB
	Bulk Water Distribution	BULKWATD
	Crop Diversification	CROPDIVR
Impact Variables	Crop Pattern	CROPATEN
	Land Productivity	LANPRODY
	Water Productivity	WATPRODY
	Labor Productivity	LABPRODY
	Rural Employment	RURALEMP
	Wage Rates	WAGERATE
	Cultivation Costs	CULTCOST
	Agricultural Income	AGLINCOM
	Land and Soil Quality	LANHELTH
	Food Production	FOODPROD
	Non-farm Enterprises	NFAMENTS
	Fodder & Feed Supply	FEDSUPLY
	Livestock/Poultry	LIVSTOCK
	Farm Income	FAMINCOM
	Labor Income	LABINCOM
	Food Availability	FOODAVAL
	Food Price	FOODPRIC
Institutional Variables	Land Tenure	LANTENUR
	Water Institutions	WATINSTN
	Customary Institutions	CUSINSTN
	Farm Input Institutions	FAMINSTN
	Market Institutions	MKTINSTN
	Price Regulations	PRICREGL
	Wage/Labor Legislations	WAGELAWS
	Rural Development Policy	RDVPOLCY
	Trade Policy	TRDPOLCY
	Farm Subsidy Policy	SUBPOLCY
	Samurdhi Policy	SAMPOLCY

BULKWATD	=	f_1 (SYSREHAB, LANTENUR)	[10.1]
CROPDIVR	=	f_2 (BULKWATD, FAMINSTN)	[10.2]
CROPATEN	=	f_3 (CROPDIVR, LANTENUR, CUSINSTN)	[10.3]
WATINSTN	=	f_4 (BULKWATD, LANTENUR, CUSINSTN)	[10.4]
WATPRODY	=	f_5 (CROPATEN, WATINSTN, FAMINSTN)	[10.5]
LANHELTH	=	f_6 (CROPATEN, WATPRODY, LANTENUR)	[10.6]
LANPRODY	=	f_7 (CROPATEN, LANHELTH, FAMINSTN)	[10.7]
FEDSUPLY	=	f_8 (CROPATEN, CUSINSTN)	[10.8]
LIVSTOCK	=	f_9 (FEDSUPLY, TRDPOLCY)	[10.9]
NFAMENTS	=	f_{10} (CROPATEN, RDVPOLCY)	[10.10]
LABPRODY	=	f_{11} (LANPRODY, CROPATEN)	[10.11]
WAGERATE	=	f_{12} (LABPRODY, NFAMENTS, WAGELAWS)	[10.12]
RURALEMP	=	f_{13} (LANPRODY, WAGERATE, NFAMENTS, LIVSTOCK)	[10.13]
CULTCOST	=	f_{14} (CROPATEN, WAGERATE, FAMINSTN, SUBPOLCY)	[10.14]
AGLINCOM	=	f_{15} (LANPRODY, CULTCOST, MKTINSTN)	[10.15]
FAMINCOM	=	f_{16} (AGLINCOM, NFAMENTS, LIVSTOCK)	[10.16]
LABINCOM	=	f_{17} (RURALEMP, NFAMENTS, LIVSTOCK, SAMPOLCY)	[10.17]
FOODPROD	=	f_{18} (CROPATEN, LANPRODY, WATPRODY)	[10.18]
FOODAVAL	=	f_{19} (FOODPROD, TRDPOLCY, MKTINSTN)	[10.19]
FOODPRIC	=	f_{20} (FOODPROD, PRICREGL, MKTINSTN)	[10.20]
FOODSECT	=	f_{21} (FOODAVAL, FOODPRIC, FAMINCOM, LABINCOM)	[10.21]

The sequential links among these equations allow a single-equation reduced form for the system model. Such an equation can track the effect of a change in a variable within the system.

Evidence for Impact Synergies and Institutional Roles

Although the system model is appealing, there are data problems for its estimation. Observed data are absent for many variables, and, even when available, they represent the past and are thus unable to capture the dynamic elements. But highly relevant information is constantly processed, stored, and shared by officials, researchers, and beneficiaries. Since the use of this latent information has both legitimacy and precedence,[8] we elicited them through a questionnaire administered to a sample of 67 stakeholders involved in the regional development process.[9] With this data set, the system model was estimated under a three-stage least-squares procedure. Using a reduced-

8. For the theoretical legitimacy that comes from the subjective nature of institutions, see Mary Douglas, *How Institutions Think* (New York: Syracuse University Press, 1986); and Elinor Ostrom, *Governing the Commons: The Evolution of Institutions for Collective Action* (Cambridge: Cambridge University Press, 1990). For the definition of stakeholders as "agents of institutional change," see North, *Institutions, Institutional Change, and Economic Performance*. For insight into the human practice of "adaptive instrumental evaluation," see Kahneman and Tversky, "Choices, Values, and Frames." For more details, see R.M. Saleth and Ariel Dinar, *The Institutional Economics of Water: A Cross-Country Analysis of Institutions and Performance* (Cheltenham: Edward Elgar, 2004).

9. The sample covers government officials (32), researchers (32), and community leaders (3). The questionnaire used is reproduced in Saleth and Dinar, *Quantifying Institutional Impacts and Development Synergies in Water Resource Programs*.

Table 10.2 Size and Flow of Development Impacts and Synergies

Endogenous Variables	Equation Numbers	Development Programs: System rehabilitation	Bulk water delivery	Crop diversification	Total Effects Received
BULKWATD	*y*1	0.886	-	-	0.886
CROPDIVR	*y*2	0.526	0.594	-	1.120
CROPATEN	*y*3	0.231	0.261	0.438	0.930
WATINSTN	*y*4	0.754	0.851	-	1.605
WATPRODY	*y*5	0.379	0.427	0.481	1.287
LANHELTH	*y*6	0.366	0.346	0.172	0.884
LANPRODY	*y*7	0.334	1.289	0.583	2.206
FEDSUPLY	*y*8	0.189	0.213	0.395	0.797
LIVSTOCK	*y*9	0.116	0.130	0.220	0.466
NFAMENTS	*y*10	0.268	0.302	0.509	1.079
LABPRODY	*y*11	0.374	0.035	0.522	0.931
WAGERATE	*y*12	0.280	0.310	0.484	1.074
RURALEMP	*y*13	0.229	0.261	0.426	0.916
CULTCOST	*y*14	0.278	0.417	0.655	1.350
AGLINCOM	*y*15	0.313	0.106	0.166	0.585
FAMINCOM	*y*16	0.262	0.081	0.137	0.480
LABINCOM	*y*17	0.275	0.782	0.249	1.306
FOODPROD	*y*18	0.239	0.296	0.390	0.925
FOODAVAL	*y*19	0.108	0.133	0.176	0.417
FOODPRIC	*y*20	0.113	0.140	0.185	0.438
FOODSECT	*y*21	0.011	0.226	0.395	0.632
Total Effects Generated		6.531	7.200	6.583	20.314

form single equation and the estimated coefficients of the system model, we can provide numerical evidence for both impact synergies and institutional effects.

By differentiating the reduced-form equation with respect to 3 development and 11 institutional variables, we can evaluate the impact synergies (table 10.2) and institutional effects (table 10.3). Although a lengthy derivative lies behind each cell, we have an intuitive way to see how the number in each cell is derived. For instance, the first cell in table 10.2 shows the marginal effect of SYSREHB on BULKWATD. Since BULKWATD is the dependent variable in the first equation of the system, the marginal effect is just the coefficient of SYSREHAB (0.886). Similarly, the second cell of the first column is the marginal effect of SYSREHAB on CROPDIVR. SYSREHAB affects only CROPDIVR indirectly via BULKWATD (see equations $y1$ and $y2$). The relevant marginal effect will be 0.526, which is the product of the coefficients of SYSREHAB (0.886) and that of BULKWATD (0.594). Similar procedures are used to obtain the values in each cell of both tables. The row totals are the total impacts captured by the 21 dependent variables (both tables), whereas

Table 10.3 Size and Flow of Institutional Impacts

Endogenous Variables	Equation Number	Institutional Variables										Total Effect Received
		LANTENUR	CUSINSTN	FAMINSTN	MKTINSTN	PRICREGL	WAGELAWS	RDVPOLCY	TRDPOLCY	SUBPOLCY	SAMPOLCY	
BULKWATD	y1	0.056	-	-	-	-	-	-	-	-	-	0.056
CROPDIVR	y2	0.033	0.385	-	-	-	-	-	-	-	-	0.418
CROPATEN	y3	0.156	0.446	0.169	-	-	-	-	-	-	-	0.771
WATINSTN	y4	0.034	-0.058	-	-	-	-	-	-	-	-	-0.024
WATPRODY	y5	0.177	0.481	0.232	-	-	-	-	-	-	-	0.890
LANHELTH	y6	0.117	0.618	0.252	-	-	-	-	-	-	-	0.987
LANPRODY	y7	0.149	0.593	0.142	-	-	-	-	-	-	-	0.884
FEDSUPLY	y8	0.128	0.518	0.139	-	-	-	-	-	-	-	0.785
LIVSTOCK	y9	0.078	0.318	0.085	-	-	-		0.028	-	-	0.509
NFAMENTS	y10	0.181	0.519	0.196	-	-	-	0.107	-	-	-	1.003
LABPRODY	y11	0.145	0.648	0.129	-	-	-	-	-	-	-	0.922
WAGERATE	y12	0.119	0.493	0.111	-	-	0.222	0.015	-	-	-	0.960
RURALEMP	y13	0.140	0.391	0.148	-	-	-0.114	0.073	0.013	-	-	0.879
CULTCOST	y14	0.114	0.487	0.088	-	-	0.233	0.016	-	-0.045	-	0.427
AGLINCOM	y15	0.136	0.553	0.121	0.097	-	0.092	0.006	-	-0.018	-	0.987
FAMINCOM	y16	0.146	0.498	0.147	0.040	-	0.038	0.049	0.004	-0.007	-	0.915
LABINCOM	y17	0.174	0.451	0.186	-	-	-0.089	0.116	-0.022	-	0.061	0.877
FOODPROD	y18	0.152	0.395	0.182	-	-	-	-	-	-	-	0.729
FOODAVAL	y19	0.069	0.178	0.082	0.319	-	-	-	0.160	-	-	0.808
FOODPRIC	y20	0.072	0.187	0.086	0.131	0.257	-	-	-	-	-	0.733
FOODSECT	y21	-0.003	0.055	0.004	0.332	0.130	0.106	-0.086	0.146	-0.004	-0.059	0.621
Total Effects Generated		2.373	8.156	2.499	0.919	0.387	0.250	0.296	0.329	-0.074	0.002	15.255

the column totals are the total impacts generated by programs (table 10.2) and those by institutions (table 10.3).[10]

Table 10.2 shows the marginal impacts of the development programs, which capture both the impacts of individual programs and the synergies from their counterparts. The synergy derived by BULKWATD (0.886) is just the direct impact of SYSREHAB. But that derived by CROPDIVR (1.120) is the sum of both the direct impact of BULKWATD (0.594) and the indirect effects of SYSREHAB (0.526). Since CROPDIVR, unlike BULKWATD, has two routes for synergies, its total development synergy is more than that of the latter. Obviously, some variables (LANPRODY, WATINSTN, CULTCOST, LABINCOM, and WATPRODY) capture these effects more than others (FOODSECT, FOODAVAL, FOODPRIC, and FAMINCOM).

As shown in table 10.3, the marginal effects caused by institutional variables differ by location and nature of interaction. For instance, the downstream institutions (MKTINSTN, PRICREGL, and TRDPOLCY), which affect only a few equations, have a larger impact on food security than the upstream institutions (LANTENUR, CUSINSTN, and FAMINSTN) that affect most equations. This difference is due to the impact dissipation caused by lengthy impact chains, weak impact links, and en route impact distortions. Although institutions with proximate effects receive policy attention, it is also necessary to minimize impact dissipation by strengthening the distortion-prone impact pathways.

Concluding Remarks

This chapter summarizes the attempt of Saleth and Dinar to develop and empirically demonstrate a methodology useful for evaluating impact synergies and institutional roles. The analytics of this methodology and its mathematical replica of the system model provide considerable insights into the inner dynamics of the generation and transmission of impacts. The main policy message of this chapter is that when a new development program for a given region is under consideration, it is crucial for planners to take stock of the potential synergies from past, ongoing, and planned programs with closely related development goals. This methodology can help in implementing development programs, especially in the packaging and sequencing of programs as well as in strengthening the institutional configurations that underlie weak impact pathways.

10. These totals are the cumulative (ripple) effects created by a marginal change in one variable on the entire system. Their magnitude depends on (1) the number of links this variable has with others; (2) the length of the impact chains; and (3) the size and sign of the coefficients of variables in those channels.

11 AGRICULTURE AND WATER ELEMENTS FROM THE UN WORLD WATER DEVELOPMENT REPORT

Olcay Ünver

Agriculture and its demand for water are driven by such fundamental processes as growing population, changes in dietary preferences as living standards rise, and increased demand for non-food agricultural products like bioenergy. The resulting evolution in agricultural practices can also be influenced by technological innovation and agricultural and trade policies, all of which eventually affect the quality and quantity of water. Growing uncertainty linked to the effects of climate change adds to the complexity.

The increasing demand for agricultural products to satisfy the needs of a growing population continues to be the main driver behind water use. Although the world's population growth has slowed since the 1970s and is expected to continue its downward trend, steady economic development—particularly in emerging market economies—has translated into demand for a more varied diet, including meat and dairy products, putting additional pressure on water resources.

Growth in world demand for food mirrors population growth, progressively declining from 2.2 percent a year in the last decades of the twentieth century and projected to decline to 1.6 percent in 2015, 1.4 percent in 2015–2030, and 0.9 percent in 2030–2050. However, these global figures hide extremely large variations, with developing countries growing faster than developed countries. The old challenge of increasing and securing food supply remains a priority in many countries as the number of people suffering from hunger remains substantial, most of them in rural areas of South Asia and sub-Saharan Africa. Countries with high population growth rates and limited agricultural resources will likely see their food deficit increase, with serious implications for economic and food security.[1]

The past 50 years have seen a dramatic increase in water development for agriculture. Development in hydraulic infrastructure (dams and large-scale public irrigation structures) as well as private and community schemes (particularly, groundwater pumping) have put water at the service of populations as part of the global effort to rapidly increase staple food production, ensure food self-sufficiency, and avoid famines. As the global population grew from 2.5 billion in 1950 to 6.5 billion at the beginning of the twenty-first century, the increase in food production outstripped population growth, irrigated areas doubled (particularly in Asia with the green revolution), and water withdrawals tripled. Today, irrigated agriculture covers 275 million hectares—about 20 percent of all cultivated land—and accounts for 40 percent of global food production.

1. World Water Assessment Program and United Nations Educational, Scientific and Cultural Organization (UNESCO), *Water in a Changing World,* United Nations World Water Development Report 3 (Paris: UNESCO Publishing and Earthscan, March 2009), http://www.unesco.org/water/wwap/wwdr/wwdr3/ pdf/WWDR3_Water_in_a_Changing_World.pdf.

Today, agriculture accounts for 70 percent of freshwater withdrawals from rivers, lakes, and aquifers—and more than 90 percent in some developing countries. Furthermore, unlike in industrial and domestic uses where most of the water returns to rivers after use, in agriculture a large part of water is consumed by evapo-transpiration. With rising living standards and urbanization, consumption of meat and dairy products will continue to rise (it has more than tripled in China over the recent decades). Part of the current pressure on water resources comes from an increasing demand for animal feed.

This success in agricultural production led to a 30-year decline in food prices in most countries, a trend that lasted until very recently. In real terms, food prices declined, until recently, to their lowest levels in history, so that consumers in many countries could eat better while spending less of their budget on food. Today, food supply accounts for a small part of average household income in rich countries, but it can constitute as much as 80 percent of income of poor people in developing countries. Declining food prices, high agricultural productivity, improved trade and markets, and progressive reduction in the risk of food shortage and famines also led to reduced investment in agriculture, particularly in irrigation, resulting in neglected maintenance of public irrigation schemes and a sharp slowdown in the growth of irrigated agriculture.

Recent increases in the prices of the main agricultural commodities (between September 2007 and March 2008) have caused the number of people suffering from hunger to rise from 850 million to 963 million. Surges in food prices thus hurt the poorest populations the most. Should food prices remain high, investment in agriculture, including water development for irrigation, is likely to grow. Higher food prices, as a result, may represent an opportunity for smallholder farmers if the right policies are adopted.

The "High-Level Conference on World Food Security: The Challenges of Climate Change and Bioenergy," the Food and Agriculture Organization's June 2008 summit in Rome, adopted a declaration acknowledging "an urgent need to help developing countries and countries in transition expand agriculture and food production, and to increase investment in agriculture, agribusiness and rural development, from both public and private sources."[2]

To meet these future food needs, pressure to develop new supply sources or increase water allocation to agriculture will continue. The latest projections available show an average increase of 0.6 percent a year in irrigated land from 1998 until 2030, compared with 1.5 percent over the 1950s through 1990s. In the same period (1998–2030), because of continued increases in agricultural productivity, 36 percent more food will be produced with 13 percent more water. Crop and animal breeding and biotechnology have already resulted in tremendous gains in yields, along with savings in production costs and pesticide use through improved resistance of genetically modified crops. Common grains such as wheat, maize and rice, which achieved significant gains from the 1960s to 1980s, are unlikely to see further gains.

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2. See "Declaration of the High-Level Conference on World Food Security: The Challenge of Climate Change and Bioenergy," http://www.fao.org/fileadmin/user_upload/foodclimate/HLCdocs/declaration-E.pdf.

New Challenges for Agriculture: Energy and Climate Change

Climate change and the recent acceleration in biofuel production bring new challenges to agriculture and put further pressure on land and water resources. In a tighter global food market, where an increasing number of major agricultural systems are reaching the limits of their productive capacity, climate events increasingly influence food prices, with devastating social and humanitarian consequences.

The potential impact of biofuel production on land and water resources varies with local agroclimatic conditions and policies. The potential impact on freshwater resources is greatest where agricultural production depends on irrigation and is practically negligible where rainfed production is practiced. Where agriculture requires irrigation, increased production of biofuel could result in reduced water allocation to other crop commodities.

Globally, irrigation water allocated to biofuel production is estimated at 44 cubic kilometers (km3), or 2 percent of all irrigation water. Under current production conditions it takes an average of roughly 2,500 liters of water (about 820 liters of it irrigation water) to produce 1 liter of liquid biofuel (the same amount needed on average to produce food for one person for one day). But regional variations can be substantial, depending primarily on the relative percentage of irrigation in biofuel crop production. The share of irrigation water used for biofuel production is negligible in Brazil and the European Union and is estimated to be 2 percent in China and 3 percent in the United States. In India, where sugarcane is fully irrigated, nearly 3,500 liters of water are withdrawn for each liter of ethanol produced. The markets for biofuel and agricultural products are strongly meshed. Because of crop substitutability, all crops tend to compete for the same inputs, land, fertilizers and irrigation water, and farmers select crops that offer the best return on their investment.

Implementing all current national biofuel policies and plans would take 30 million hectares of cropland and 180 km3 of additional irrigation water. Although globally less than a few percentage points of total area and water use, the impacts could be large for some countries, including China and India, and for some regions of large countries, such as the United States.

More Uncertainty for Agriculture under Climate Change

The issues of agricultural production are complicated by increasing climate uncertainty. The relationship between agriculture and climate change is complex. Agriculture contributes to global warming through emissions of methane and nitrous oxide. Changes in land use practices (management of cropland and grazing land) are considered to be the best mitigation options. Agriculture is also extremely sensitive to climate change, and it is anticipated that large areas of croplands, in particular in semi-arid zones, will need to adapt to new conditions with lower precipitation. Climate change is expected to alter hydrologic regimes and patterns of freshwater resource availability, with impacts on both rainfed and irrigated agriculture. Projections converge in indicating a reduction in precipitation in semi-arid areas, greater variability in rainfall distribution, greater frequency of extreme events and rising temperature, particularly affecting agriculture in low latitudes. Severe reductions in river runoff and aquifer recharge are expected in the Mediterranean basin and in the semi-arid areas of Southern Africa, Australia and the Americas, affecting water availability for all uses.

Changes in runoff affect water availability in rivers and aquifers, placing an additional burden on areas where human pressure on water resources is already high. In addition, rising temperatures and lower precipitation associated with diminishing runoff will increase crop water demand in irrigated areas. The impacts of climate change on irrigation water requirements may therefore be substantial. In large irrigation systems that rely on high mountain glaciers for water (Andes, Himalayas, and Rocky Mountains), temperature changes will cause high runoff periods to shift to earlier in the spring, when irrigation water demand is still low. Such changes could incite demand for new water control infrastructure to compensate for changes in river runoff.

Options for Water Management in Agriculture

It is possible to produce enough food and other agricultural products at a global level to meet demand while reducing the negative impacts of water use in agriculture. But doing so will require a change from today's food production and environmental trends, which, if continued, will lead to crises in many parts of the world.

The increasing number of areas where water has become a limiting factor for irrigated agriculture, associated with rising claims for releasing water to other economic uses (cities, industries), to guarantee or restore environmental services, has tightened food production in some regions. The Middle East, for example, can no longer satisfy its food requirements and relies increasingly on food imports (e.g., importing virtual water from other countries).

A combination of supply- and demand-side measures is needed to address the acute water challenges in the coming 50 years. The difficult task at hand is to manage the additional water supply in a way that minimizes the adverse impacts and—where possible—enhances ecosystem services and aquatic food production, while achieving the necessary gains in food production and poverty alleviation.

Improved water management in agriculture includes reduced water wastage in irrigation. Irrigated agriculture is often seen as inefficient, in both water use and added value. While on average only an estimated 37 percent of the water withdrawn for agriculture is effectively consumed by plants, a substantial share of the unused water of irrigation schemes returns to rivers and aquifers and is available for downstream uses. The net loss of water due to irrigation is therefore substantially less than may be apparent, and the potential gains from programmes aimed at increasing water use efficiency are often overestimated. Programmes aimed only at reducing losses in irrigation are unlikely to have a substantial impact on water use. Most large irrigation schemes also serve other functions, such as providing water for drinking, bathing, swimming, fishing and livestock, and water savings may take water away from these uses. Management thus needs to focus instead on multiple use strategies.

More efficient use of water—higher socioeconomic returns and more crop per drop—can be obtained primarily through intensification (improved crop varieties plus better agronomic practices).

Over the last 40 years major food yields have increased progressively and crop water productivity has doubled. However, yields in rainfed agriculture are still far from their potential. Opportunities therefore exist to contain future increases in water use in agriculture by reducing the yield gap. In 2005 cereal yields were about 1-1.5 tonnes per hectare in sub-Saharan Africa, compared with 5 tonnes per hectare in Europe. However, where land or water constrain future development, the yield gap is closing rapidly, and leaving little prospect for easy improvement. China and Egypt, for instance, are close to realizing their maximum potential for major food crops.

Better design and better matching of technologies, management and institutional arrangements are needed. Technological improvements can occur at all levels and affect all types of irrigation systems. Better technologies are not necessarily new, expensive or sophisticated options, but rather ones that are appropriate to agricultural needs and demands, the managerial capacity of system managers and farmers, and the financial and economic capacity needed to ensure proper operation and maintenance.

Technological innovation will occur in three broad categories:

- At the irrigation system level: water level, flow control, and storage management within surface irrigation systems at all scales.
- On the farm: storage, reuse, water lifting (manual and mechanical) and precision application technologies such as overhead sprinklers and localized irrigation.
- Across sectors: multiple-use systems in rural areas and urban agriculture with wastewater.

Multiple-use initiatives for water recognize the benefits to poor households of having adequate water for non-household, income-earning activities. But such initiatives are often not in line with water efficiency efforts. Surface irrigation is the most water-demanding form of irrigation, but the excess water can have other benefits: it enables aquaculture (as in rice fields in China) and washes off the salt accumulating in topsoil (avoiding salinization of cultivated lands). Efforts to save water by reducing water input would thus mean the loss of an income source (fish production) and potentially of cultivated lands, if salt accumulation becomes severe. Integrated multiple-use systems are found worldwide—usually documented at the farm and field levels—but conflicting management objectives are just as common and create hurdles for the promotion of these systems. Multiple uses of water imply multiple interest groups whose water management objectives may not always be compatible.

Despite much evidence of integrated water use at the farm level (such as rice-fish systems and irrigation-aquaculture systems), sectoral management at higher levels impedes true integration of water and irrigation with other sectors, including fisheries, forestry and sanitation. Furthermore, multiple uses and demands for water can generate opportunity costs and externalities, even when some uses are non-consumptive (fish farming in irrigation canals, for example).

These problems are intensified by the seasonality of supply and the limited availability of irrigation water in semi-arid tropical countries as well as the common pool, open access nature of the resource.

Lasting win-win benefits for water and agriculture often result from explicitly recognizing and analyzing trade-offs and factoring them into decisionmaking. Doing so may depend on the availability of information, collaborative decisionmaking, and perceptions of available alternatives.

In poor communities where survival is the main concern, people may have few choices about how they use land and water, or the perceived risks of alternatives could outweigh the potential benefits. This is why most successful integrated rural development initiatives are designed to help such communities reduce risks, develop alternatives, and bring trade-offs to the forefront in decisionmaking.

12 TACKLING THE WATER CRISIS IN PAKISTAN
WHAT ENTREPRENEURIAL APPROACHES CAN ADD

Adrien Couton

The availability of water in Pakistan is shrinking at an alarming rate, creating a dire prospect for a country largely dependent on agriculture. Aiming for rapid results, the government is implementing schemes to address the crisis—yet such schemes run the risk of bypassing smallholders, the very people most in need of help. This chapter uses the example of the Acumen Fund's work on drip irrigation to illustrate how market-based solutions can be used to provide an effective "voice mechanism" for poor farmers who rely on these government support strategies and at the same time help raise their incomes and improve the quality of their lives. By providing small investments coupled with management support, Acumen is assisting the development of two companies focused on smallholders. The success of these ventures hinges on making sure that their products and distribution channels meet the needs of the smallholders. The strategy has already been very successful in India and could be used to increase the efficiency of the subsidy scheme rolled out by Pakistan's government over the past few years.

Blue Gold

Pakistan has one of the world's most arid climates, with an average rainfall of under 240 millimeters a year. The population and economy are heavily dependent on an annual influx of water into the Indus River system coming from neighboring countries and derived mostly from snowmelt in the Himalayas.

Despite the dry climate, agriculture continues to be the single-largest sector of the Pakistani economy. According to Pakistan's latest economic survey, released in June 2009, the sector provides livelihoods to 66 percent of the country's population, employs 44.7 percent of the total workforce in the country, and accounts for 21.8 percent of gross domestic product.[1]

One of the largest integrated irrigation networks in the world makes Pakistan's reliance on agriculture possible: 96 percent of the country's water is used in farming.[2] Pakistan gets the bulk of its water from the mighty Indus River Basin system, which originates in the northern and northwestern parts of the country. Since the 1960 Indus Waters Treaty with India (which determined how the waters of the Indus system were to be shared by the two countries), many water development

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An earlier version of this chapter appeared in *Running on Empty: Pakistan's Water Crisis*, ed. Michael Kugelman and Robert M. Hathaway (Washington, D.C.: Woodrow Wilson International Center for Scholars, 2009).

1. Government of Pakistan, *Economic Survey, 2008–2009,* http://www.finance.gov.pk/admin/images/survey/chapters/02-Agriculture09.pdf.

2. Government of Pakistan, Ministry of Water and Power, Office of the Chief Engineering Advisor and Chairman, Federal Flood Commission, *Pakistan Water Sector Strategy—Detailed Strategy Formulation* (Islamabad, 2002).

projects—including the massive Mangla and Tarbela dams, link canals, and a number of barrages—have been executed in the country. The creation of this large infrastructure complex has given Pakistan one of the world's largest gravity-flow irrigation systems, with three big reservoirs storing some 20 million–acre feet of water, 19 barrages, 12 river-interlinking canals, and 59,200 kilometers of distribution canals. More than 160,000 watercourses comprise the distribution network that takes water directly to the farms—more than half of them in Punjab, the largest of the country's four provinces and the biggest agricultural producer. In total, the irrigation system of Pakistan serves close to 36 million acres of contiguous cultivated land.[3]

The Looming Water Crisis

This fragile balance, however, is coming under the increasing stress of a rising population and an aging infrastructure. Population growth of about 4 million people a year puts a significant strain on the country's resources. Meanwhile, after decades of deficient investments, the country's water infrastructure is on the decline. Between the commissioning of the Tarbela Dam in 1976 and the launch of the Diamer-Bhasha Dam project in 2006, no major water project was undertaken. Siltation is reducing the storage capacity of the dams, and huge volumes of water seep through poorly maintained canals. According to an estimate by the Ministry of Water and Power, 35 million–acre feet, "the equivalent of six Tarbela reservoirs," are lost in ground seepage annually.[4]

Overall, per capita water availability declined from 2,002.6 cubic meters in 1950–1951 to 1,136.5 cubic meters in 2003–2004, leaving the country only marginally above the threshold of scarcity (1,000 cubic meters per capita),[5] a decline accompanied by growing water-quality issues. More recent data suggest that per capita water availability continues to plummet. The sustainability of agriculture in Pakistan will depend largely on the judicious use and management of available water resources. Failure to handle scarce water supplies prudently will have major social implications.

Approaches to the Issue

Solutions to the challenge of water availability can be approached in three ways: by increasing the upstream storage capacity, by improving the efficiency of the transportation and distribution infrastructure, and by better allocating water to end uses.

Infrastructure improvements have received significant attention. Under the gigantic National Water Resources and Hydropower Development Program—Vision 2025, the Pakistan Water and Power Development Authority launched the construction of several medium-size reservoirs as well as major irrigation extension projects (the Greater Thal and Kachi canals), while planning for and advocating additional new reservoirs.

Unsustainable water-use practices are likely to be more difficult to address. As an illustration, numerous studies have documented that the sugarcane industry in Pakistan consumes a disproportionate amount of water in return for a low sugar output. This conclusion came from a recent

3. Ibid.
4. Ibid.
5. Data from the International Food Policy Research Institute (IFPRI), "20/20 Vision for Food, Agriculture, and the Environment," http://www.ifpri.org/book-753/ourwork/program/2020-vision-food-agriculture-and-environment.

study by the Islamabad-based Sustainable Development Policy Institute,[6] echoing a 2001 study that noted that "the return on the cash crop is not commensurate with the input of water that is required to produce sugar. [Pakistan] could import sugar from Cuba at less than half our production costs."[7] In Pakistan, however, the sugar industry represents a formidable lobby.

Estimates of the resources needed to address the crisis vary, but all concur that it will require considerable investment. As an illustration, the National Water Resources Development Program, designed by the government to address the crisis, estimated the investment needs for water resource development over 10 years at $14.8 billion. Out of this total investment, the share of dams represented around 40 percent, new canal construction 20 percent, lining and maintenance of existing canal systems 26 percent, and drainage 14 percent.[8]

The Attractiveness of Drip Irrigation

Among approaches to the water issue, drip irrigation appears very promising. Very simply, drip irrigation consists of running water through pipes to supply small amounts of water continuously at the base of plants (surface drip) or directly to the roots (subsurface type) through emitters attached to lateral lines. It is one of the most efficient forms of irrigation technologies currently available. With this technology, water can be conserved and yields increased for farmers, especially for those cultivating crops in semiarid regions. Drip irrigation, in fact, offers many advantages over conventional flood irrigation, including water savings, reduced labor requirements, less soil erosion, and increased crop productivity.

Among all solutions considered by policymakers for addressing the issue of water availability, drip irrigation has particularly attractive characteristics. It generates massive increases in the efficiency of water use (the increase in yield as compared to conventional irrigation methods is 20–100 percent, while savings in water are in the 40–70 percent range).[9] It offers much more flexibility than typical infrastructure intervention, since no heavy capital investments are involved and investments can easily be spread geographically and over time. It also delivers immediate benefits. Finally, drip irrigation is a mechanism for educating end users about the immediacy of the water issue and the urgent need for more water efficiency.

In August 2007, the government of Pakistan launched a $1.3 billion subsidized drip irrigation program. It sought help from the Japanese government to double the efficiency of water use in irrigation from the present 45 percent to 90 percent, mainly through drip irrigation. Pakistan's federal minister for food and agriculture set a target of 300,000 acres of land to be brought under drip and sprinkler irrigation in the first year, with federal and provincial governments to provide an 80 percent subsidy for equipment.

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6. Nadia M. Akbar and Mahmood A. Khwaja, *Study on Effluents from Selected Sugar Mills in Pakistan: Potential Environmental, Health, and Economic Consequences of an Excessive Pollution Load* (Islamabad: Sustainable Development and Policy Institute, June 2006).

7. United Nations (UN), "Integrated Regional Information Networks (IRIN) Special Report on the Water Crisis," UN Office for the Coordination of Humanitarian Affairs, May 14, 2001.

8. State Bank of Pakistan, *State Bank of Pakistan Annual Report FY04,* http://www.sbp.gov.pk/reports/annual/arfy04/Chapter_2.pdf.

9. To illustrate yield increases and water savings when using drip irrigation for two of Pakistan's major crops: sugarcane, 33 percent yield increase and 56 percent water savings; cotton, 27 percent yield increase and 53 percent water savings.

Table 12.1 Evolution of Farm Size in Pakistan

Census Year	Average Farm Size (hectares)	Total Area of Holding (hectares)	Number of Farms under Two Hectares
1971–1973	5.3	19,913,000	1,059,038
1989	3.8	19,149,637	2,404,057
2000	3.1	20,437,554	3,814,798

Source: Oksana Nagayets, "Small Farms: Current Status and Key Trends," Information Brief Prepared for the Future of Small Farms Research Workshop, Wye College, June 26–29, 2005, http://www.ifpri.org/sites/default/files/publications/sfproc.pdf, 355. Calculations by Nagayets are based on FAO 2001 and 2004 data and on data from national statistical agencies.

While this type of program aims for quick results, it may be of no benefit for smallholders, as the Indian experience, detailed below, has shown. Indeed, existing product offerings and distribution channels in place are typically suited to the needs of larger farmers. Since its commercial acceptance in the mid-1970s, the hardware used in drip irrigation systems has evolved to fit large fields and to minimize management and labor requirements. As a result, the standard equipment now available is expensive and rather sophisticated. Most commercially available micro-irrigation systems are optimized for fields of 4 hectares or more and require expensive emitters (to do the dripping) and highly qualified staff to operate and maintain the system. The cost of installing a drip irrigation system is high—typically at least $1,200 per acre. Systems are usually too expensive and impractical to operate in small plots and are therefore irrelevant to the majority of poor farmers.

Yet, small farmers represent a growing population in Pakistan. Average farm size declined from 5.3 hectares in 1971–1973 to 3.1 hectares in 2000, during which time the number of small farms more than tripled, as illustrated in table 12.1.

Lessons from India

Neighboring India has had significant experience with drip irrigation. Supported by public programs, the technology gained popularity there in the late 1980s. Various research institutes conducted experiments on drip irrigation and made people aware of its benefits. Some manufacturers also conducted their own studies by importing the materials before venturing into commercial production. Today, India has about 0.6 million hectares under micro-irrigation, out of an estimated 6.1 million hectares worldwide. Jain Irrigation, an Indian company, is one of the world's leading commercial drip irrigation companies.[10]

India has also produced a leader in drip irrigation technology for smallholders International Development Enterprises India (IDEI). IDEI is a nonprofit with 17 years of experience in the development of irrigation technologies and market links for smallholder farmers. In response to the lack of technologies appropriate for the small farmers it was working with, IDEI developed a product to meet their needs, building on work conducted in Nepal by its parent organization, International Development Enterprises.

10. Government of India, Lok Sabha, Question No. 1602 from the International Commission on Irrigation and Drainage, June 3, 2006.

IDEI's design principles followed three golden rules: miniaturization, affordability, and expandability. As a starting point, IDEI acknowledged that the basic unit had to be small; smallholders typically have less than 2 hectares of land, divided into five or six separate plots. As a result, the company took the quarter-acre plot as the building block within which new technology for small farmers should be developed. Second, IDEI saw affordability as a priority so that smallholder farmers could gain access to income-generating technologies. As CEO Amitabha Sadangi explained, "Shrinking a drip irrigation system from ten acres to a quarter acre not only makes it fit a small farmer's field, but it also makes it considerably cheaper." Systems are cheap, and the money invested in the drip system leads to quick improvements in yields and profits, returning a rapid payback. Finally, IDEI designed its systems to be expandable. "If a farmer can only afford a drip system that irrigates a sixteenth of an acre to start with, design it so he can use the income it generates to seamlessly double or triple its size the next year," Sadangi has said.[11]

With these principles in mind, IDEI designed a system that worked on a small scale and enabled farmers to gain access to an affordable and efficient technology that has increased water efficiency by 50 percent and yields by over 30 percent. Drip system technology generates dramatic economic benefits for small farmers: they can immediately harvest three crops each year instead of one, they can grow higher-value crops (chilies, for example), and they can achieve higher yields. By offering a price some 60 percent lower than previously available solutions, IDEI puts these benefits within reach of small farmers—even without public subsidies. Indeed, the subsidies typically put the poorer farmers at a disadvantage, being ill-equipped to follow the procedures that allow them to receive a subsidy; and with little cash at hand, they also suffer more because of long waits for refunds than more wealthy farmers.

Spreading the Technology: The Acumen Fund's Experience

Acumen is a global nonprofit venture fund, founded in 2001 to address world poverty in a unique way: it fills a niche between traditional capital markets and grant-based philanthropy by investing in enterprises that bring critical goods and services to low-income consumers. Its objective is to create markets for the poor in essential goods and services where such markets do not currently exist. The fund combines targeted investments, financial leverage, and management support to build thriving enterprises that address the needs of the poor. Its country offices in India, Pakistan, and Kenya work closely with a team based in New York to identify and support local social enterprises. Acumen has successfully reached over 10 million people so far, through more than $40 million invested in South Asia and Africa.

While the early focus of IDEI was on smallholder farmers in India, the company's ambitions were international in scope. With the Acumen Fund's support, IDEI created a socially minded, for-profit wholesale distribution company called Global Easy Water Products. The nonprofit IDEI continued to focus on research as well as advocacy, while the for-profit company concentrated on building a sales and distribution model that serves the very poor. In the past seven years, IDEI and Global Easy Water have sold more than 250,000 drip irrigation systems in six Indian states, bettering the lives of more than 1.2 million people through improved nutrition and higher incomes.

11. Author's interview with Amitabha Sadangi, Delhi, May 2007.

In Pakistan, Acumen contracted with the Thardeep Rural Development Program (TRDP), a major nonprofit and the third largest of the Rural Support Programs, a group of integrated rural development organizations operating across Pakistan. TRDP operates in 3,000 villages in the arid regions of Sindh Province and serves over 130,000 households. Its core model involves mobilizing and organizing villagers into "self-managed" organizations that serve as channels for microfinance services and other integrated poverty alleviation programs that TRDP offers to rural communities. The regions where TRDP operates are among the poorest in Pakistan. In these areas, the scarcity of water restricts farming and sometimes forces the poorest and most vulnerable families to sell the few assets they possess and migrate to other regions.

In 2005, Acumen introduced International Development Enterprises India to the Thardeep Rural Development Program. TRDP's founder immediately saw the potential value of IDEI's irrigation technologies for its customers. That same year, demonstration plots were set up in Pakistan with a $50,000 grant from Unilever, which had been supporting TRDP's work. The demonstration plots were largely successful; the agronomic conditions were close to those experienced by IDEI across the border in nearby Rajasthan, and IDEI's technology proved to work very well in Sindh.

During 2006–2007, Acumen facilitated further cooperation between TRDP and IDEI by placing a consultant at TRDP to lead the rollout of the project in Pakistan and by seconding a staff member at Global Easy Water Products. Acumen then approved a $1 million investment in Global Easy Water and a $500,000 investment in MicroDrip, a joint venture between TRDP and Acumen. Meanwhile, the collaboration between IDEI and TRDP achieved significant progress. In the fall of 2006, IDEI's marketing manager visited the demonstration plots in Pakistan, and several months later one of IDEI's area managers came out to see an installation demonstration. TRDP received its first large-scale shipment of goods in the spring of 2007, with a second shipment arriving over the summer.

Although the rollout of IDEI's low-cost drip irrigation technologies in Pakistan is only beginning, it has the potential to transform the lives of the rural families that MicroDrip will service. MicroDrip plans to reach between 20,000 and 30,000 farmers over the next five years, improving their income and health and also generating environmental benefits for their communities.

MicroDrip's work provides direct feedback on the needs of smallholder farmers, their comfort with the technology, and the specifications of the products that they need. By treating smallholders as customers rather than as recipients of charity, this approach gives smallholders a voice and ensures that the products and distribution channels used do not benefit only the wealthier farmers. The subsidy scheme initiated by the government of Pakistan can build on MicroDrip's work if the organization is able to leverage subsidies efficiently while maintaining its ability to serve smallholder farmers proactively.

Conclusion

In 2005, the World Bank's Country Water Resources Assistance Strategy highlighted Pakistan's ability to overcome significant water-related challenges throughout its history. The first challenge came when the lines of partition of the India-Pakistan subcontinent severed the irrigated heartland of Punjab from the life-giving waters of the Ravi, Beas, and Sutlej rivers; this challenge was solved by the Indus Waters Treaty.[12] The second challenge arose because of the disconnect between the location of Pakistan's waters (in the western rivers) and the major irrigated areas in the east: building the world's largest earth-filled dam, the Tarbela, on the Indus, and constructing link canals running for hundreds of kilometers and carrying flows 10 times the flow of the Thames River met the second challenge.

The third major challenge, which remains today, is to manage the twin curse of waterlogging and salinity. By responding to the first two challenges, Pakistan took measures that addressed issues of upstream water capacity and improved the transportation and distribution infrastructure. Such measures, however, addressed neither the inefficient water use by a rapidly growing population nor the strong disparities in access to water between rich and poor farmers.

Today, Pakistan needs a more decentralized solution. As illustrated by the example of drip irrigation, private sector–led approaches can be efficient vehicles for giving a voice to smallholder farmers. By treating farmers as customers, such private sector approaches offer a valuable listening device, a way to understand the needs of the smallholder farmers, and a mechanism for tailoring solutions to the water crisis. The private sector alone will not solve Pakistan's water challenges, but it can inform and strengthen public programs for a more equitable resolution.

12. The treaty gave Pakistan rights in perpetuity to the waters of the Indus, Jhelum, and Chenab Rivers, which compose 75 percent of the flow of the whole Indus system.

13 A TABLE FOR 9 BILLION, PLEASE
BUILDING GLOBAL WATER, FOOD, AND ENERGY RESILIENCE

Ger Bergkamp

To many in the water sector around the world, the inaugural address of President Barack Obama provided a glimmer of hope that the American way is still alive. The sentence—"To the people of poor nations, we pledge to work alongside you to make your farms flourish and let clean waters flow"—portrays a pragmatic, self-interested, yet altruistic, approach. For when water brings stability to any poor nation, it brings global security to us all. In doing so, water becomes a vital force of resilience.

Yet, we must avoid simplistic slogans and ideological extremes, whether they come from technophiles who assume desalination is a panacea for scarcity, or social activists who call for more rights without a clear sense of the way in which these can be implemented. Governments, civil society, and markets all have a role to play when it comes to bringing about efficiencies, fair distribution, and improved access to water. This can be a balancing act between ideological extremes without looking at the bigger picture of the world toward which we are moving: A world with more than 9 billion people in need of water, food, and energy—a world with aspirations and patterns of behavior and consumption that reach well beyond the carrying capacity of ecosystems and water resources.

We increasingly realize that water is never merely a resource "end" unto itself, but is also a "means" to an end. This is particularly manifest in the water, food, and energy nexus, the three-sided linkages between water management, food, and energy production and consumption on a sustainable basis. With the continuing growth in population and consumption, how can nations, whether pragmatic, altruistic, ideological, or extreme, approach the challenges posed by this nexus in a way that turns a dangerous and vicious cycle into a resilient and benevolent symbiosis? How can they begin to change the relationships between water, food, and energy and establish a fundamental shift toward a development for all that is sustainable?

Making that shift happen is not only the task of high-level decisionmakers. On the contrary, bringing this shift about will depend on active participation by the hundreds of millions of farmers and consumers who will need to change their practices and engage in creating a new world. And it will also require greater political will among elected officials in charge of setting policies, allocating budgets, and signing agreements.

5th World Water Forum—Water, Food, and Energy on the Menu

During the 5th World Water Forum in Istanbul, a significant emphasis was put on engaging a wide range of stakeholders. Over two years, month after month, the World Water Council worked with Turkey, the host country, and hundreds of organizations from around the world to build consensus among various interests so as to elevate water issues onto the political arena.

The World Water Council is uniquely positioned to help catalyze change. With more than 300 member organizations from more than 60 countries, the council groups a cross section of water leaders from around the world, including from governments, NGOs, the United Nations, companies, professional networks, and research institutions.

We cannot pretend that, during the forum's six days of meetings, the council and the participants managed to "crack the code" or solve the world's water challenges. However, we managed to bring many of the significant players to the table: more than 16,000 participants from more than 180 countries actively engaged in the debates. We started to address some of the key questions for our civilizations, focusing not only on the technological fixes or engineered outcomes proposed by sound experts. The participants went well beyond these and tackled ways to create resilient systems of governance and management that can adapt to rapid change, withstand shocks from disasters and volatility, conserve the resource base we depend on, and provide access to water and sanitation for all.

The water, food, and energy nexus attracted strong interest and provoked a robust debate during the forum. The reason for the universal appeal is obvious: water, food, and energy are the three most elemental resources on which we all depend. These resources affect all societies and are therefore not only technical issues but inherently bring a political dimension as they cut to the marrow of our existence. In the face of the current economic crisis, it is hard to imagine more daunting stakes than the ones this nexus brings.

Yet, what we could see emerging at the forum was not a focus solely on the macro aspects through a top-down approach. A keen desire was brought to the fore to develop decentralized approaches to economic development and good governance that would engage people and make them part of the solution to tackle the water, food, and energy nexus. The "billions on the brink"—those who live on less than a few dollars a day—demand to, and are being asked to, play a role as partners and are no longer seen as victims. These people are beginning to access their own vital resources to tackle their day-to-day challenges in securing water, food, and energy.

If we therefore apply to the nexus the old cliché of seeing crisis as an opportunity, are we pushing it a bit far? Let us briefly consider the scale of this "opportunity," starting with agriculture.

Food for Thought

In just 15 years, global population will reach 8 billion thirsty, hungry, energy-demanding humans. During that time, cereal demand will expand 42 percent, growing from 585 million tons to 828 million tons. Meanwhile, milk and meat requirements will double. To meet the needs of 2 to 3 billion more people and to satisfy the changing diets of today's grain eaters who will soon crave more meat and vegetables, we will need to double the amount of food that ends up on people's plates over the next four decades.

Meat is on average 10 to 15 times thirstier than vegetables; the affluent omnivores "eat" 6,000 liters of water, twice what vegetarians in the developing world require in, say, China, Mexico, or India. And yet in those lands, farmers are running water resources dry. Despite the gains of the Green Revolution, a quarter of India's harvest is at risk as groundwater is depleted beyond recovery.

The signs of trouble are obvious:

- Right now agriculture takes 70 percent of all water used;
- The world's rural families continue to migrate en masse to cities, where half the world's population now grows nothing while consuming more food;
- "Tapped out" farmers are instructed to double water withdrawals to ensure that food supplies doubles.

The equation simply fails to add up, because more water cannot be diverted from desiccated rivers and empty aquifers. And this quick view of only one aspect ignores the escalation of competing pressure on water by another resource—energy.

Power Play

When the words "water" and "energy" are put together, they evoke "hydropower" in most people's minds. Indeed, hydropower produces about 20 percent of the world's energy. But electricity-generating dams are just one sliver of the complex and intricate linkages that bind the two other sides of the nexus. It takes prodigious amounts of water to produce energy, not just as currents turning dam turbines, but in thermal and nuclear cooling, in cultivating biofuels, and even in the production of coal and oil from the ground.

Not so long ago, it used to be water quality that mattered. Now, it is water quantity that limits energy production in the richest countries on earth. If the United States, France, and Switzerland are hitting the water-energy wall, imagine what the situation looks like in Tanzania, Nepal, or Bolivia.

The food-energy link has grown more intense with rising energy demand and with our trying to find alternatives for fossil fuel and seeking to burn what we grow and could eat. The volatility of oil prices affects the production of biofuels, whether it is Brazilian sugar cane, Thai cassava, Indonesian palm oil, or U.S. corn-based ethanol. Notwithstanding, firewood remains the most-used bioenergy for many hundreds of millions of people.

There are huge consequences for food prices in energy decisions, but even more profound impacts on water. Nuclear power consumes up to 3 cubic meters of water to generate one megawatt hour while oil consumes about 6 cubic meters. Hydropower evaporates in the order of 17 cubic meters per megawatt hour while biofuels eat 360 cubic meters for the same amount of power produced.

With the rising demand for energy, the demand for water to produce that energy will be growing. An approach focused on biofuels could have dramatic consequences for water availability at the regional and local level. Yet often the consequences play out sharply only in specific situations.

Unpacking the Nexus

Over the last decades, we have seen an unprecedented rise in consumption, population growth, and resource use—in many ways, a truly historic period. As a result, many millions were lifted out of poverty, but at the same time resources, many of which are not evenly distributed, have come under serious strain. Hotspots are already emerging when it comes to physical and economic water scarcity: the fast-growing American Southwest shares uncomfortable attributes with places such as Northern India, Northern China, Zimbabwe, Pakistan, Uzbekistan, and Jordan.

Population growth triples within the course of our life span, putting further stress on food and energy and on the resource they both require—water. By 2050, we will have to feed 9 billion people. Thus, could the underlying problem for the water, food, and energy stress be as simple as taming population growth? If we could halt population at today's level, would the other problems evaporate?

Unfortunately, human impact on the world's resources is less a reflection of simple numbers than of a hungry diet and thirst for energy. The world can support 9 billion people who eat like Bangladeshis or burn electricity like Ethiopians. But what happens when 9 billion people live like the average European or American?

We want everyone to enjoy the same standard of healthy, comfortable living that many in the industrialized world have, hence the upward tilt of water withdrawn for food, energy, industry, and residential use. Yet, at the same time, with the lack of access to food, undernourishment is likely to hit 1 billion within the next few years. This situation suggests one of the consequences of water scarcity and a warning about why we must elevate water on the global political agenda: The consequences of doing nothing, or waiting too long, can lead to situations where physical and economic resource scarcities converge, including geopolitical hotspots such as Sudan, West Africa, or Pakistan.

To all this must be added the influence of climate change. When the practice of planning water resources was based on historic records, it made perfect sense to have "more crop per drop." In those days, energy experts could tell us we must generate "more kilowatt per drop." But today, hydrologists are no longer certain when those drops might land, where they can be expected, or if they will exist at all.

Light in the Tunnel?

To start unpacking the water, food, and energy nexus, we have to ask ourselves whether we are any closer to turning the problem into a positive change toward development and sustainability. To do so, we will need to continue to ask the right questions. What are effective ways of integrating water, food, and energy in policymaking and management decisions? What are approaches that turn reducing wastage of water, food, and energy and tackling inefficiencies into a profit for consumers, farmers, and businesses?

Without tackling key questions around the water, food, and energy nexus, we face significant risk that some of the best technology transfers, most targeted lending programs, or both small- and large-scale infrastructure schemes may falter. Solutions to the water, food, and energy nexus need to be firmly anchored in policies that secure the flow of clean water of the people, by the people, for the people, driven by the edge rather than pushed from the center. To increase water, food, and energy security, efficiency, and sustainability, we must

- **Reduce the water footprint of energy by focusing on water-efficient energy technology.** Start incorporating the water footprint of energy options into the analysis and decisionmaking, including a stronger focus on energy demand management. Shift to the next generation of biofuels based on waste, which avoids the capture of valuable cropland for biofuels.
- **Reduce post-harvest losses and the waste of water throughout the supply chain by reducing food waste.** With more than 2,700 cubic kilometers of water used for irrigation and 50 percent

of food wasted, we can save up to 1,350 cubic kilometers of water globally. The amount of water that can be saved through reducing food losses and changing diets is thus many times larger than through dual-flush toilets or water-efficient dishwashers. All consumers have a role to play here.

- **Decrease the risk of highly volatile prices by increasing the global food reserves to buffer against a tight market.** This effort requires a global and local reorganization of the food market infrastructure and institutions. The "crowds" of small farmers should receive most of the benefit—for example, through access to micro-credit to restart the investment needed in micro-enterprises for increased water efficiency in food production and storage.
- **Reduce the water pressures in hotspot regions and countries by investing in water efficiency and importing virtual water through crops.** Food supply guarantees to nations should be put in place at the global level as part of the reorganization of the food market institutions.
- **Support farmers and help create diversified and resilient agricultural production systems** that not only maximize crop output but also continue to foster agro-ecosystem services such as soil conservation, water flow regulation, pollination, and habitats for plants and animals. A diversified and resilient agricultural production system is the backbone of rural societies and economies and provides a cornerstone of tackling rural poverty.

But most important of all, to gain efficiencies in water, food, and energy, we need to entrust and empower people to allocate their own water from the basins in which they live. That shift in trust, authority, and responsibility requires a step change toward democratic policies and decentralized control. On behalf of the United States, President Obama pledged to work alongside the people of poor nations to make farms flourish and to let clean waters flow. His wording emphasized a partnership among equals, where all parties benefit. Building on his insight, we can say that it is only through the empowerment of the poor and the middle class, and the creation of further political will, that we can unlock the water, food, and energy nexus and create stability, prosperity, and sustainability.

14 THE POLITICAL ECONOMY OF URBAN AND RURAL WATER ACCESS IN EGYPT

Shaden Abdel-Gawad

Water, humans' life artery, is the cornerstone of every country's development. Egypt is no exception. The Egyptian government is thus making every effort to institute proper management and use of its water resources so that it can attain a high standard of national development and improve the quality of life for its population.

Agriculture is the primary user of water in Egypt, with around 80 percent of the nation's water going to that sector. Access to water for different purposes (agricultural, municipal, and industrial) and for different sectors of the population (urban and rural communities) is generally considered an important indicator of national development and a better quality of life. However, several factors, both internal and external, profoundly affect such access, including socioeconomic factors that touch on urban and rural communities alike.

Characteristics of Water Access

Within the Egyptian social context, any approach to the issue of water accessibility has to view it from the perspectives of its three primary purposes—agricultural, municipal, and industrial. Even within those perspectives, though, variations in internal and external factors and in rural and urban communities come into play, directly and indirectly.

Internal Factors

Internal factors include demographic conditions, employment, and poverty and income distribution.

Demographic conditions

Egypt is facing a crisis of population growth, which has two dimensions. First is the rate of population growth itself: it dropped from 2.4 percent during the period 1960–1996 to its current rate of 2.1 percent thereafter in response to government programs aimed at reducing that rate. Although the growth rate had dropped, it is still too high. Second is the distribution of population between urban and rural areas. Current data show that about 43 percent of the country's population live in urban areas and some 57 percent live in rural areas. The growth rate of the urban population, however, increased from 1.8 percent in 1986–1996 to 2.3 percent in 1996–2006 as a result of migration from rural to urban areas.[1] Because of a rapidly rising standard of living and the consequent increase in consumption per person and a changing diet, Egypt will face the need to increase its food supply in combination with increased imports.

1. United Nations Development Programme (UNDP) and the Institute of National Planning, *Human Development Report* (Egypt: UNDP, 2008).

Employment conditions

Industry, agriculture, and services are the main categories of employment, with the service sector accounting for more than 46 percent, industry for 30.6 percent, and agriculture for 23.4 percent, by number employed. Services and industrial activities are concentrated in urban areas and attract people from rural areas who are seeking work.

Poverty and income distribution

Although the Egyptian government has adopted several development measures for both rural and urban areas, a gap between the development levels of the two communities still remains, primarily in literacy, access to clean water, sanitation services, poverty, and income distribution. The current statistical data show a gap between rural and urban areas in all governorates in general but also a strong regional gap. In Upper Egypt, for example, the illiteracy rate is 44.8 percent in the rural areas while its poverty rate is 20.1 percent. Figures 14.1 and 14.2 show the percentages of those with access to water in urban and rural communities in the regions. Sanitation services have typically lagged about a decade behind water supply. This urban bias, together with other biases, contributes to the migration of the rural populations into urban areas and the consequent growth of urban population. Economic development also drives farmers from their lands to urban areas. For instance, many rural areas are experiencing a "feminization" of agriculture that occurs when men leave their farms for military service or for part-time work in urban areas.

Informal settlements are another challenge, where slums are illegally built outside urban areas. Such settlements force the government to choose between not extending drinking water services to illegal settlements as disincentives to violators or upholding people's right to clean water. In many cases, the government chooses the latter, and the problem remains to be solved in the context of overall development and poverty reduction.

All these factors—as well as others such as water availability, national plans for water management, and national water projects—influence the government's decision and plans for providing water access to urban and rural communities for their different uses.[2]

External Factors

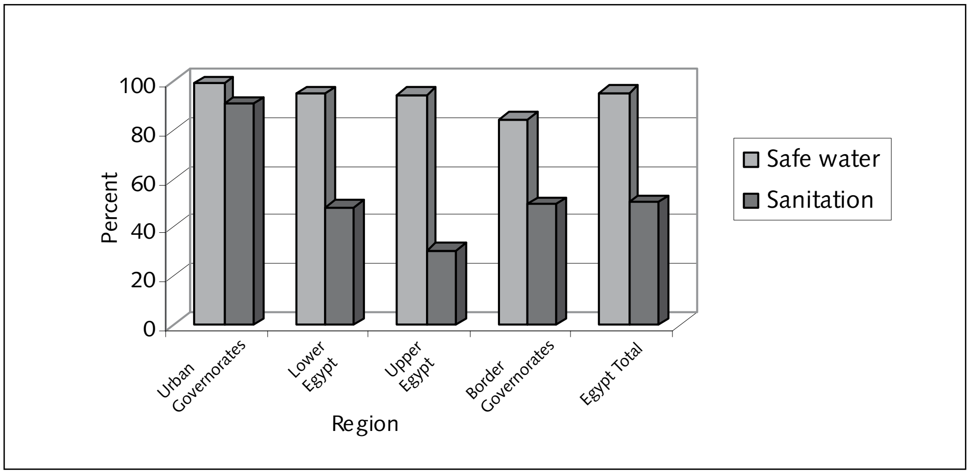
External factors—including the potential impacts of climate change and the demand for biofuels—will also affect the future of water resources and the food supply.

Potential impacts of climate change

Climate change is a global phenomenon. Its local impacts, however, are different from one place to another, because of the nature and sensitivity of the ecosystems in each region. It is expected that climate change will cause a chain of global, regional, and local impacts that affect all economic sectors in one way or another. The predicted change is likely to have an impact on natural ecosystems, including forests, wetlands, coastal areas, water resource systems, food supplies, human health, and socioeconomic systems. It is therefore necessary to assess Egypt's vulnerability—particularly its wealth of natural resources such as water and land as well as the future of agricultural production—in light of changing conditions.

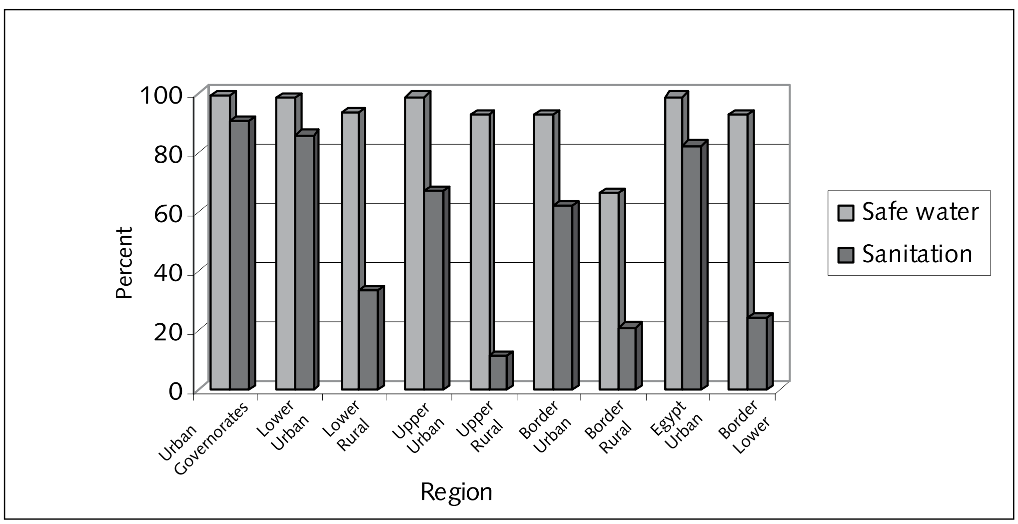
2. Mai El-Mosallamy, Egyptian Cabinet, Information and Decision Support Center (IDSC), *Poverty and the Characteristics of the Poor in Egypt* (Cairo: IDSC, 2005).

Figure 14.1 Percentage of Safe Water and Sanitation in Main Egyptian Regions in 2008



Source: United Nations Development Programme (UNDP) and the Institute of National Planning, *Egypt Human Development Report* (Egypt: UNDP, 2008).

Figure 14.2 Percentage of Safe Water and Sanitation for Both Urban and Rural Populations in the Main Egyptian Regions in 2008



Source: Ibid.

Impact of climate change on water resources

The Nile River is the main source of water for Egypt, supplying Egypt with around 95 percent of its water (55.5 billion cubic meters per year), while rainfall on the northern coast and groundwater contribute around 5 percent. As noted earlier, the agriculture sector consumes at least 80 percent of Egyptian water, while municipalities and industry consume around 20 percent.

Given the importance of forecasting the Nile water flows, the research community has used several mathematical models for predicting them. While results have shown that these models cannot accurately predict the precise effects of a change in temperature in the Nile River basin on water flows, indications point to serious consequences from an expected shortfall:

- Increased temperatures will lead to increased rates of evaporation and thereby increase the pressure on water sources, agriculture, industry, and human consumption.
- Changing rates and locations of rainfall and variable seasons will lead to a loss of rainfall that can be used for agriculture and human consumption along the northern coast, unless improved management can counteract those losses.
- Increased dust and industrial pollutants and higher human consumption will lead to a deterioration of water quality.
- Rising sea levels will degrade the quality of groundwater in shallow wells in the coastal areas.

It is widely accepted that global circulation models (GCM) are the best physically based means for describing the altered climate of the future. They are able to reproduce the global scale climate fairly well but fail to show features of local and regional climates.

GCM experiments show very different pictures of climate change over the Nile Basin. While they all agree on the temperature rise, they disagree on the direction of precipitation change. Analysis from seven different GCM models reveals an average increase in temperature over the basin by 2–4.3°C by 2050, with larger rises in Sudan and Egypt and smaller rises around the equator. Most of the analyzed experiments showed an increase in precipitation over the basin of 18 percent; some showed a reduction of 22 percent. Three models indicate an increase in natural river flow at Aswan of more than 50 percent, while a fourth model shows a 12 percent reduction. In summary, there are large uncertainties in predicting climate changes in the Nile Basin and their impacts on its flows. The large spatial scales of GCM uncertainties required downscaling of these global models to regional circulation models (RCM).

Impact of climate change on agriculture, livestock, and food sources

Agriculture is the backbone of Egypt's national wealth and covers nearly 6.6 million acres planted with rotating crops. Agricultural income is estimated at 15–20 percent of national income, and smallholder farmers represent the majority of the agricultural population. Given its continuous increase in population, Egypt cannot be self-sufficient in food production and must import strategic crops such as wheat. With the country's semi-arid climate and dependence on the Nile, Egyptian agriculture is particularly sensitive to climate changes. According to the UN Food and Agriculture Organization, climate change will have several major impacts on Egyptian agriculture:[3]

3. United Nations, Food and Agriculture Organization, The Challenges of Climate Change Challenge and Bioenergy: Conference on World Food Security, Rome, June 3–4, 2008.

- Increasing temperatures and changing frequencies and times of heat and cold waves are predicted to reduce the productivity of some crops (some crops will be more affected than others).
- Change in the yearly average temperature is expected to reduce the quality of agricultural production.
- Desertification rates are expected to change.
- Increased temperatures are predicted to increase evaporation and consequently increase water consumption.
- The patterns of livestock production are expected to change.
- Micro and macro socioeconomic status is expected to change in response to new migration patterns.

Impact of climate change on energy sources

Climate changes are also likely to affect other aspects of daily life, including energy and its availability for the different uses of urban and rural communities:[4]

- Increased temperatures will add pressure for more water for domestic use in rural and urban areas.
- The reduction of the Nile water flow (if it occurs) is expected to reduce the quantity of electrical power generated by the High Aswan Dam.
- Increased dust will shorten the life span of electrical equipment and increase the rates of their electricity consumption.
- Increased wind speeds may be useful in generating electricity through wind power in some areas along the northwest coast of Egypt or the Red Sea.

Impacts of biofuel production

Biofuel is a new source of demand for agricultural commodities such as maize, oilseeds, and sugarcane. The use of such commodities in the production of biofuels will lead to a shift from their use as human food and animal fodders to the production of biofuels. As a result, prices for these commodities may rise in local markets. In addition, the new demand has already begun to affect the cropping pattern and consequently the demand for water. Any changes in demand for water generally affect the access to water for both rural and urban communities.

The UN report on biofuels raises issues regarding food security and biofuel production. While the argument for biofuels for energy efficiency and climate change is legitimate, the effect on the world's hungry of transforming wheat and maize crops into biofuels would be absolutely catastrophic.

It is important to determine what investments, policies, and agreements are needed to ensure that the diversion of land and water resources for biofuel production does not offset national and international efforts to alleviate poverty and enhance food security. It will also be important to know whether such a shift would really improve the conditions of smallholder farmers.

4. Climate Change Unit, Ministry of State for Environmental Affairs, Egyptian Environmental Affairs Agency, *Egypt and Climate Change* (Cairo: Ministry of State for Environmental Affairs, 2005).

ABOUT THE AUTHORS

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Jason Clay is senior vice president of markets transformation at the World Wildlife Fund. He graduated with an M.S. in anthropology from Harvard College and a Ph.D. in anthropology and international agriculture from Cornell University. His areas of expertise include indigenous people; nation/state conflicts; natural resource management; global trends; corporate social responsibility; reducing social and environmental risks; water and carbon neutrality; agriculture and aquaculture; impact assessments of large-scale development projects; trend analysis on the impact of biofuels; metric-based standards for agriculture and aquaculture; and animal protein consumption. In his work at the World Wildlife Fund, Clay brings people together to effect change and improve environmentally sensitive practices in worldwide agriculture and aquaculture. Clay's goal is to create global standards for resource sustainability, particularly in terms of ingredient sourcing and carbon and water neutrality. He has been instrumental in convening industry roundtables of buyers, producers, and environmentalists to develop innovative business ideas for the conservation of salmon, shrimp, mollusks, catfish, and tilapia. Dr. Clay's published articles include *Resource Wars—Nation and State Conflicts of the Twentieth Century*, *Nature's Subsidies to Shrimp and Salmon Farming, Shrimp Aquaculture and the Environment,* and *World Bank Policy on Tribal People: Application to Africa* (AFTEN Technical Note No. 16). His book publications include *World Agriculture and the Environment*, *World Aquaculture and the Environment, Generating Income and Conserving Resources—20 Lessons from the Field*, *Indigenous Peoples and Tropical Forests,* and *Exploring the Links between International Business and Poverty Reduction*.

Juan José Consejo is director of the Institute for Nature and Society of Oaxaca, México. He received his M.S. at the National University of Mexico, where he taught ecology for five years. In the early 1980s, he joined and created several ecological groups, became president of the Federación Latinoamericana de Jóvenes Ambientalistas, and was general coordinator of the International Youth Federation for Environmental Studies and Conservation. Earlier Consejo was appointed to the planning office of protected areas in Mexico's Federal Ministry of Environment, where he worked actively to create the Sian Ka'an biosphere reserve in the State of Quintana Roo and became its director. Since 1987 Consejo has worked independently for several federal and state government agencies and national and international nongovernmental groups. He has produced several surveys, books, and papers on ecology and conservation, particularly on Indian and local inhabitants' participation, ecological politics, and planning and managing protected areas in southeastern Mexico. He has also collaborated with national and local newspapers and magazines and with radio and TV programs. He lives in Oaxaca, where he has conducted conservation research and has worked for government and nongovernmental organizations. He coordinated a survey for the Chimalapas region, a state ecological program and the master plan of the State Protected Areas System. He also created and was former executive officer of the Commission for the Ecological Defense of Oaxaca, a coalition of 60 government and nongovernmental groups, research centers, and community organizations. Consejo, who lives in a small Indian community near Oaxaca City, is currently consultant to the IUCN National Parks and Protected Areas Commission and coordinates the Institute for Nature and Society of Oaxaca, which he founded. The institute has launched projects on ware issues, soil conservation, community participation in land use planning, alternate technology, and environmental education, among other issues.

Qiuqiong Huang has been an assistant professor at the Department of Applied Economics, University of Minnesota, since 2006. She holds a Ph.D. in agricultural and resource economics from University of California, Davis, and a B.A. in Food Science from People's University of China. Her research focuses on the determinants and effects of different institutional arrangements in surface water and groundwater management, water pricing policy, and estimation of agricultural production technology. Most of her empirical research focuses on China. One of her research efforts has been collecting community-level and household-level survey data on water resources management in rural China over the years. Her publications have appeared in *Environment and Development Economics*, *Agricultural Water Management*, *Australian Journal of Agricultural and Resource Economics*, *Food Policy,* and *Asia-Pacific Development Journal*. For the past three years, she has taught courses on applied econometrics and microeconomics.

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Peter G. McCornick, director for water at Duke University's Nicholas Institute, has spent approximately three decades addressing the water challenges in the agricultural, environmental, and health sectors. This work has included policy and strategy development, planning and management, implementation, teaching, research, and capacity building. He has worked throughout North America, Asia, Africa, and the Middle East, including long-term assignments in Colorado, Alberta, Washington, D.C., the United Kingdom, Ethiopia, Eritrea, India, Indonesia, Jordan, and Sri Lanka. In his present role, which he assumed in 2008, McCornick leads the water program at the Nicholas Institute to provide strategic knowledge and advice in meeting complex water challenges. Before joining Duke University, he was the Asia director for the International Water Management Institute and earlier was seconded to the United State Agency for International Development in Washington, D.C., as senior water resources and irrigation adviser. He holds a Ph.D. and an M.S. in water resources and irrigation engineering from Colorado State University and a B.Sc. in agricultural engineering from the University of Newcastle upon Tyne in the UK. He is a registered civil engineer in Colorado and a member of the American Academy of Water Resources Engineers. McCornick is widely published, including 25 peer-reviewed publications, and many technical papers and reports.

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Adrien Couton, who was water portfolio manager for the Acumen Fund in 2007–2009, is helping to launch a new water venture India. His professional interest and passion is in developing entrepreneurial approaches to the water and sanitation crisis. At the Acumen Fund, a nonprofit venture fund, he developed a portfolio of investments in for-profit social ventures bringing water and sanitation services to poor customers in India, Pakistan, and East Africa. He joined Acumen Fund in 2006 as part of the inaugural class of the Acumen Fund Fellows Program and was seconded during his fellowship to International Development Enterprises India, where he assisted the CEO and COO in scaling up the distribution of low-cost drip irrigation systems in India and Pakistan. Before joining Acumen Fund, Adrien worked at McKinsey & Company, in private equity for five years, and as a consultant for the World Bank's Water and Sanitation Program to improve slum dwellers' access to the piped water supply in Delhi. Adrien received an MBA from HEC Paris, a master in political science from La Sorbonne University, and an MPA from the Kennedy School of Government at Harvard University.

Ger Bergkamp, director general of the World Water Council, has 20 years of experience serving the water community, including at the World Conservation Union. After completing his university studies, extensive travel and field experience persuaded Berkamp that successful "ecosystem management" did not depend on managing ecosystems. To the contrary, it meant managing humans, empowering communities, and making people the principal actors of the change they need and seek in every level in society, from the local farmer to transboundary river basin negotiators. Not long after becoming the water adviser for the International Union for Conservation of Nature, he began to quietly test his hypothesis. He prepared a background study for the United Nations Commission on Sustainable Development, defining ecosystems through their basic services to humanity and putting people at the center of water governance. He then began to advise governments and NGOs on how to translate this approach on the ground and where to bring environmental sustainability into their own water management practices. Bergkamp's quest for people-centered, community-empowered water management led him first to become an active governor of the World Water Council, and in June 2008 he was appointed director general of that organization.

Shaden Abdel-Gawad is president of the National Water Research Center of the Ministry of Water Resources and Irrigation of Egypt. The center is the sole research organization in Egypt responsible for conducting water research activities at the highest policymaking level to support the development and management of Egypt's water resources. Via its 12 research institutes, research carried out has strongly contributed to the outlining and proposing of long-term water resources policies in Egypt, solving technical and field problems associated with general policies for irrigation, drainage, and water resources, and proposing measures for environmentally sound development of the water resources system. Professor Shaden Abdel-Gawad is a graduate of the faculty of engineering, Cairo University, Egypt's elite engineering university. She holds a Ph.D. in environmental engineering from the University of Windsor, Canada. Professor Abdel-Gawad has more than 30 years experience in water resources management and environmental protection, assuming several leadership positions besides her role as a research professor. She has supervised and managed several foreign-funded projects as well as local programs in the field of water quality monitoring, modeling and assessment, drainage and rational use and management of water resources. She took the lead in catalyzing the Integrated National Water Quality Monitoring Program in Egypt. She has also served as a short-term consultant for the World Bank, UNDP, and USAID.