Proceedings of the South Asia Groundwater Forum:

Regional Challenges and Opportunities for Building Drought and Climate Resilience for Farmers, Cities, and Villages

Chokhi Dhani Resort, Jaipur, Rajasthan, June 1–3, 2016

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South Asia Water Initiative

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Preface

South Asia—the world's fastest growing region—is the largest abstractor of groundwater; it pumps nearly a third of the groundwater used globally and half of global groundwater for irrigation. Groundwater drove the Green Revolution, which lifted hundreds of millions of people out of poverty across the region; in addition to irrigation, it is critical to rural, urban, and industrial water supplies. However, intensive pumping and unregulated use have caused rapid declines in water tables, putting these benefits at risk. In addition, groundwater contamination (from arsenic, fluoride, salinity, sewage, industrial effluent, and agricultural chemicals) is undermining the value of the resource, increasing water treatment costs, and causing significant health impacts. While groundwater depletion can be quickly reversed, contamination, saltwater intrusion, and land subsidence are either too costly or impossible to reverse.

In spite of these growing concerns, groundwater in South Asia remains essential for sustaining livelihoods and economic growth and for building climate resilience. If planned and managed with surface water, groundwater offers important cost-effective future options for building drought and climate resilience.

Given both these important challenges and significant opportunities—all of which are shared across the region—the World Bank with the support of various partners convened a South Asia Groundwater Forum in India in 2016 to discuss groundwater policy and management, to share good practices and lessons from across and outside, and to strengthen technical and knowledge-sharing networks. The active participation in the forum of 128 current and former policy makers and groundwater managers from governments across the region, regional and international specialists, researchers, and academics is testimony to the criticality of groundwater management and governance in South Asia. The wealth of knowledge and experience shared, and the networks and connections established and strengthened, provide a sound basis for promoting and accelerating groundwater policy and institutional reforms and enhanced local, national, and regional action for sustainable groundwater management. These proceedings capture the knowledge and lessons shared and the dialogue that took place during the forum, with a view to providing a lasting record and facilitating wider dissemination.

Acknowledgements

The South Asia Groundwater Forum – Regional Challenges and Opportunities for Building Drought and Climate Resilience for Farmers, Cities and Villages – was held in Jaipur, Rajasthan, India from June 1–3, 2016. This Forum was convened by the World Bank in partnership with the Government of India and the International Water Association. Valuable technical and leadership support was provided by the International Water Management Institute. The Forum continued and broadened the dialogue started at the regional water-energy-food nexus workshop in Kathmandu, Nepal (February 2015), convened by the World Bank, the Nepal Fulbright Commission, the US Department of State, the International Centre for Integrated Mountain Development and the Nepal Water Conservation Foundation. Both dialogue events were funded primarily by the South Asia Water Initiative – a multi-donor trust fund managed by World Bank and generously supported by the governments of the United Kingdom, Australia and Norway.

The World Bank team for the Forum was led by Dr. Rafik Hirji and included Ms. Priyanka Chaturvedi and Dr. William Young. The World Bank thanks the many individuals, institutions and partners who contributed to the success of the Forum. Critical support for the original concept came from Mr. Parameswaran Iyer (then World Bank Water Practice Manager for South Asia), Mr. Shashi Shekhar and Dr. Amita Prasad (then Secretary, and Joint Secretary, respectively, of the Ministry of Water Resources, River Development & Ganga Rejuvenation, India).

The International Water Association was contracted to lead the planning and delivery of the Forum. The IWA team, led by Mr. Ganesh Pangare with excellent support from Ms. Sushmita Mandal, Dr. Ger Bergkamp and Ms. Neena Rao, was instrumental in making the event a success, and in helping to compile the Forum proceedings. The World Bank acknowledges the support from Indian central and state departments (especially the Central Groundwater Board), numerous international partners and collaborators (AWP, CSIRO, DFAT, DFID, IGRAC, IWMI, OECD, USGS, USWP) as well as participants who assisted as speakers, session chairs, facilitators and conveners.

The team also thanks the Water Global Practice leadership team for their encouragement, guidance and participation in the Forum, especially Jennifer Sara (Director), Jyoti Shukla (Director) and Meike van Ginneken (Practice Manager).

Finally, the SAWI team is thankful to Alex Behr for copyediting; XXX for desk topping, cover design and formatting; and YY for printing the proceedings. [[AQ: to come]]

Abbreviations

ACIWRM	Advanced Centre for Integrated Water Resources Management, India
AIT	Asian Institute of Technology, Bangkok
AWP	Australia Water Partnership
BWDB	Bangladesh Water Development Board
CGWB	Central Ground Water Board
CKDu	Chronic kidney disease of unknown etiology
COP	Conference of the Parties
CSIRO	Commonwealth Scientific and Industrial Research Organisation, Australia
DFAT	Department of Foreign Affairs and Trade, Australia
DFID	Department for International Development, United Kingdom
DJB	Delhi Jal Board
DRBC	Delaware River Basin Commission
DSCGPP	Delaware State Comprehensive Groundwater Protection Program
DTW	Deep tube wells
DWASA	Dhaka Water and Sanitation Agency
EPA	Environmental Protection Agency
ESTH	Environment, Science, Technology and Health
FAO	Food and Agriculture Organization, United Nations
GDP	Gross domestic product
GEF	Global Environment Facility
GIS	Geographic information system
GoB	Government of Bangladesh
GoI	Government of India
GRAPHIC	Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (UNESCO)
GWRDC	Gujarat Water Resources Development Corporation
IAH	International Association of Hydrologists
ICIMOD	International Centre for Integrated Mountain Development
IEC	Information, education, and communication
IGB	Indo-Gangetic Basin
IGRAC	International Groundwater Resources Assessment Centre
INDCs	Intended Nationally Determined Contributions
IPCC	Intergovernmental Panel on Climate Change
IRDP	Irrigation Restoration and Development Project, Afghanistan
IT	Information technology
IWA	International Water Association
IWMI	International Water Management Institute
LEAD	Leadership for Environment and Development
LLP	Low loft pumps

MAR	Managed aquifer recharge
MARVI	Managed Aquifer Recharge through Village-level Intervention
MEW	Ministry of Energy and Water, Government of Afghanistan
MJSY	Mukhyamantri Jal Swavlamban Yojana
MoEFCC	Ministry of Environment, Forest and Climate Change, India
MoWRRDGR	Ministry of Water Resources, River Development and Ganga Rejuvenation, India
NASA	National Aeronautics and Space Administration
NGO	Nongovernmental organization
NWCF	Nepal Water Conservation Foundation
OECD	Organisation for Economic Co-operation and Development
PCSIAP	Pothohar Climate Smart Irrigated Agriculture Project
SAARC	South Asian Association for Regional Cooperation
SAWI	South Asian Water Initiative
SCARP	Salinity Control and Reclamation
SDG	Sustainable Development Goal
SEWA	Self Employed Women's Association
SPIP	Solar-powered irrigation pumps
STW	Shallow tube wells
TOD	Time of day
UNESCO	United Nations Educational, Scientific and Cultural Organization
UNICEF	United Nations Children's Fund
USAID	United States Agency for International Development
USDS	United States Department of State
USGS	United States Geological Survey
USWP	United States Water Partnership
WARPO	Water Resources Planning Organization, Bangladesh
WASA	Water and Sanitation Agency, Pakistan
WEF	Water and Environment Foundation, Pakistan
WENEXA	Water-Energy-Nexus, USAID
WHO	World Health Organization

Executive Summary

The South Asia Groundwater Forum provided a platform for sharing of knowledge, experience, innovation and lessons on groundwater management, and offered a platform for discussing strategies for elevating, at the policy level, the vital role groundwater plays in the water sector across South Asia. Groundwater, a common pool resource, offers low-cost, drought-resistant and usually high-quality water to meet rural, urban, industrial, and irrigation demands.

The region is highly dependent on groundwater and this dependence is expected to increase as economies grow, populations grow, surface supplies become less reliable and climate changes. Yet groundwater management in South Asia is a complex challenge. Its quasi open-access nature makes its management one of the most complex and socially challenging sets of issues facing the region today. Its management spans numerous sectors – agriculture, energy, environment, health, industry, land, rural, urban, and water - and many administrative and political jurisdictions – villages, towns, cities, districts, states or provinces, and nations.

If protected, used wisely and managed conjunctively with surface water, groundwater can play a vital role in and provide a highly cost effective option for adapting to climate change and building water sector resilience. The alternative – unmanaged groundwater development – is a major, long-term threat to economic growth, livelihoods, health and environmental sustainability. Under-valuing groundwater in water policies, limited groundwater knowledge and weak governance are amongst the key causes of unsustainable groundwater management. Addressing these challenges is central to achieving drought and climate resilience. The forum described the current groundwater situation in South Asia, discussed policy and management options, considered transboundary issues, and recommended policy reforms and local, national and regional action for sustainable use and management of groundwater to build drought and climate resilience in South Asia. A summary is provided below.

The South Asia Groundwater Situation

Droughts are frequent in South Asia; they impact large areas and devastate livelihoods. Arid and semi-arid areas of Afghanistan, Pakistan, and north-west India are the most vulnerable, but other parts of the region (including Sri Lanka), are also vulnerable. Arid/semi-arid and variable climates require storage and judicious use of water. About 80% of rain in much of South Asia falls from June to September, making seasonal storage of water critical (in dams, reservoirs and tanks, as well as in aquifers, wetlands and lakes) to provide reliable supply buffer for lean periods. The 2015-16 El Nino monsoon failure, coupled with soaring temperatures, affected 330 million people in India alone, with devastating socioeconomic impacts. In Sri Lanka, water for drinking, irrigation, livestock and hydropower was affected, with significant livelihood consequences. This drought reinforced the learning that drought is not always caused solely by meteorological conditions, but can also partly be a results of failed water resources planning and management.

Both alluvial and hard rock aquifers are common in South Asia, and require different approaches to management given the differences in aquifer resilience to change and ease of abstraction and *recharge*. The large storage volumes, slow response time, and protection from evaporation are important characteristics for drought resilience, as aquifers provide a buffer against short and medium term climate variability. Integrating these characteristics in water resources planning and management decision making can help to harness substantial opportunities for developing drought and climate resilient strategies.

The region's immense natural storage is underappreciated and underutilized. The transboundary Indo-Gangetic Basin (IGB) alluvial aquifer, underlying most of Pakistan, northern India, southern Nepal and Bangladesh, is one of the most productive and highly used aquifers in the world. Hard rock aquifers are found in peninsular India, Nepal and Sri Lanka. The IGB aquifer has immense natural storage – 100 times the total constructed surface water storage-dams, reservoirs and tanks-in the region, and more than 20 times the combined annual flow of the Indus, Brahmaputra and Ganges rivers. This vital IGB aquifer remains underappreciated; it is largely unprotected, insufficiently monitored, inadequately managed and utilized sub-optimally.

Groundwater was key to the "green revolution" in South Asia, lifting millions out of poverty through improved water and food security and greater farmer control. About 62% of the region's 555 BCM of renewable groundwater has been developed, making South Asia world's largest abstractor of groundwater with over 30 million private irrigation wells and tube wells pumping about 347 BCM/year (~34% of global groundwater use). India, Pakistan and Bangladesh combined, pump almost half of the world's groundwater used for irrigation, supporting the livelihoods of 60-80% of the population; and groundwater supports 60-80 % of regional domestic and industrial supply. While there are opportunities for further development in several parts of South Asia, intensive, unplanned, unregulated and unmanaged pumping for irrigation, exacerbated by free or subsidized electricity, has caused rapid water level decline in the densely populated areas of the Middle Indus and Upper Ganges. Rapidly declining water levels are causing yield reduction, pump failure, unreliable rural and urban water supply, saltwater intrusion, land subsidence, and drying wetlands. They increase the cost of drilling and pumping deeper, and disproportionately impact the poor.

Groundwater contamination is a serious and widespread problem – in many cases being a bigger problem than depletion. Natural and anthropogenic contaminants are impacting drinking supplies in cities, major towns and villages, exacting a heavy cost on public health. Chronic Kidney Disease or unknown etiology (CKDu) linked to groundwater is costing lives in Sri Lanka. Salinity is impacting irrigation supplies. Parts of Sri Lanka are facing CKDu linked to groundwater. Policy responses need to support integrated top down and bottom up actions, supported by properly designed groundwater monitoring programs, improved knowledge, targeted research, diagnostic capabilities and health services. Many cities in the region (Lahore, Karachi, Lucknow, Delhi, Bangalore, Kabul, Dhaka and Kathmandu) are faced with both falling groundwater tables and contamination from arsenic and fluoride, as well as from sewage, industrial effluent, and solid waste leachate. Urbanization with inadequate land use planning and control, reduces the areas, rates and quality of groundwater recharge. Nanotechnology filter offers cost-effective solutions for arsenic removal.

South Asian water policies are hsurface water biased. Despite the region's heavy dependence on groundwater, South Asian water policies are heavily biased toward surface water. In India, a disproportionate emphasis has been placed on surface water management and investment compared to groundwater, even though groundwater supports 65% of irrigation supply and 85% of drinking supply. The region's groundwater departments have limited mandates and limited technical and administrative capacity to regulate, control, manage, and protect groundwater. Financial investment in groundwater governance and management is not commensurate with the resource value. Groundwater governance has not been accorded a priority. All South Asia countries could benefit from reforming water policies, improving groundwater knowledge, promoting collective action, building groundwater management capacity, and funding and strengthening groundwater governance. The high recharge potential of the Terai, Aravalli and other forests, and the storage value of traditional structures (tankas and baolis), represent often overlooked opportunities. Strong policies are required to drive change in farmer behavior.

Policy and Management Options

Building a sound knowledge base for linking science to water policy is essential for improving groundwater management. Investment in in situ groundwater monitoring, a sound knowledge base, and assessment capability are essential for building adaptive capacity. This is important for quantifying aquifer characteristics; aquifer discharge, recharge and storage; groundwater withdrawal and sustainable yields; understanding contaminant movement and establishing how land use impacts recharge. Groundwater models can aid in estimating safe yield, understanding aquifer response to different degrees of stress, and predicting the fate and transport of contaminants in aquifers. Development of a groundwater typology can help to define appropriate development and management strategies. Geographic information system (GIS) tools and remote sensing applications can be used to complement and validate in situ observations and analysis. Box ES.1 notes the need for monitoring and studying transboundary aquifers and lessons from international cases that could be useful for South Asia. Investment in groundwater monitoring networks and in building a sound knowledge base needs to be prioritized for building adaptive capacity.

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Box ES.1: Management of Transboundary Aquifers of South Asia

There is a growing need for joint monitoring and study of South Asia's transboundary aquifers. A recent NASA study using the GRACE satellite found that the Indus basin aquifer is the world's second most stressed aquifer, confirming in-situ observations. While many in-country groundwater studies have been carried out by the respective government agencies, there are no formal arrangements for jointly monitoring, studying or managing the region's transboundary aquifers. Joint monitoring of shared aquifers can improve understanding of the resource and

guide management decisions and joint studies can help develop regional solutions to regional problems**.** Transboundary groundwater management case studies presented at the forum offer useful lessons for South Asia. The U.S.–Mexico border aquifers and the Middle East aquifer shared by Israel, Palestine, and Jordan are examples in which joint monitoring and studies provided the foundations for eventual joint management of transboundary aquifers. They demonstrate how scientific and organizational challenges of managing transboundary aquifers can be overcome and how collaboration and cooperation can be fostered.
[end box]]

Understanding the political economy of the groundwater-energy-food nexus is central to developing solutions for sustainably managing groundwater. Experience from OECD nations and South Asia shows that multiple instruments like economic, regulatory and collective actions can be used to respond to long term aquifer depletion and environmental externalities - pollution, saltwater intrusion, aquifer compactions. Solutions need to be farmer-centric; understanding famer behavior is key, especially with regards to electricity subsidies.

Greater policy coherence across water, energy, agriculture, environment, industry, health, and land sectors is required. With growing water scarcity and vulnerability to climate change, greater policy coherence across the water, energy, agriculture and other sectors is required, aligning incentives for farmers, politicians, governments, power utilities and utility employees, and simultaneously promoting efficiency in energy and groundwater for implementing "win-win" solutions for sustainable groundwater use. Urban water supply needs to integrate surface water and groundwater, and be based on regulating and controlling groundwater use and municipal and industrial wastewater discharges, and protecting recharge areas. Rural groundwater supply needs to integrate community, water, and health sectors. With a rapid growing interest in solar-powered groundwater pumps, caution is required as widespread adoption without regulation will likely accelerate groundwater depletion and result is a déjà vu situation for South Asia.

Sustained financial and political commitment is essential for sustained water policy and institutional reforms. Incremental responses will result in incremental impact, which cannot lead to building effective drought and climate resilience. Administering reforms is a long process of continual learning and adaptation and it needs sustained efforts and funding and political commitments.

Groundwater governance in South Asia is challenged by dated laws or a lack of adequate legal frameworks or weak institutions. For example, Easements Act (India, Pakistan and Bangladesh), 1882, with limited responsibility assigned at the federal level, makes top-down and national water resource management efforts difficult to implement. In additional, clear policy frameworks for groundwater management are lacking. Better regulation for controlling and regulating use, protecting and conserving groundwater is needed in most countries, based on clear definitions, identification of issues, clear roles, responsibilities and accountabilities, and strong institutions for enforcement. Regulation helps control abstraction and use; control waste discharges; control land use; and support community based groundwater management. Implementation and enforcement are key to the success of groundwater regulation but the record is weak.

Experience shows that successful implementation hinges on the engagement with target users in all phases of the regulatory cycle. The existence of a dedicated groundwater administration, structured and phased preparations by the groundwater administration in advance of regulation roll out, and effective monitoring, and pursuit of unlawful behavior were important for successful implementation of groundwater regulation. In several South Asia countries, federal-provincial groundwater management arrangements need to be properly defined and funded. In addition, legal frameworks can facilitate and support the management of transboundary aquifers.

Promising community-based groundwater management lessons need to be sustained and scaled up. When farmers and villagers are educated about the importance of groundwater to their livelihoods and about ways to protect it; they become more enthusiastic about monitoring and protecting groundwater once they realize that this will benefit them in the long run. Communities and villages need to be actively involved and empowered in the process. Various examples from Bangladesh, India and Pakistan were shared by participants. Policymakers need to combine traditional wisdom of local communities with the latest in science and technology to come up with region-specific solutions. Building capacities of communities, empowering them to make decisions, and holding them accountable to their decisions are essential elements for promoting sustainable community based groundwater management.

Groundwater protection and conservation is very cost effective. Slow aquifer response time means that problems (e.g., pollution, saltwater intrusion) become apparent slowly; there is always a lag between when they occur and when they become evident. Some consequences of poor groundwater management (e.g., saltwater intrusion, land subsidence) are either irreversible or very costly to reverse, justifying proactive planning, protection and management. Aquifer protection plans can be developed to control abstraction. Pollution control and managed aquifer recharge need to be carried out in conjunction with land-use planning and zoning.

Managed aquifer recharge and conjunctive use and management of surface and groundwater offer promising adaptation opportunities, by promoting efficient use of aquifer storage during wet periods to off-set limited surface supplies during lean periods. Recharge structures, like check dams, need to be located and designed using sound hydrogeological knowledge as does the design of conjunctive management of surface water and groundwater to optimize use of water.

A shift from "top-down versus bottom-up" to harmonizing "top-down and bottom up" is needed. Top-down centralized approaches have limitations in managing a common pool resource yet they are needed to serve vital functions such as setting national water use priorities, promoting links with food, energy and environment policies, establishing laws, extraction control, supporting strategic planning for urban water supply or facilitating management of aquifers shared by different districts, provinces/states or nations. But top-down approaches are not sufficient nor practical for regulating millions of individuals pumping across the region. Incentives to inform collective action need to be an essential element of management. Experience in community based groundwater management is evolving, with some successes. But there are limitations in bottom-up approaches, including lack of clear policy, reliable data and information, capacity, accountable decision making and sustainability beyond project funding. The severity of South Asia's groundwater crisis, the recurrence of drought and changing climate leaves little choice to continue ad hoc experimentation between top down and bottom up approaches. The urgency to act calls for adopting both top down and bottom up approaches in a coherent but phased manner drawing from numerous emerging experiences. In the long run, harmonizing top down and bottom up approaches will be key for sustainable groundwater management and governance.

Forum Recommendations

Adaptive groundwater management requires implementing a variety of policy reform options. The forum discussions converged towards the following water policy reform actions to address the region's groundwater management challenges in a more concerted manner with surface water through adopting integrated water resources management:

- Invest in groundwater knowledge and science to support evidence-based decision making
- Elevate political/public awareness of the value of groundwater and opportunities it presents
- Develop, strengthen, and implement groundwater policies and legislation
- Prioritize training and capacity building for farmers, professionals and policy makers
- Scale up community-based groundwater management and collection action initiatives
- Build technical and administrative capacity, empower and fund groundwater institutions
- Build and strengthen groundwater regulatory capacity
- Invest in demand management, including improved irrigation water use efficiency
- Promote planned MAR and conjunctive management of surface and groundwater
- Develop groundwater management plans
- Encourage cooperative monitoring, assessment, and management of transboundary aquifers
- Act now to take the necessary decisions to address what is known
- Organize and mobilize support for addressing complex and longer term actions and reforms

In addition, the closing speakers noted the importance of continuing the open dialogue and knowledge sharing that characterized this important forum, recommended relooking at the existing water policies, legislation, institutions, and capacity building with a strong groundwater lens, and conducting in-depth research to operationally define how improved groundwater governance and management builds drought and climate resilience.

Chapter 1
Background

The Government of India (GoI), in partnership with the World Bank and the International Water Association (IWA) and with the support of the International Water Management Institute (IWMI), hosted the three-day conference "South Asia Groundwater Forum: Regional Challenges and Opportunities for Building Drought and Climate Resilience for Farmers, Cities and Villages," funded by the South Asia Water Initiative (SAWI), at Choki Dhani Resort in Jaipur, Rajasthan, from June 1–3, 2016.

Forum Context

Groundwater is a vast and vital resource that has provided abundant social and economic benefits in South Asia, but it remains highly undervalued. Groundwater can provide low-cost, reliable, drought-resilient, decentralized, and usually high-quality water supply to meet the rural, urban, industrial, irrigation, and livestock demands of over a billion people and sustain vital ecosystems. In arid and semi-arid regions, it is often the sole source of water supply.

Over the past six decades, groundwater development has accelerated rapidly but largely in an unplanned, uncontrolled, and unmanaged manner. Prominent hydrogeologists call this the "silent revolution" since it has occurred largely unnoticed and in a policy vacuum. Unmanaged groundwater development is contributing to rapidly declining water tables, contamination, land subsidence, saltwater intrusion, and overall deteriorating resource base. Some of these consequences impose a high cost on irrigation and drinking water supplies, and in some areas groundwater is no longer sufficiently reliable to provide drought resilience. Other consequences are irreversible or costly to reverse. While groundwater helped spur the Green Revolution, the resulting benefits are now at risk from the depletion or contamination of aquifers.

Forum Objectives

The forum objectives were to (a) elevate the discourse, at the policy level, on the vital role groundwater plays in the water sector across the region (Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Pakistan, and Sri Lanka), and (b) build a cooperative network of technical expertise to guide improved groundwater management in South Asia. The forum brought together 128 participants including 48 decision makers and 80 technical experts, and community representatives from across and outside South Asia and provided a platform to (a) share knowledge and experiences in groundwater management and governance, and (b) discuss opportunities for local, national, and regional action to achieve sustainable groundwater use and build drought and climate resilience.

Participants and Resource Persons

Forum participation was by invitation only. The 128 participants came from 18 countries (including five out of the six largest groundwater abstracting nations of the world) and eight institutions. They formed an eclectic group of senior bureaucrats, including former ministers of water resources, policy makers, scientists, and experts from all the seven countries of South Asia (Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan, and Sri Lanka) and China; and local, national, regional, and international experts on various disciplines related to the governance of groundwater. See appendix A for the list of forum participants.

Forum Approach

Recognizing the complexity of managing groundwater across South Asia, the forum adopted a multisectoral and multijurisdictional perspective on groundwater focusing on the vital role it plays in urban and rural economic development. The conference drew from emerging knowledge, experiences, and innovations generated from within and outside South Asia.

The forum adopted a multisectoral perspective by focusing on knowledge, experience, and opportunities to inform policy reforms; practical action; and groundwater programs for supporting rural, urban, and irrigation supply. Such a perspective recognizes that aquifers are impacted by rural and urban development and land use changes, energy policies, and waste discharges from industries, municipalities, and agriculture. The forum explored the groundwater-energy-food nexus, building on recent work and the regional water-energy-food nexus workshop convened in Kathmandu, Nepal (February 2015) by the Fulbright Commission with World Bank support. In addition, the conference drew from experiences from South Asia and Organisation of Economic Co-operation and Development (OECD) nations.

The forum recognized that aquifers span across and are shared by multiple administrative and political boundaries from villages, cities, districts, states, and provinces to nation states. To optimize benefits of groundwater, the multijurisdictional nature of aquifer boundaries is vital to understand and integrate in its planning and management decision making. Sustainable management of groundwater requires a collaborative and cooperative approach to planning, management, and development of the aquifer systems. A recent regional study of the Indo-Gangetic Basin (IGB) aquifer (MacDonald et al. 2015[1]), and international case studies offered useful lessons about the challenges of managing transboundary aquifers and approaches to foster collaborative and cooperative management of shared groundwater systems.

The forum drew from existing and emerging experiences and knowledge generated from within and outside South Asia. These experiences included policy issues related to the groundwater-energy-food nexus; the challenges of instituting and enforcing groundwater regulation; experiences on community-based groundwater management, urban water supply management, and irrigation development; and lessons about building drought and climate resilience.

[1] MacDonald, A. M., H. C., Bonsor, K. M. Ahmed, W. G. Burgess, M. Basharat, R. C. Calow, A. Dixit, S. S. D. Foster, K. Gopal, D. J. Lapworth, and R. M. Lark. 2016. “Groundwater Quality and Depletion in the Indo-Gangetic Basin Mapped from in Situ Observations. *Nature Geoscience* 9: 762–66.

Groundwater quality management issues were presented and innovative use of nanotechnology discussed. Lessons from the recently completed Global Environment Facility- (GEF)-funded global project (Groundwater Governance: A Call for Action) implemented jointly by the Food and Agriculture Organization (FAO), the United Nations Educational, Scientific and Cultural Organization (UNESCO), International Association of Hydrologists (IAH) and the World Bank, work done by the International Groundwater Resources Assessment Center (IGRAC), the International Water Management Institute (IWMI), and the World Bank, and findings of a regional Department for International Development (DFID) study and groundwater governance studies, as well as a collection of articles, studies, and reports from local, national, and regional research on groundwater management and governance were shared in USB flash drives with forum participants.

Forum Format

The three-day forum was structured around three broad themes and 14 sessions (an inaugural session, nine sessions, three breakout sessions, and a closing session). The first day's theme, "Understanding the Value and Limits of a Vital Hidden Resource," included the inaugural session and sessions 1–4. The second day's theme, "Foundation for Sustainable Groundwater Use and Management," included sessions 5–9. The third day's theme, "Building Drought and Climate Resilience for Farmers, Cities and Villages," included sessions 10–12 and the closing session. Appendix A contains the forum program. Appendix B contains the list of participants. Appendix C includes the forum's PowerPoint presentation slides.

Day 1: "Understanding the Value and Limits of a Vital Hidden Resource." The inaugural session opened with high-level messages from the host on the devastating impacts of two years of drought, the urgency to find solutions to the water crisis, and the need for a more balanced water policy that integrates the role of groundwater in the economy and in drought and climate resilience. Welcome remarks by the World Bank senior director stressed the criticality of groundwater management. The opening address by the director general of the International Water Management Institute highlighted groundwater megatrends in South Asia. Session 1 framed the key role of groundwater in drought resilience and climate-change adaptation and discussed the political economy of groundwater-energy-food nexus. Session 2 discussed the major regional aquifers and the main challenges—depletion and contamination—contributing to unsustainable groundwater use, and emerging concerns about climate resilience and groundwater contamination. Session 3 presented national groundwater priorities in Afghanistan, Bangladesh, Bhutan, China, India, Nepal, Pakistan, and Sri Lanka. Breakout groups discussed priority actions and distilled lessons for building a knowledge base, identifying institutional capacity and policy needs for tackling depletion and groundwater-quality issues in irrigation and domestic water supply.

Day 2: "Foundations for Sustainable Groundwater Use and Management." The second day centered on sharing knowledge and experiences from South Asia and around the world on the governance foundations for sustainable groundwater management. Its focus was on understanding how science is used to inform groundwater policy as well as regulatory and management decisions; scaling up community-based groundwater management; supporting urban supply management; and learning about cooperative and collaborative groundwater management. It drew from diverse experiences and case studies from across South Asian nations (Bangladesh, India, Pakistan, Sri Lanka), the OECD, the United States, the U.S–Mexico aquifers, the Middle East, and global reviews. Urban groundwater supply cases were drawn from a regional study across Asia and case studies from Lahore, Delhi, and Dhaka. Breakout groups deliberated on success factors of best practice groundwater policy, regulations, and institutions.

Day 3: "Building Drought and Climate Resilience for Farmers, Cities and Communities." The final day started with lessons from local and international groundwater-management experiences on managed aquifer recharge, conjunctive use of surface and groundwater, and nanotechnology-based solutions for treating arsenic. This was followed by discussion on the groundwater-adaptation framework and a road map for building drought and climate resilience. Breakout groups identified climate change adaptation opportunities and policy incentives for sustainable rural, urban, and irrigation groundwater supply. The last session included a valedictory address by the guest of honor, a summary of key forum messages, and closing remarks by representative of the GoI, the International Water Association (IWA), and the World Bank.

Day 1: Understanding the Value and Limits of a Vital Hidden Resource

Inaugural Session
Master of Ceremony: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, International Water Association (IWA)

Welcome and Setting the Scene, Mr. Shashi Shekhar, Secretary, Ministry of Water Resources, River Development and Ganga Rejuvenation (MoWRRDGR), India
Welcoming Remarks, Ms. Jennifer Sara, Senior Director, Water Global Practice, World Bank
Groundwater Megatrends in South Asia, Mr. Jeremy Bird, Director General, International Water Management Institute (IWMI)

Political Economy of Groundwater
Chair: Mr. Shashi Shekhar, Secretary, MoWRRDGR, India

Groundwater Policy Implications for Building Drought and Climate Resilience in South Asia, Dr. Rafik Hirji, Team Leader, World Bank
The Political Economy of the Groundwater-Energy-Food Nexus: Towards Drought and Climate Resilience, Dr. Tushaar Shah, Senior Fellow, IWMI
Direct Delivery of Power Subsidy to Manage Groundwater-Energy-Food Nexus, Mr. Mohinder Gulati, former CEO, UN Sustainable Energy for All
High-Level Panel Discussion: Groundwater Policy Implications for Drought and Climate Resilience. **Moderator:** Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA. **Panelists:** (a) Mr. Shashi Shekhar, Secretary, MoWRRDGR, Government of India, (b) Mr. Nisar A. Memon, former Federal Minister, Pakistan, and Chairman, Water and Environment Forum (WEF), (c) Mr. Dipak Gyawali, Chair, Nepal Water Conservation Foundation (NWCF), and (d) Dr. Bill Young, Lead Water Resources Specialist, World Bank

Regional Groundwater Management Perspectives
Chair: Mr. Jeremy Bird, Director General, IWMI

Groundwater Resilience to Climate Change and Abstraction in the Indo-Gangetic Basin, Prof. Alan MacDonald, Principal Hydrogeologist, British Geological Survey
Groundwater Quality Challenges in South Asia and Options for Management, Prof. Kazi Matin Ahmed, Dhaka University

Panel: Country Groundwater Priorities
Co-chairs: Mr. Nisar A. Memon, former Federal Minister, Pakistan, and Chairman, WEF, and Ms. Mieke van Ginneken, Manager, World Bank

Country Presentations

- Afghanistan: Mr. Sayed Sharif Shobair, Coordinator and Chief Engineer, Food and Agriculture Organization (FAO)/Irrigation Restoration and Development Project (IRDP), Afghanistan
- Bangladesh: Dr. Anwar Zahid, Deputy Director, Bangladesh Water Development Board
- Bhutan: Mr. G. K. Chhopel, Chief Environment Officer, Water Resources Coordination Division, National Environment Commission
- China: Prof. Guangheng Ni, Director, Institute of Hydrology and Water Resources, Tsinghua University
- India: Mr. Dipankar Saha, Senior Member, Central Ground Water Board (CGWB)
- Nepal: Mr. Dhana Bahadur Tamang, Secretary, Water and Energy Commission Secretariat, Government of Nepal
- Pakistan: Dr. Muhammad Riaz, Director, Program Monitoring and Implementation Unit, Punjab Irrigation Department
- Sri Lanka: Mr. Ranjith Seevali Wijesekera, General Manager, Water Resources Board, Government of Sri Lanka

Group Work I—Tackling Irrigation and Domestic Water Supply Challenges
Facilitator: Dr. John Dore, Senior Water Resources Specialist, Department of Foreign Affairs and Trade (DFAT)

Chapter 2
Inaugural Session

Master of Ceremony: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA

Welcome and Setting the Scene—Mr. Shashi Shekhar, Secretary, MoWRRDGR, India. Secretary Shashi Shekhar extended a warm welcome, on behalf of his government, to all delegates and organizers to Jaipur, especially to those who had traveled from afar. He acknowledged that the forum was very timely since India was grappling with a severe drought due to the failure of two years of the monsoons that impacted the livelihoods of more than 300 million people. He enunciated the importance of groundwater for India: it provides 65 percent of the nation's irrigation water supply and 85 percent of the drinking water supply. He noted that poor water management was a widespread problem in spite of such good examples as Hiware Bazar (Maharashtra) Gram Panchayat, in which water was rationed to prioritize the needs of humans and agriculture. He called for solutions that integrate traditional systems and wisdom with modern science and technology for water budgeting, prioritization, and harvesting, with local community participation.

Secretary Shekhar highlighted the failure of government's water policy for putting a disproportionate emphasis on surface water as opposed to groundwater, leading to investment of vast sums of funds for surface water storage with little attention to the management of groundwater. On an average year, India receives 30–35 downpours over 90 days, and this water has to sustain 90 percent of the country's water requirements: 30–35 days of rainfall must meet the needs of 365 days. With all the funds used, surface storage capacity is still very limited, and the opportunity for systematically recharging rainwater into aquifer is limited. Cautioning against over exhaustion of groundwater, he said digging deeper is not a viable option in many areas, such as in hard rock areas, so funds are wasted. Extensive rainwater harvesting needs to be a solution. The government had earmarked 2.3 million ha for recharging groundwater. All areas with high recharge potential, such as the bountiful Terai, Aravalli, and other forests, must be used to increase groundwater recharge. Water storage needs to be increased. Capacities of traditional storage structures, such as *tankas* and *baolis,* and big reservoirs need to improve.

The impact of climate change is clearly visible; three-quarters of the country has been affected by drought over the last two years. Groundwater can provide resilience against climate change. And today, political will for realizing this opportunity exists. In response to the ongoing drought over the last month alone, the prime minister held 11 meetings with chief ministers of 14 states to develop short- and long-term solutions to the water crisis. Secretary Shekar urged forum experts from around the region and the world to bring relevant knowledge and experiences to address the region's groundwater crisis.

Welcoming Remarks—Ms. Jennifer Sara, Senior Director, Water Global Practice, World Bank. Ms. Sara's remarks stated the importance of water security for all and made a case for the criticality of groundwater management. Water, central to development, has not been managed as a renewable resource. She noted that the impact of water scarcity on gross domestic product

(GDP) was high, especially in the South and East Asia regions, but improved water management can drive growth. She highlighted the need to (a) build resilience against water-related hazards such as floods, droughts, and pollution; (b) increase access to safe, sufficient, and affordable water for meeting domestic drinking, sanitation, and hygiene needs; (c) provide adequate water for food and energy production, industry, transport, and tourism; and (d) preserve ecosystems to deliver their services on which both nature and people rely. Over 4 billion people currently live in areas that face different degrees of water scarcity.

The World Bank's commitment to water development is reflected in the Water Global Practice lending of US$ 25 billion, including 172 projects in its water portfolio (plus US$ 10 billion in water programs in other global practices). Twenty-eight percent of this lending (US$ 6.9 billion, including 25 projects) was in the South Asia Region.

Ms. Sara stated that sustainable development goal (SDG) 6 relates to improving water management, which requires better planning, improved efficiency, and acting against pollution as well as implementing integrated water resources management at all levels, including transboundary cooperation. Policy and institutional reforms were important and needed to be followed by investments.

South Asia faced complex water management issues, including being a global groundwater hotspot. Ms. Sara noted that 54 percent of India faced high water stress, and water levels in 54 percent of India's wells were declining.

Groundwater management is a complex multisectoral challenge, compounded by the common pool nature of the resource. The region needs to develop solutions that can be applied at small and large scales. Solutions must address the water, energy and food nexus.

Ms. Sara noted that the World Bank was working with the GoI to prepare a major groundwater project, and stated the importance of developing new models that can be adopted and replicated in various states. In this regard, the forum was timely in addressing a critical development challenge and was where international experiences would be shared from all over South Asia and beyond. She ended her remarks by extending a warm welcome to all the participants to the South Asia Groundwater Forum.

Groundwater Megatrends in South Asia—Mr. Jeremy Bird, Director General, IWMI. Mr. Bird highlighted the importance of groundwater in South Asia not only for meeting the basic needs of livelihood but also for future growth opportunities, and expressed his hope that the forum would enable a rich exchange of experiences on groundwater monitoring and productive usage.

Mr. Bird spoke about the challenges of deteriorating groundwater quality and its impact. If groundwater is exhausted beyond a limit, it becomes unsustainable, thus rendering it a nonrenewable water source, and a lack of awareness about this problem was a big concern. Surface water is visible but groundwater is not. This characteristic makes it more difficult to assess the availability and quality of groundwater compared to surface water. In addition, there is a lack of common collective responsibility to manage groundwater. A recent report of the World Economic Forum (2016)[2] mentions declining water as a threat to businesses as well as public supply and private farmers.

Climate change has intensified problems concerning water resources, and groundwater is part of the solution. Change in policy leading to behavioral change needs to be at the heart of the discussion. For this purpose, communicating with the public and policy community regarding these issues is very important. For example, in the state of West Bengal, well endowed with groundwater, expansion of groundwater irrigation was possible as a result of communication on the state of resources, leading to policy directives incentivizing the use of groundwater for irrigation. However, without proper regulations in place it may not be sustainable, hence the same needs to be adapted in policy making.

Mr. Bird hoped that a forum like this, with representatives from various states and countries, would be useful to raise awareness about the challenges of the field and create political will for policy changes necessary for improving groundwater governance and usage. Adaptive policy making for groundwater governance is critical, but there is no one solution for all cases. For example, groundwater is a driving force behind irrigation, and farmers respond to policy signals. One of the first steps could be to promote use of small pumps for rainfed farmers to become more resilient. Mr. Bird concluded that the challenge is to foster resilience, adaptation, and transformation. Climate change and sustainable development goals agenda can be the opportunity to make this happen.

[2] World Economic Forum. 2016. *Global Risks Report 2016*. Davos, Switzerland: World Economic Forum. http://reports.weforum.org/global-risks-2016/.

Chapter 3
Political Economy of Groundwater

Chair: Shashi Shekhar, Secretary, MoWRRDGR, India

Groundwater Policy Implications for Building Drought and Climate Resilience in South Asia—Dr. Rafik Hirji, **Team Leader**, **World Bank**. Dr. Hirji set the context for the forum—how groundwater policy can promote the development of drought and climate resilience in South Asia—and the forum objectives. Groundwater plays a vital role in South Asia's socioeconomic development. It has delivered significant socioeconomic benefits, including improved water security; expanded urban, rural, industrial, and irrigation water supplies; enhanced food security; improved rural livelihoods; drought resilience; greater farmer control; and high-quality (sediment-free) water. In commercial agriculture, groundwater has supported the generation of more crops and jobs per drop than surface water for high-value crops.

Groundwater also sustains valuable ecosystems, including base flow in rivers, wetlands, and terrestrial vegetation. In some arid and semi-arid areas, it is often the sole water supply for people and livestock. It is also a relatively secure source of water supply for food production especially in times of drought. This makes groundwater a very important resource for developing drought and climate resilience.

South Asia is the largest user of groundwater; it accounts for nearly 50 percent of the total groundwater pumped for irrigation globally. Total groundwater abstracted in the Indo-Gangetic Basin (IGB) alone is about one-fourth of the global groundwater abstraction. The region has 555 billion cubic meters of renewable groundwater that can be used sustainably, and currently, around 62 percent (about 347 billion cubic meters) is developed. India, Pakistan, and Bangladesh are, respectively, the first, fourth, and sixth largest users of groundwater globally. India pumps more than the United States and China, the second and third largest users, respectively, combined.

Over the past six decades, groundwater development has accelerated rapidly but largely in an unplanned, uncontrolled, and unmanaged manner, especially in arid and semi-arid regions. Prominent hydrogeologists termed this phenomena the "Silent Revolution" in the editorial of the 2005 *Journal of Water Resources Planning and Management and Hydrogeology* (Llamas and Martínez-Santos 2005[3]); it has occurred largely unnoticed and in a policy vacuum. Rapid development of groundwater has occurred because of many factors, including increasing surface water scarcity from failing public supply, and cheap or free power supply to subsidize pumping costs. Unlike surface systems, groundwater does not require community infrastructure. It is also

[3] Llamas, M. R., and P. Martínez-Santos. 2005. "Intensive Groundwater Use: Silent Revolution and Potential Source of Social Conflicts." *Journal of Water Resources Planning and Management* September/October: 337–41.

relatively cheap to develop, and it is easy to bypass regulation. Resilience of aquifers to dry periods also makes groundwater attractive to develop. Improved technologies have also led to cheaper submersible pumps and drilling technologies. Although there is a significant potential to develop parts of the regional alluvial aquifer system in parts of South Asia, current groundwater use is unsustainable in many parts of South Asia. There is irrefutable evidence of unsustainable groundwater conditions. In situ monitoring data and satellite information indicate clear trends: declining groundwater levels, reduced storage, deteriorating groundwater quality, increasing salinization in inland and coastal aquifers, and emerging land subsidence problems. These trends represent a serious social and economic cost on farmers, cities, and villages since water supply and irrigation well failures are increasing, yields are declining, pumping costs are increasing, and water quality is deteriorating. In some cases, environmental externalities (such as salinization, land subsidence, and contamination) are either too costly to reverse or irreversible. Farmer suicide levels are on the rise, especially during droughts.

Groundwater has a few unique characteristics that differ from surface water. Understanding and integrating them in water policies and water management planning and decision making is key to harnessing the substantial opportunities for developing drought- and climate-resilient water resources system. Aquifers are large natural storage areas, have a relatively long detention time, and have a slow response to variations in precipitation and recharge. Therefore, coupled with aquifers' protection from evaporation, they provide a more effective buffer compared to surface water system against increased short- or long-term climate variability.

According to MacDonald et al. (2016[4]), the IGB aquifer has very large storage compared to surface water storage. Surface water storage in all South Asian dams, reservoirs, and tanks is less than 300 cubic kilometers. In contrast, the volume of groundwater stored only in the upper 200 meters of the IGB alluvial aquifer is estimated to be 30,000 cubic kilometers, or 100 times bigger than the existing surface storage. This groundwater storage is more than 20 times the combined annual flow of the Indus, Brahmaputra, and Ganges rivers. Low surface water storage means limited capacity for interseasonal or interannual storage. The large groundwater storage capacity can potentially provide an effective buffer to seasonal and interannual variations in climate and surface water flows, if these systems are managed well. And there lies South Asia's dilemma and opportunity.

Groundwater management is a complex challenge. It is not just a water resources problem, but a multisectoral and multijurisdictional urban and rural economic development challenge. It relates to many sectors, including agriculture, energy, environment, industry, health, lands, water, and rural and urban development. Aquifer boundaries are never limited to a single village,

[4] MacDonald, A. M., H. C., Bonsor, K. M. Ahmed, W. G. Burgess, M. Basharat, R. C. Calow, A. Dixit, S. S. D. Foster, K. Gopal, D. J. Lapworth, and R. M. Lark. 2016. "Groundwater Quality and Depletion in the Indo-Gangetic Basin Mapped from in Situ Observations. *Nature Geoscience* 9: 762–66.

city, district, state, province, or nation. They often span multiple administrative jurisdictions. The common pool nature of groundwater, multiple externalities, and data inadequacy compound the challenge.

According to major research done over the past few years by the Organisation for Economic Co-operation and Development (OECD 2015[5]), the United Nations Educational, Scientific and Cultural Organization Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (UNESCO GRAPHIC 2015[6]), and the World Bank (Clifton et al. 2010[7]), groundwater, if well managed, can and should act as a powerful drought-resilient and climate adaptation option for South Asia; in other words, it can be a natural insurance mechanism and not just a component of freshwater supplies. This overall goal of the South Asia Groundwater Forum was to start and facilitate a structured dialogue through sharing knowledge, experiences, ideas, and innovation that can help to harness the opportunities that groundwater potentially offers in building drought and climate resilience in South Asia. The South Asia Groundwater Forum objectives were to:

- Elevate, at the policy level, the vital role groundwater plays in the water sector across South Asia
- Build a community of practice—a network of technical expertise—to guide improved groundwater management in South Asia
- Share knowledge and experiences in groundwater management and governance
- Discuss opportunities for local, national, and regional action to achieve sustainable groundwater use and build drought and climate resilience

The Political Economy of the Groundwater-Energy-Food Nexus: Towards Drought and Climate Resilience—Prof. Tushaar Shah, Senior Fellow, IWMI. Prof. Shah noted that at the end of the colonial period, India inherited the world's largest (surface) canal irrigation infrastructure from the British government, but by the 1960s it had emerged as the world's largest groundwater irrigator. Rapid groundwater development in South Asia was currently consuming 1,280–1,350 billion units of electricity equivalent of energy use.

Large-scale groundwater development has little relationship with aquifer properties and potential. The main drivers of South Asia's groundwater boom included rapid population growth and the importance of agriculture for the rural poor. These factors have contributed to extreme pressure to intensify and diversify land use, and have increased demand for year-round, in-farm

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[5] OECD. 2015. *Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use*. OECD Studies on Water. Paris: OECD.

[6] UNESCO GRAPHIC. 2015. *Groundwater and Climate Change: Mitigating the Global Groundwater Crisis and Adapting to Climate Change, Position Paper and Call to Action*. UNESCO: Paris.

[7] Clifton, C., R. Evans, S. Hayes, R. Hirji, G. Puz, and C. Pizzaro. 2010. "Water and Climate Change: Impacts on Groundwater Resources and Adaptation Options." Water Working Note 25, World Bank, Washington, DC.

water control. In turn, different types of irrigation systems have increased dependence and pressure on groundwater, leading to unsustainable exploitation of this resource. Use of mechanical energy and year-round availability with low infrastructure costs has contributed further to the easy accessibility, taking it to the level of over exhaustion.

Historically, groundwater has offered greater drought resilience due to its stabilization and carry-over storage compared to surface water. In the future, it will be key to climate change adaptation because of the opportunities provided by effectively utilizing natural aquifer storage. Adaptation will require a postmonsoon groundwater level bounce through supply and demand management.

Prof. Shah discussed the energy-groundwater-food nexus: in states and provinces where there was no free electricity provided to the farmers, the cost of diesel acted like a speed breaker for groundwater exploitation. But in many states in India, electricity provides over 80 percent of the power used for pumping groundwater. Electricity subsidies to the farmers come in the form of waving connection costs, no metering, and free or subsidized power; these have contributed to intensifying groundwater exploitation and pumping deeper. Data from a survey of well owners from India and Bangladesh indicate that the annual hours of operating electrical pumps was more than double that of operating diesel pumps.

Solar irrigation pumps offer numerous opportunities and threats. They are a better alternative to costly diesel and poor-quality electric power and could possibly transform South Asia's groundwater economy. With the rise of solar irrigation pumps, the region, however, is at a déjà vu moment. If it is promoted thoughtlessly as electricity subsidies were, it will accelerate groundwater depletion like never before. Solar pumps will have a higher average use factor, be a boom for resource poor water buyers, intensify groundwater exploitation, and will make groundwater regulation impossible. The only practical way to make solar pumps benign is to connect them to the grid, net-meter them, and offer irrigators a long-term buyback contract for surplus solar energy. This will require addressing power company worries about high transaction costs of buying power back from numerous farmers. Feed-in tariffs offered to farmers in a solarized groundwater economy can be the central tool of groundwater governance.

Direct Delivery of Power Subsidy to Manage Groundwater-Energy-Food Nexus—Mr. Mohinder Gulati, former CEO, UN Sustainable Energy for All. Mr. Gulati presented findings from a recent study (Gulati and Pahuja 2015[8]) which offers a practical approach recommended for India: direct delivery of power subsidy to agriculture. The report focuses on how to create and align incentives of stakeholders to adopt sustainable use of groundwater in agriculture.

[8] Gulati, M., and S. Pahuja. 2015. *Direct Delivery of Power Subsidy to Agriculture in India*. Washington, DC: ESMAP. https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/SE4All-%20Direct%20Delivery%20of%20Power%20Subsidy%20to%20Agriculture%20in%20India_Optimized.pdf.

The agro-dependence of the majority of the rural population in South Asia, plus the electrification and subsidized energy for agriculture, have contributed to overexploitation of groundwater. In India, groundwater meets 60 percent of irrigation needs and 85 percent of drinking water needs. This heavy dependence has led to serious over abstraction in states such as Rajasthan and Punjab, and has made rural economies vulnerable to droughts, which will be further aggravated by climate change. Sustainable groundwater use was the cheapest adaptation measure against drought.

Mr. Gulati discussed the intractable problem of the energy-groundwater-agriculture nexus in India; the mutation of the subsidy policy (from free power to unmetered power); the contribution of groundwater irrigation to the Green Revolution (now an Achilles heel of the power sector); the severe and widespread groundwater depletion problem in India; National Aeronautics and Space Administration (NASA) data showing evidence of very large groundwater withdrawals; the deteriorating financial performance of power sector utilities; the key drivers of weak financial health; and the persistent capacity and energy sector deficits. In addition, he underscored a conundrum of a services-dominated economy for an agriculture dependent population and described reasons why solutions have eluded India for so long. He described the objectives of his study (Gulati and Pahuja 2015)[9] (based in Andhra, Karnataka, and Punjab) and its four key elements: (a) segregated feeders, (b) minimum energy support, and (c) smart metering and subsidy delivery and performance-based incentives for utility employees based on information and communications technology (ICT), and (d) incentives for key stakeholders: farmers, power utility staff, political executives, governments, and power utilities.

Mr. Gulati stated that sustainable use of groundwater is the cheapest adaptation measure against climate change and for mitigation of impact of drought. Water scarcity and growing vulnerability due to climate change requires policy coherence across water, energy, agriculture, and environment sectors. Dependence of 60 percent to 80 percent of the population in South Asia on agriculture drives the political economy of groundwater; thus, solutions have to be farmer-centric. Alignment of incentives for farmers, politicians, governments, power utilities, and utility employees, and simultaneous promotion of efficiency in energy and groundwater is critical for practical "win-win" solutions for sustainable use of groundwater. Keeping this in mind, he proposed some specific policy interventions, such as Jyotigram yojana (an initiative of the Government of Gujarat launched in 2006) to ensure availability of 24-hour, three-phase quality power supply to rural areas of the state and to supply power to farmers residing in scattered farm houses through feeders having specially designed transformers. It recommends a shift in approach from "power for irrigation" to "power and irrigation" with feeder segregation,

[9] Gulati, M., and S. Pahuja. 2015. *Direct Delivery of Power Subsidy to Agriculture in India*. Washington, DC: ESMAP. https://www.esmap.org/sites/esmap.org/files/DocumentLibrary/SE4All-%20Direct%20Delivery%20of%20Power%20Subsidy%20to%20Agriculture%20in%20India_Optimized.pdf.

improved supply and rostering, and feeder metering for better load management. These have been experimented with groundwater schemes and have proved to be successful in bringing about huge socioeconomic and political benefits. Experiences from Mexico; Columbia Water Center support in Gujrat; Water-Energy-Nexus- (WENEXA-) funded support in Karnataka; and field studies in east Uttar Pradesh, south Bihar, Gujrat, and Punjab also offer useful lessons.

High-Level Panel Discussion: Groundwater Policy Implications for Drought and Climate Resilience. Moderator Mr. Ganesh Pangare, Regional Director, Asia-Pacific, International Water Association (IWA), directed specific questions to and invited panelists to share their views on groundwater management in the region.

Mr. Deepak Gyawali, Nepal's former Water Resources Minister, was asked to explain the concept of groundwater-food-energy nexus. He responded that it can be viewed as an attempt to grapple with complexity. So far, water was treated in an extremely sectoral manner; from a nexus perspective this is a big problem. People do not like uncomfortable knowledge. For example, today when solar pumps are promoted as a good innovation from an energy demand and crisis perspective, it is necessary to take into account their side effects spilling over into other sectors such as groundwater. Thus, nexus thinking requires behavioral innovations and market innovations to manage water resources in an integrated fashion. All agencies (including government agencies) involved in water management need to be pluralistic and should provide space for anthropologists, sociologists, and so on, in the area of water resource management. So far, Singapore provides a good example in this part of the world.

When asked about the expectations and take-home message from this forum, **Dr. Bill Young, Lead Water Resources Specialist of the World Bank**, said that when we look at groundwater at the forum, it is not only to discuss issues of groundwater per se but also to look at it as a nexus. Groundwater is only a part of the bigger system. There are many other nuanced aspects within the water sector. The first step is to discuss it from a policy perspective. Thus the conversation is very important. The forum was a continuation of the conversation that had begun the previous year at the regional water-energy-food nexus workshop convened in Kathmandu, Nepal (February 2015). While addressing issues such as these, having an ongoing conversation is important in its own right. In the past, discussions have been largely supply-driven, focused primarily on abstraction. However, we need to look at "recharge" in a big way. There is traditional knowledge on recharge but not much work on recharge from new technology and innovations perspectives. Thus, there is need for critical thinking and analysis with regard to recharge of groundwater.

When asked about studies on groundwater in the region, **Mr. Nisar A. Memon, former Water Resources Minister, Pakistan**, said that good messages about groundwater have come up in the forum; however, we need to go back and ask the question: who are we addressing through these discussions? We talk about stakeholders: the biggest stakeholders are the people of the region. It is necessary to discuss the security of the people and the solutions that would help these people. We need regional solutions. A groundwater problem in Punjab (India) could be similar to that of the problem in Punjab (Pakistan). These are transboundary problems. Groundwater pollution is an example. Groundwater quantity and quality are severely affected by the amount of water that is pumped and wastewater discharged in these areas in both countries.

Various groundwater studies have been conducted in individual countries, but there is a great need for joint studies and research since the aquifers and the impact of their use are interconnected. One example is the Indus Waters Treaty, which has been successful so far, but it does not address groundwater. Mr. Memon expressed the need for Pakistan and India to conduct a joint groundwater study on the Indus Basin, and Pakistan and Afghanistan to conduct a joint study on surface and groundwater.

Prof. Maheshwari from Sydney stated that top-down approaches to groundwater management do not work. Instead village-level interventions can work, such as the MARVI project in Rajasthan.

When he asked a question on what needs to change from a policy perspective, **Mr. Shashi Shekhar** responded that groundwater plays a very important role in South Asia's economy. Policy makers need to understand groundwater and its dynamic nature to manage it. Stating the example of free power to farmers, he also emphasized the need for policy correction. Since 1998, he has witnessed ministers and bureaucrats from successive governments plead to charge farmers for electricity, but no decision has ever been taken against subsidies due to political pressures.

In the future, with solar pump prices going down, subsidies will not be required, but that is not going to solve the problem of groundwater overabstraction. Mr. Shekhar referred to inappropriate policies such as incentives to grow sugarcane in Maharashtra (a water scarce state) leading to depletion of groundwater. This has only worsened the drought situation. He reiterated the need to share knowledge on groundwater and its characteristics across all levels from the policy maker to the citizen. He also highlighted that groundwater quality (e.g., problems with arsenic or fluoride) is as important as its quantity.

Mr. Shekhar stated: "We are in a stress situation now and have reached a point of real crisis. There are continuing disputes between states due to water usage. Thus, this crisis has to lead to measures (and actions). Addressing the issues in parts (or ad hoc basis) is not enough anymore. Perhaps generations of efforts (long-term solutions) are required. Thus, it is important to understand this problem systemically at all governance levels and should be addressed at all the levels. This includes addressing water storage provisions, community participation and prioritizing water use, economizing consumption, and changing cropping patterns and eating habits."

Mr. Shekhar concluded by stating that it will not help to use only top-down policy tools in a hugely populated country like India. A huge army will be needed for its implementation. For implementation of progressive policies, we need the support of the people on the ground, and capacity building is an important tool for that. We need to develop institutions at the village level to build capacities. People have to be told that stable reserves of groundwater are like a fixed deposit that has to be carefully managed. Civil society has a big role to play in creating this understanding among the people. The MoWRRDGR has departed from legislation dominated by supply side to demand side management. The main thrust of the new law is on the demand side, community participation, and community capacity development. Water is a state subject, and he hopes that the model bill will take root in states and across villages to make sustainable groundwater use a reality.

Prof. Tushaar Shah was asked a question regarding the use of subsidies as a tool for the sustainable use of groundwater. He stated that this tool can be used imaginatively by changing the type of subsidy and by changing its pattern. For example, in the context of Pakistan, to regulate groundwater exhaustion subsidy or support could be given to farmers for water harvesting.

Mr. Gulati was asked why he had focused his study on agriculture alone and not looked at impacts on groundwater due to industrial use and urbanization. He responded by saying that urbanization and industrial use definitely are impacting groundwater in current scenarios but their impacts are localized and not widespread yet, unlike that of agriculture. There are microlevel impacts that are being experienced, for example, in places such as Dhaka where extraction of groundwater for drinking water are significant.

Bharati Ben from Self Employed Women's Association (SEWA), an Indian NGO, stated that this organization has supported rainwater harvesting and conservation efforts in Kutch and these lessons need to be replicated elsewhere in the country where problems of both water quantity and quality are rising.

Chapter 4
Regional Groundwater Management Perspectives

Chair: Mr. Jeremy Bird, Director General, IWMI

Groundwater Resilience to Climate Change and Abstraction in the Indo-Gangetic Basin—Prof. Alan MacDonald, Principal Hydrogeologist, British Geological Survey. Prof. MacDonald presented findings of a recently published Indo-Gangetic Basin (IGB) groundwater resilience study (MacDonald et al 2015). He quoted the 2014 IPCC report that “Climate change is projected to reduce renewable surface water and groundwater resources significantly in most dry subtropical regions” (IPCC 2014: 13[10]). Groundwater abstraction in South Asia is 340 km^3, or 34 percent of total current use globally.

Abstraction from the IGB is 25 percent of the global groundwater abstraction. Groundwater storage is 30,000 km^3, about 20 times the annual flows of the Ganges, Meghna, and Brahmaputra rivers, and 100 times the storage in all dams in South Asia. Yields are high: greater than 20 L/s. There are large variations in aquifer permeability, storage, and anisotropy. Groundwater levels are stable in 60 percent of the IGB aquifer and falling in 33 percent of the aquifer. Groundwater salinity, arsenic, and fluoride impact up to 60 percent of the aquifer areas. Salinity is both natural and manmade. Arsenic (natural) is associated with Holocene deposits and organic soils. Detailed case studies were investigated under the British Geological Survey study.[11] The Bengal case study reviews how deep groundwater (greater than 50 meters to 350 meters deep) responds to pumping. The Punjab case study reviews what the dominant recharge mechanisms were and how connected were the shallow and deep aquifers. The Himalayan foothills case reviews how much groundwater was used in the Middle Hills and how sensitive it was to climate change and land use changes. The IGB aquifer, with its immense natural storage, offers an excellent buffer to change. In the IGB, groundwater quality degradation is arguably a greater concern than depletion.

Groundwater is more vulnerable to abstraction than climate change. Aquifer properties and typologies are important for defining proper management strategies. Different geologies and characteristics of aquifers determine aquifer resilience to change and ease of abstraction and recharge. Recharge is from rainfall, canals, and rivers. Canal systems and canal lining—although meant to increase efficiency of surface water irrigation—limit groundwater recharge.

[10] IPCC. 2014. *Climate Change 2014: Synthesis Report Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.* Geneva, Switzerland: IPCC.

[11] MacDonald, A. M., H. C. Bonsor, R. Taylor, M. Shamsudduha, W. G. Burgess, K. M. Ahmed, A. Mukherjee, A. Zahid, D. Lapworth, K. Gopal, M. S. Rao, M. Moench, S. H. Bricker, S. K. Yadav, Y. Satyal, L. Smith, A. Dixit, R. Bell, F. van Steenbergen, M. Basharat, M. S. Gohar, J. Tucker, R. C. Calow, and L. Maurice. 2015. *Groundwater Resources in the Indo-Gangetic Basin: Resilience to Climate Change and Abstraction*. BGS Open Report, OR/15/047. Nottingham, U.K.: BGS.

Strategically, groundwater resources that need protection are (a) the Himalayan aquifers, since they protect the base flow of the Greater Himalayas rivers, and (b) deep aquifers to protect groundwater from arsenic pollution. Aquifer protection plans are needed to avoid over abstraction in the Indo-Gangetic plain. Agrochemical use has to be reduced. Land use planning for watershed protection is important. Groundwater quality needs to be monitored continuously to see whether strategies are effective or need to be adjusted. In situ monitoring of groundwater levels needs to continue with—and not as a substitute to—monitoring through satellites. Sound governance needs three-dimensional knowledge of local aquifers.

Groundwater and surface water are clearly linked; both sources should be protected and treated as connected systems. Conjunctive management of surface and groundwater is important for maximizing the storage and needs to incorporate quality considerations. Targeted research—e.g., recharge processes, surface and groundwater interaction, vulnerable areas, and degradation—needs to be promoted.

Groundwater Quality Challenges in South Asia and Options for Management—Prof. Kazi Matin Ahmed, Dhaka University, Bangladesh. Prof. Ahmed discussed the groundwater quality challenges across the region and experiences with management options in Bangladesh. The region's aquifers are part of the world's largest fluvial systems and most productive aquifers. Over 20 million wells pump nearly half of the global groundwater abstractions, supporting potable supply, public health, and food security. The region has many groundwater dependent megacities; some face serious overexploitation. Availability of usable groundwater varies considerably across the region. Continued supplies of safe water from many of the aquifers are constrained by the presence of natural contaminants such as arsenic, fluoride, and salinity, and anthropogenic contaminations from large populations, agricultural intensification, poor sanitation, rapid urbanization, and industrialization. Over 100 million people live in areas of poor water quality. Climate change is likely to complicate the development of strategies for using groundwater resources sustainably.

Prof. Ahmed described management options for addressing arsenic and salinity from experiences in Bangladesh. Maps of arsenic, fluoride, and saline and brackish groundwater and a basin model for predicting arsenic release mechanism in groundwater were discussed. Bangladesh has developed maps of arsenic safe aquifers and a sediment color tool (with black indicating the highest risk and red the lowest risk) for guiding drillers. A conceptual model of pumping induced flow for Dhaka was discussed.

Prof. Ahmed stressed the governance challenges of managing this invisible resource about which so little was known and understood. Despite heavy dependence on groundwater, all nations lacked adequate groundwater governance and effective institutions. This was not due to the absence of policies, guidelines, and laws for the development and management of water resources or legislations and guidelines for groundwater management, but rather to weak enforcement of existing policies, legislation, and guidelines. There were no institutions with the capacity to effectively manage and protect groundwater in most countries.

Systematic water quality monitoring systems need to be installed to avoid quality-related disasters such as arsenic. Water quality might be addressed more effectively if communities were empowered to manage their drinking water systems, including with responsibilities for monitoring water quality and implementing water safety plans. Cross-country learning can help to ensure sustainable supplies of safe water and protect the aquifers. Integrated cross-border monitoring networks are needed for understanding the quality aspects of the transboundary aquifers.

Chapter 5

Panel—Country Groundwater Priorities

Co-chairs: Mr. Nisar A. Memon, former Federal Minister, Pakistan, and Chairman, Water and Environment Foundation (WEF), and Ms. Mieke van Ginneken, Practice Manager for Water, World Bank

Mr. Sayed Sharif Shobair, Coordinator and Chief Engineer, Food and Agriculture Organization (FAO)/ Irrigation Restoration and Development Project (IRDP), Afghanistan. Afghanistan is semi-arid with highly variable precipitation and five river basins. It has 57 billion cubic meters of surface water and 18 billion cubic meters of groundwater. For 90 percent to 95 percent of Afghans, groundwater is the main source of potable water. Agriculture and domestic supplies use 3 billion cubic meters to 4 billion cubic meters and 0.5 billion cubic meters of groundwater, respectively, per annum. Groundwater use for industry and mining is limited, but is projected to increase.

Afghanistan faces a wide range of groundwater management challenges from unfavorable natural conditions to anthropogenic problems. Although Afghanistan's water policy is based on sound principles,[12] policy implementation is weak. Although there is a good potential to develop and use more groundwater, the sector faces bigger challenges. There is limited availability of hydrogeological data and information; and monitoring stations were destroyed or abandoned during wars and periods of instability. Even where data exist, data sharing among different water users and sectors is inadequate. Overall, the level of knowledge on the development and management of water resources is low.

Protection of quality is also a key part of groundwater management, especially in densely populated areas where groundwater quality is affected by different sources of pollution. In larger cities, lack of sanitation facilities causes high levels of biological contamination in addition to growing overuse of groundwater. Limited infrastructure for utilizing and managing surface water is contributing to increased pressure on groundwater. This is resulting in uncontrolled abstraction and possible overuse locally.

Protection zones for drinking water supplies and abstraction limits need to be established. Local authorities need to be empowered so they can monitor local abstraction and use of resources. Infrastructure to manage aquifer recharge needs to be built. In addition, the impact of climate

[12] They include the following: (a) water is a basic human need, (b) ecologically sustainable management of groundwater resources, (c) precautionary principle, (d) water conservation, (e) conjunctive management of groundwater and surface water, (f) polluter pays, (g) transparency and information sharing, (h) participation and the role of women, and (i) river-basin management.

change, frequent droughts, and salinity in groundwater needs to be addressed by building capacities for developing and implementing systematic groundwater monitoring programs, enforcing existing regulations, and developing solutions using modern technology and infrastructure.

Dr. Anwar Zahid, Deputy Director, Bangladesh Water Development Board. In Bangladesh, agriculture is the major source of livelihood, supporting about 75 percent of the population. The steady growth in agriculture has made Bangladesh achieve near self-sufficiency in cereal production. Self-sufficiency became possible initially through surface irrigation in the 1970s and 1980s, and groundwater irrigation using deep tube wells (DTW) and shallow tube wells (STW) to supplement surface sources from the 1980s to 2014. STWs have increased from 133,800 in 1985 to 1,182,525 in 2006 to about 1,500,000 in 2014.

The national water supply coverage is about 83 percent to 88 percent (UNICEF/WHO 2015[13]). Providing safe water supply in hard-to-reach areas remains a big challenge. Drinking water supply is impacted by poor quality of groundwater in areas of high arsenic, fluoride, and salinity. The water market is dominated by a dynamic private sector with over 1.7 million managers of mechanized irrigation devices and 0.76 million owners of nonmechanized and traditional irrigation devices.

Bangladesh has 700 rivers and tributaries, 98,000 hectares of inland water bodies and over 24,000 kilometers of streams. However, many surface bodies of water have dried or have been encroached by human activities. In the dry season when irrigation water demand is high, surface supplies are inadequate to meet the crop water requirements. During this period, river water level in many areas falls below the suction limit of low lift pumps. During the monsoon this situation reverses with abundant water and widespread seasonal floods in large areas almost every year.

Bangladesh is highly vulnerable to the impacts of climate change. Global warming is expected to increase the snowmelt in the Himalayas, cause flash floods, rise sea levels, submerge coastal areas, and increase frequency of drought. In addition, the precipitation in monsoon is expected to increase, with prolonged monsoons, yet precipitation is expected to decrease in the dry season; both situations would worsen the water management situation.

Mr. G. K. Chhopel, Chief Environment Officer, Water Resources Coordination Division, National Environment Commission, Bhutan. Bhutan is a water surplus nation with a pristine environment, 60 percent forest cover, which is mostly protected, and an important biodiversity hotspot of the world. The high level of political commitment to environmental health is enshrined in its

[13] UNICEF/WHO. 2015. *Progress on Sanitation and Drinking Water: 2015 Update and MDG Assessment*, *Joint Monitoring Programme for Water Supply and Sanitation*. New York: UNICEF. https://www.unicef.org/publications/index_82419.html.

Constitution. Deep reverence for the environment is also embedded in the religion and culture of Bhutan.

Bhutan has a mean annual per capita water availability of 109,000m^3, mostly surface water. Groundwater is used as a last resort. The Water Regulation of Bhutan 2014 stipulates that "groundwater abstraction may be considered permissible where there is no other alternative surface water source." Current use of groundwater is almost negligible. Groundwater management challenges that may become important to address in the future are (a) building databases for monitoring and managing groundwater, (b) delineating high arsenic level areas in the hot springs, and (c) monitoring groundwater development.

Prof. Guangheng Ni, Director, Institute of Hydrology and Water Resources, Tsinghua University, China. According to *China Water Resources Bulletin 2014*,[14] China has an annual average groundwater resources of 775 billion cubic meters, or 28 percent of the country's total water resources. Groundwater accounts for 18 percent of water supply. In northern China, groundwater is an important source of supply for many cities. At the end of 2011, there were 97.49 million wells pumping around 108.4 billion cubic meters (the first national census for water).

At present, 65 percent of domestic, 50 percent of industrial, and 33 percent of irrigation water in northern China is supplied from groundwater. Over 400 of 655 cities depend on groundwater. Extensive use of groundwater and continuous pumping is decreasing groundwater levels. In arid and semi-arid regions, groundwater is the major source of drinking water supply. Pollution from urbanization, industrial, and mining developments is an emerging threat to groundwater quality. Over pumping is also a growing problem. In Beijing it has led to groundwater levels declining to bedrock. Groundwater vulnerability is exacerbated by climate change, which adds considerable uncertainty for future water resources and supply planning and management.

The existing management instruments are groundwater development and protection plans, groundwater function zoning, forbidden development zones, restricted development zones, water resources justification for construction projects, water abstraction permits, water resources fees, planned water use systems, well-drilling permits, water user associations, and so on. Also, Prof. Ni referred to the need to set up groundwater monitoring network across the country. Additional measures to be undertaken to improve groundwater management in China include the development of an aquifer management plan, development of an integrated groundwater management system, restructuring of the existing groundwater management systems, reforming the groundwater abstraction permit system, exploring ways to develop the groundwater quality management system, and building capacity for better management.

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[14] China, Government of, Ministry of Water Resources. 2015. *China Water Resources Bulletin 2014*. Beijing: China Waterpower Press.

Mr. Dipankar Saha, Member, Central Ground Water Board (CGWB), India. In India, groundwater provides 85 percent of the rural water supply, 50 percent of the urban water supply, and 60 percent of the net irrigation supply. In the last four decades groundwater contributed to 84 percent of the total increase in net irrigated area. Different parts of India have different types of aquifer systems and face different types of management challenges. About 70 percent of the country is underlain by hard rock aquifers; aquifer storage and yields are low. In the Indo-Gangetic Basin (IGB) plains, which cover about 30 percent of the country, there are prolific aquifers with high yields and large storage, and there is still scope for further development in some areas. However, water levels are declining in many states, and water extraction exceeds annual recharge rates. Arsenic contamination is a problem in shallow aquifers.

In the western arid region, i.e., the states of Rajasthan and Gujarat, groundwater recharge is low due to less rainfall and deep water levels. About 42 percent of the blocks in this region are overexploited. The extent of withdrawal of groundwater in Rajasthan is 137 percent and in Gujarat it is 67 percent. High temperatures contribute to higher evaporation losses and reduce surface water available for recharging groundwater.

In the central plateau region, comprising the states of Maharashtra, Madhya Pradesh, and Chhattisgarh, a mainly hard rock region, and groundwater potential is low and linked to monsoons. Groundwater provides short-term storage with limited recharge potential. The southern peninsular region (including Andhra Pradesh, Telangana, Goa, Karnataka, Kerala, and Tamil Nadu) is underlain predominantly with hard rock aquifers with low groundwater potential. Groundwater is used excessively for irrigation in this region, and there is low sustainability of groundwater resources. In the eastern plain region comprising eastern Uttar Pradesh, Bihar, Jharkhand, Odisha, and West Bengal, the level of groundwater is shallow, thus sub-optimal development of groundwater is recommended here. The hilly region, including Jammu and Kashmir, Himachal Pradesh, Uttarakand, and the northeastern states, has a complex hydrological setup. Many areas are unexplored due to the difficult terrain. There is a limited occurrence of groundwater in this valley. Sustainability of springs and protection of recharge areas are some challenges in this region. Several factors contribute to declining groundwater levels in India, including the following:

- Low recharge due to scanty rainfall in arid and semi-arid regions
- Increasing demand for groundwater for agricultural, industrial, and drinking purposes
- Extraction of large amount of groundwater when other sources of water are fully committed
- Change in cropping pattern and growing of paddy and cash crops that consume large quantities of water
- Rapid pace of urbanization resulting in reduced natural recharge and concentrated extraction
- Flat-rate or free electricity for extracting groundwater in certain states

To address these issues, the 2012 National Water Policy[15] emphasizes issues related to water governance that have not been addressed adequately. It highlights the mismanagement of water resources that has led to critical situations in many parts of the country. Groundwater, though a community resource, is still perceived as private property and exploited inequitably and without any consideration for its sustainability, which has led to overexploitation in several areas. The policy emphasizes that water needs to be managed as a “common-pool community resource” held by the state under public trust doctrine to achieve food security, support livelihood, and ensure equitable and sustainable development of all.

Good governance through transparent and informed decision making is crucial to meet the objectives of equity, social justice, and sustainability. Meaningful participation, transparency, and accountability need to guide decision making and regulation of water resources in the country.

Mr. Dhana Bahadur Tamang, Secretary, Water and Energy Commission Secretariat, Nepal. Nepal is a water surplus nation; it receives on average 1,530 millimeters of rainfall per year. Nepal has 6,000 river and rivulet systems. Its present demand is 27 billion cubic meters against available supply of 230 billion cubic meters. Total groundwater resources available are about 10 billion cubic meters, annual recharge about 5.8 billion cubic meters, and present withdrawal about 1.5 billion cubic meters per year. Water availability is a high variable spatially and temporally, influenced by topography, ecological zones, and seasons (monsoons). Eighty-two percent of river flow occurs from June to November, and it drops to as low as 12.5 percent in summer.

Although the pressures on Nepal’s groundwater are not severe yet, signs of stress are emerging. For example, groundwater depletion is evident in the Kathmandu Valley and other urban centers. Groundwater quality is being impacted by natural contaminants (e.g., arsenic in the Churia foothills) and anthropogenic contaminants (such as untreated sewage and solid and industrial wastes in urban centers such as Kathmandu). Frequent load shedding interrupts power supply and impacts groundwater pumping. Political instability and resource gaps are challenges impacting groundwater governance. They also hinder enactment of appropriate laws and institution building for groundwater development and management. Human capacity and technological constraints hinder sustainable management of groundwater.

Dr. Muhammad Riaz, Director, Programme Monitoring and Implementation Unit, Punjab Irrigation Department, Pakistan. Groundwater supports 40 percent to 50 percent of Pakistan’s irrigation requirements and a significant portion of domestic and industrial supply. Farmers have installed over a million private tube wells—in addition to domestic pumps. Groundwater use has resulted in increased cropping intensity from 70 percent to 150 percent.

Intensive and unregulated groundwater pumping has contributed to falling water tables in several areas, including Lahore, increasing the cost of pumping. The quality of groundwater is deteriorating. Saline water is intruding in fresh water. Soil salinization is impacting the

[15] GoI, Ministry of Water Resources. 2012. *National Water Policy (2012)*. Delhi: GoI. http://wrmin.nic.in/writereaddata/NationalWaterPolicy/NWP2012Eng6495132651.pdf.

sustainability of agriculture. In a number of areas, groundwater is being pumped beyond sustainable limits. However, establishing an enforceable groundwater entitlement program is a complex undertaking. It requires stakeholder understanding and awareness about groundwater management issues as well as a holistic groundwater management policy framework, none of which exist in Pakistan. Current groundwater management strategies in Pakistan can be summarized as follows:

- Groundwater monitoring arrangements
- Understanding the institutional setup
- Development of groundwater management policy
- Public awareness on groundwater management and regulation
- Identification of critical areas
- Development of legal framework
- Phased implementation of the management regime
- Gradual shift from management to groundwater regulation

In spite of the previously stated strategies, implementation of management actions and regulations remain an impediment to sustainable development of groundwater in Pakistan. To address these limitations, groundwater monitoring programs are being established and implemented. Punjab has been divided into various groundwater monitoring units. Pre- and post-monsoon water level and quality are being measured and analyzed. Geographic information system (GIS) and other tools are used for data analysis and mapping. A groundwater policy framework has been drafted, and a groundwater management act is under preparation. Groundwater maps and a geo database are being developed. A groundwater management cell has been established in the Punjab Irrigation Department.

Ownership of groundwater has yet to be addressed, and a comprehensive groundwater monitoring and mapping program has not been instituted. Groundwater basins have to be identified and aquifer potential estimated. Integrated water resource management framework (for surface and groundwater) needs to be developed. Effective institutions that promote sustainable groundwater management have to be set up at all levels, including provincial levels. Farmer organization and stakeholder training and capacity building need to be undertaken, and management of groundwater coordinated with farmer community at grassroots level. To address groundwater depletion, the capacity to monitor groundwater need to be improved. There is need to support and encourage rainwater harvesting, recycling, and enhance underground storage through artificial recharge and injection. Detailed mapping of aquifers at sub-basin level and identification of possible areas and sources for recharge need to be undertaken.

Mr. R.S. Wijesekera, General Manager, Water Resources Board, Sri Lanka. In Sri Lanka, the impacts of groundwater over abstraction include salinization in coastal areas, depletion of groundwater levels, dried-up wells in surrounding areas, and water quality changes. Groundwater contamination occurs from human activities (e.g., sand mining, groundwater over pumping, industrial wastewater disposal, dumping of garbage and intensive agriculture using heavy fertilizer, and pesticide use causing nitrate pollution).

In Sri Lanka, groundwater issues are not serious yet and can still be mitigated if timely actions are taken. To manage the development of groundwater successfully, a sound information base has to be established, and a proper groundwater management system needs to be developed and maintained. A monitoring network for measuring groundwater levels and quality covering the whole country needs to be established. Long-term trends in changes in groundwater levels and quality need to be developed and analyzed for priority and stressed aquifers.

Training to address the capacity gaps for sustainably developing and managing groundwater needs to be provided. To address capacity gaps, hydrogeologists in the Water Resources Board should be trained in handling, processing, and analyzing real-time data using software and in preparing hydrogeological maps and developing hydrogeological models. Regional data centers need to be properly equipped. Long-term funding is required for groundwater monitoring programs that can generate reliable and timely information accessible to decision makers, researchers, stakeholders, and the general public. Such evidence-based information can help stakeholders understand the groundwater issues and trends and be used to inform groundwater-related decision making.

Chapter 6

Group Work I—Tackling Irrigation and Domestic Water Supply Challenges

Facilitator: Dr. John Dore, Senior Water Resources Specialist, Department of Foreign Affairs and Trade (DFAT)

During the first breakout session, groups discussed priority actions and distilled lessons for building the knowledge base and identifying institutional capacity and policy needs for addressing groundwater depletion and quality issues in irrigation and domestic water supply. Lessons from "Group Work 1":

Quantity and Quality—Irrigation and Rural Water Supply

- Promote a regulatory framework to regulate water extraction and effectively enforce it
- Change cropping pattern toward less water-consuming and more drought-resilient varieties
- Develop policy for wastewater treatment and reuse, stipulating standards that need to be applied to allow reuse of water for a variety of purposes
- Promote a multi-sectoral approach for groundwater protection, use, and management
- Develop price regulation for better use of groundwater, e.g., energy, water, and fertilizer subsidies should be removed
- Develop economic instruments for pricing use of water and pollution reduction by tax rebates
- Encourage stakeholder participation in monitoring and regulation activities
- Develop policy to enhance awareness of and education about water quality issues
- Institutions closely related to agriculture, e.g., village *panchayats* and schools, should help spread awareness and monitor the irrigation water quality
- Organic farming should be promoted
- Set goals, identify parameters, and understand the sources of pollution for water quality monitoring
- Build capacity for monitoring water quality
- Monitor geogenic contaminants (e.g., arsenic, fluoride, salinity) and anthropogenic contaminants (e.g., nitrates, heavy metals, fertilizers, pesticides, and urban pollutants) that impact rural groundwater
- Develop scientific advice and build capacity for improving crop water efficiency

Quantity and Quality—Urban Water Supply

- Build strong intersectoral linkages with clear roles, responsibilities, and accountabilities of the relevant departments and agencies to ensure complementary and efficient actions and knowledge sharing
- Encourage conjunctive use and management of surface water and groundwater

- Combination of top-down or bottom-up approach needs to be applied to address context specific issues
- Policies for the management of transboundary water need to be established
- Quality of groundwater recharge needs to be monitored
- Market-oriented solutions and policies for them need to be developed and applied
- Develop country-specific information, education and communication (IEC) materials
- Invest in infrastructure (e.g., pipelines) to address water supply needs
- Promote use of digital technology for water quality monitoring
- Institute better land use planning for protecting and managing groundwater
- Monitor geogenic contaminants (e.g., arsenic, fluoride, salinity) and anthropogenic contaminants (e.g., nitrates, heavy metals, fertilizers, pesticides, and urban pollutants) that impact urban groundwater

Day 2: Foundation for Sustainable Groundwater Use and Management

Groundwater-Energy-Food Nexus: Policy Implications

Chair: Mr. Dipak Gyawali, Chair, Nepal Water Conservation Foundation (NWCF)

Food-Irrigation-Energy Nexus in the Context of Groundwater Use in India, Dr. Aditi Mukherji, Theme Leader, Water and Air, International Centre for Integrated Mountain Development (ICIMOD)
Managing Groundwater Use in Agriculture Sustainably: Lessons from OECD Countries, Dr. Guillaume Gruere, Senior Policy Analyst, Organisation for Economic Co-operation and Development (OECD)

Lessons on Regulating Groundwater

Chair: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, International Water Association (IWA)

Groundwater Regulation and Implementation: An Overview, Mr. Stefano Burchi, Executive Chairman, International Association for Water Law
Model Bill for Regulation of Groundwater Development, Mr. Y. B. Kaushik, Regional Director, Central Ground Water Board (CGWB), India
Groundwater Management Legislation in the Indus Basin, Ms. Hina Lotia, Director, Programs, Leadership for Environment and Development (LEAD) Pakistan
Lessons on Regulating Groundwater in India, Justice Madan B. Lokur, Supreme Court of India

Urban Groundwater Supply

Chair: Mr. Md. Sarafat Hossain, Director General, Water Resources Planning Organization (WARPO), Government of Bangladesh

Groundwater Management Challenges in Urban Asia, Dr. Sangam Shrestha, Asian Institute of Technology (AIT), Bangkok
Sustainable Groundwater Supply: Issues and Options for the Border City of Lahore, Mr. Ali Tauqeer Sheikh, CEO, LEAD, Pakistan, and Director, Asia, Climate and Development Knowledge Network
Water Resources Management of Delhi and Groundwater Supply Challenges, Prof. Shashank Shekhar, Department of Geology, University of Delhi
Dhaka City Water Supply Issues and Challenges, Dr. Anwar Zahid, Deputy Director, Bangladesh Water Development Board

Community-Based Groundwater

Chair: Mr. Ari Nathan, Director, Regional Environmental, Science and Technology, and Health (ESTH), Office for South Asia, U.S. Embassy, Kathmandu

Working with Communities to Tackle the Arsenic Problem in Groundwater in Bangladesh, Ms. Hasin Jahan, Country Director, Practical Action
Learning from the Andhra Pradesh Farmer-Managed Groundwater Systems Initiative, Mr. P. S. Rao, Director (Technical), Advanced Centre for Integrated Water Resources Management (ACIWRM), India
Farmer Participatory Groundwater Monitoring: A Blueprint for Pakistan, Dr. Arif Aziz Anwar, Principal Researcher, International Water Management Institute (IWMI)
Tackling the Chronic Kidney Disease in Sri Lanka, Dr. Tushara Chaminda, University of Ruhuna, Sri Lanka

Cooperative Groundwater Management—International Experiences

Chair: Dr. Bill Young, Lead Water Resources Specialist, World Bank

Lessons from Delaware: Implementation of the State Comprehensive Groundwater Protection Program, Science Support, and Data Sharing, Dr. David R. Wunsch, State Geologist and Director, Delaware Geological Survey
Towards Management of U.S.–Mexico Aquifers, Mr. Richard Kropp, Director, United States Geological Survey (USGS)
Middle East Water Databanks and Groundwater Awareness for Israeli, Jordanian and Palestinian Aquifers, Mr. Daniel J. Goode, Research Hydrologist, USGS

Group Work II—Good Practices in Groundwater Policy, Regulations and Institutions

Facilitator: Dr. John Dore, Senior Water Resources Specialist, Department of Foreign Affairs and Trade (DFAT)

Chapter 7
Groundwater-Energy-Food Nexus: Policy Implications

Chair: Mr. Dipak Gyawali, Chair, Nepal Water Conservation Foundation (NWCF)

Food-Irrigation-Energy Nexus in the Context of Groundwater Use in India—Dr. Aditi Mukherjee, Theme Leader, Water and Air, ICIMOD. India's irrigation sector is heavily dependent on groundwater. Since the 1970s, area irrigated by groundwater has increased as have the number of wells and tube wells. However, rising contribution of groundwater in agriculture has led to depletion, scarcity, and overexploitation emerging as serious problems. Currently, groundwater is overexploited in many states. Much of this groundwater is pumped using electricity. Groundwater use exceeds sustainable recharge in most states leading to groundwater overexploitation. Electricity is subsidized in most (though not all) states. This creates a nexus in which one sector (agriculture) is dependent on groundwater, and the electricity sector (subsidized for agriculture) is contributing to unsustainable trends in all sectors**.**

Growth in electricity consumption in agriculture has outpaced growth in other sectors. There has been a 12 times increase in overall electricity demand in India from 1950 to 2010, but there has been a 25 times increase in agricultural electricity demand. Electricity subsidy as a percentage and proportion of state fiscal deficits is very high in some states.

Agriculture is often blamed for the poor state of electricity utilities. Yet farmers receive poor quality service. Demand for subsidy is increasing: net electricity subsidy in India, today, is close to US$ 9 billion per year and is rising every year. Farmers get free or highly subsidized electricity in many states. When farmers pay for electricity, they pay a flat rate. The only exception is the state of West Bengal where agricultural tube wells are metered and farmers pay a time of the day (TOD) tariff. An energy divide exists: in eastern India, farmers depend predominantly on diesel pumps, while the rest of India has electric pumps. The groundwater-energy-food nexus differs in the east versus rest of India.

In West Bengal alluvial aquifers have high recharge capacities and low groundwater use. Water tables recover after monsoons and average depth to water table in 88 percent of the villages is less than 10 m. About 42 percent of groundwater is used and none of the blocks are overexploited. The food-energy-irrigation nexus in West Bengal is managed through TOD and high-tech metering. By March 2010, 90 percent of tube wells were metered, and high-tech metering with remotely read meters were implemented. The impact of the metering was beneficial to pump owners from lower electricity bills, fewer hours of selling water, and higher bargaining power in regards to water buyers. On the other hand, water buyers had to pay 30 percent to 50 percent more in water charges, buy fewer hours from pump owners, and agree to adverse terms and conditions for buying water. Groundwater efficiency increased due to these consequences, and there was an increase in adoption of plastic pipes for conveyance, better maintenance of field channels, and construction of underground pipelines.

It is well known that groundwater extraction in Punjab has reached unsustainable levels. To mend the situation, the state government has taken steps such as feeder segregation and energy audits, which include metering at feeder level and improved method of calculating aggregate power consumption. These measures have helped reduce transmission and distribution losses marginally. However, farmer's subsidy burden keeps rising as government keeps on issuing more electricity connections: currently, 1.2 million pump sets are used by 1.1 million farmers.

The food-energy-irrigation nexus in Karnataka is mismanaged mainly because of half-hearted measures taken at feeder segregation. The power load is mixed and there is no proper way to estimate average energy use. This has led to chaos below the feeder level, rampant theft, and illegal connections.

While the broad issues are the same in West Bengal, Punjab, and Karnataka, these states have managed the water-energy-food nexus differently, ranging from a high-tech and textbook solution in West Bengal, to second-best solution in Punjab, to utter anarchy in Karnataka. This clearly indicates that success significantly depends on the political will and overall governance at state levels since both water and electricity are state subjects in India.

Managing Groundwater Use in Agriculture Sustainably: Lessons from OECD Countries—Dr. Guillaume Gruère, Senior Policy Analyst, Natural Resources Policy Division, OECD Directorate. The OECD comprises 34 member countries with five key partner countries: Brazil, China, India, Indonesia, and South Africa. One of its important functions is to provide data, economic, and policy analysis to foster national and international policy discussion on a wide range of policy issues (in all areas except culture and defense).

Dr. Gruère shared lessons from a recent OECD study (2015) on sustainable agricultural groundwater use[16] that would be useful for South Asia. Groundwater, because of its abundance, is a valuable asset for irrigators in South Asian and OECD countries because of its characteristics: efficient, complementary to surface water, and available on demand. Most important, it can be a powerful adaptation tool against climate change due to being relatively insulated from it. However, managing groundwater is challenging. The most common challenges of unregulated groundwater development are long-term depletion of aquifers and negative environmental externalities, including stream depletion, ingress of saline and polluted water, aquifer compaction, and land subsidence.

Multiple instruments, such as economic, regulatory, and collective actions, can be used to respond to these challenges. To combat these challenges, it is necessary to take immediate measures and gradually move toward sustainable systems. It is crucial to build a robust information system, favor demand-side instruments, use groundwater conjunctively, enforce existing regulations first, favor use of direct approaches, and remove perverse incentives. In

[16] OECD. 2015. *Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use.* Paris: OECD.

regions with intensive groundwater use, the above-mentioned tripod approach—with economic, regulatory, and collective action instruments—is recommended. For regions with high stress, agronomic tools and supply-side instruments are recommended. The following groundwater reform lessons from OECD countries may be useful for South Asia.

For general conditions:

- Invest in better information systems
- Favor demand-side responses first
- Strengthen regulatory capacity for enforcement
- Remove electricity subsidies
- Use social support if needed

For regions with intensive groundwater use:

- Apply the tripod approach: clarify groundwater entitlements, provide general incentives to act on consumption, and allow user groups to play a role in management.

For regions with high stress:

- Improve the efficiency of irrigation
- Consider multiple approaches to groundwater storage

Chapter 8
Lessons on Regulating Groundwater

Chair: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA

Groundwater Regulation and Implementation: An Overview—Mr. Stefano Burchi, Executive Chairman, International Association for Water Law. An implementable domestic groundwater regulatory framework is critical for developing a structured response to drought and climate change. Enforcing such a regulatory framework effectively needs a strong backing of the law. This need has steadily driven groundwater in the public domain, trust, and superior state control powers and has resulted in statute law and judicial pronouncements. As a result, groundwater has increasingly come under the scope of regulations for well drilling, extraction, and use. This is generally accomplished by means of administrative permits and licenses, which are time-bound and subject to terms and conditions based on aquifer "safe yield" determinations and extraction charges ("user pays" principle).

Implementation, administration, and enforcement are ultimately critical for the credibility and success of groundwater regulation. As of today, the record is patchy and anecdotal. However, the keys to the eventual success of groundwater regulation are (a) education of, and uptake by, the target groundwater users; (b) preparedness of the government groundwater administration to take action to protect and manage groundwater; and (c) effective monitoring of groundwater users' behavior.

Implementation and enforcement of regulation requires surveying in advance the implications and requirements of groundwater regulations in terms of manpower requirements, internal procedures needed, hardware and software requirements, budget requirements, etc. It is essential to chart out a clear pathway to address, including a timeline and costs that will be incurred. With groundwater quality or groundwater pollution, point source pollution is in general prohibited throughout because of the risk of irreversible harm, and nonpoint source pollution can be regulated through land use planning and zoning.

The limited experience available regarding law enforcement action by the government and by the judiciary suggests that the chances of successful enforcement of groundwater regulation increase with the involvement of groundwater users in the monitoring and policing of their behavior, especially when they understand that it is in their self-interest. Police corps, in the public prosecutor offices and among the judiciary, should possess specific environmental skills. There should be coordinated action among the police corps and the public prosecutor offices. Innovative use of law enforcement mechanisms should be encouraged. Aquifers that cross the boundary lines (across nations, states, and provinces) should be subject to a separate set of rules based on principles such as equitable and reasonable use by states, not to cause significant harm to other states, data and information exchange among states, and prior notification by states of planned measures.

Groundwater Management Legislation in the Indus Basin—Ms. Hina Lotia, Director, Programs, Leadership for Environment and Development (LEAD) Pakistan. Groundwater has emerged as a savior for water and food security in Pakistan against the backdrop of insufficient surface storage and declining capacity of existing reservoirs. Today, however, depleting and over drafting aquifers with increased pumping costs and environmental concerns, deteriorating groundwater quality and increasing soil salinization are confronting the sustainability of groundwater use.

The Constitution of Pakistan respects the legislative competence of the states and provinces in regard to water, making it a subject of provincial legislative competence. Water is not mentioned in the Federal Legislative List, although in practice there are mechanisms that allow the federal government control over groundwater. Water, however, is mentioned in the Pakistani Constitution, in its provisions regarding the Council of Common Interests.

Several acts passed before and after independence provide the legislative basis for groundwater governance. The Irrigation and Drainage Act of 1873 gives the provincial governments and irrigation departments two forms of control over groundwater. One is through notification of any groundwater to be used for a proposed or existing canal or drainage work. Two is general control to manage groundwater properly and to draw up management schemes for its use. The Sindh Irrigation Act of 1879 allows the provincial government to notify, inter alia, that the subsoil water should be applied or used by the provincial government for the purpose of any existing or projected canal. If groundwater is notified for any such use, the act considers such water to be included in the definition of *canal*." The Easements Act of 1882 provides a right over immovable property. It is part of the English Common Law that has remained the same to date. An easement is defined as "a right which the owner or occupier of certain land possesses. It does not operate or exist over water that flows naturally." It is not adapted to different climatic conditions or water use.

The Soil Reclamation Act of 1952 provides for the reclamation and improvement of areas impacted by salinity and waterlogging and for maximizing agricultural production. The Punjab Land and Water Development Board was established under the same act. The Water and Power Development Authority Act of 1958 calls for the preparation of comprehensive plans for development and use of water and power resources. The Punjab Irrigation and Drainage Authority Act of 1997 established the Punjab Irrigation and Drainage Authority and gave it limited control over groundwater resources "to affect schemes" prepared under the act for public purposes. It does not provide overall groundwater control.

Provincial laws provide the respective irrigation department's limited control of groundwater to control the subsoil water for existing or proposed canal. The Punjab provincial government has the responsibility to manage sub-soil water to prevent pollution and overexploitation.

Devolution of administrative control to local governments shapes the manner in which groundwater law is understood and implemented. In Punjab, the local governments have wide powers to maintain natural sources of water as well as control over infrastructure for drinking water purposes. In Sindh, the control of groundwater sources for drinking purposes as well as for preservation and reclamation of soil is vested in the local governments.

Many points of convergence and divergence on rights, control, and management of groundwater exist. The Constitution respects state and province legislation and envisages a larger role of local bodies in decision making. However, in practice these local bodies lack the financial, technical, and operational capacities that need to be built to develop sound groundwater management in Pakistan. Both demand- and supply-side options need to be addressed. On the supply-side groundwater zoning, levying of groundwater tax, appropriate cropping patterns, irrigation scheduling, and enactment of laws for use and abuse are recommended.

Other major challenges are the identification, spatial mapping, and characterization of transboundary aquifers and identification and sharing of data. Understanding hydraulics of flow changes and contaminant transport, monitoring of hydrological parameters and policy, and practice gap analysis need to be jointly explored by the Indus basin nations.

Model Bill for Regulation of Groundwater Development—Mr. Y. B. Kaushik, Regional Director, Central Ground Water Board (CGWB), India. To protect and safeguard groundwater against overexploitation, the Government of India (GoI) has framed a model groundwater (control and regulation) bill for adoption by the states in 1970. It was revised in 1972, 1996, 2005, and 2011. It provides a framework to regulate indiscriminate extraction of groundwater. The 2011 Model Bill for the Conservation, Protection and Regulation of Groundwater was prepared by the Planning Commission. It was based on the principle put forward by the Supreme Court that water, and groundwater specifically, is held in public trust, and is also recognized as a fundamental right by the Supreme Court. The institutional framework proposed for it is based on the principle of subsidiarity and framed around existing administrative units of villages and *panchayats*. It provides for an institutional framework to ensure appropriate management of groundwater from the local to state levels.

In this model bill, nondiscrimination, equity, subsidiarity, and decentralization are mandatory principles. It includes provisions for the protection, precaution, and prior assessment of aquifers to be protected from impacts that affect the equity of access and sustainability of the resource (e.g., depletion and deterioration in quality) and planning of management measures to conserve, replenish, and recharge groundwater. The model bill also mandates integrated approach for management of water resources: protection, conservation, and regulation of groundwater; and groundwater integrated with surface water resources on a watershed, land, and forest basis.

The bill was reviewed and sent back for revisions to include river basin approach, elaborate provisions for rainwater harvesting, measures to take into account the “polluter pays” principle, conservation of water through agricultural practices and land use, and technological developments including space technology and information technology (IT). The revised bill is posted on the website of CGWB.

To improve and enforce groundwater regulation, state groundwater departments and CGWB need to be strengthened by ensuring that manpower and infrastructure are available. A database on groundwater availability, number of abstraction structures, quantity of groundwater withdrawal, water level changes, and water quality changes needs to be in place. Registration of groundwater structures through a centralized website that gives access to all stakeholders needs to be instituted.

Lessons on Regulating Groundwater in India—Justice Madan B. Lokur, Supreme Court of India. Water and groundwater are under the jurisdiction of the state; however, water and groundwater (aquifer) by their very nature don’t confine themselves to these administrative units. There are times when a state can come out with legislation that does not necessarily align with those of the neighboring states. At such times there are ways in which states can move the issue to Parliament for legislation, for example, the Wildlife (Protection) Act of 1970. Justice Lokur also gave the example of the Indian Easements Act of 1882, which created issues regarding local landowners and usage of groundwater. He suggested that an amendment is needed to shift the ownership of groundwater to the state or public trust.

From a legislative perspective, Justice Lokur identified the following issues with respect to groundwater management. First, he stated the need for clear definitions. For example, varying definitions of *drought* adapted by different states make passing of any legislation regarding the issue very difficult. Second, to pass any legislation regarding groundwater there needs to be clarity and understanding about the issues addressed by the passage of the law. Third, once a law has been passed, there needs to be proper implementation and enforcement. For example, if a penalty or fine is being imposed for violation of some rule with respect to groundwater exploitation, there needs to be specific, detailed guidelines, such as the amount of penalty. Finally, an institutional mechanism is necessary for active implementation and monitoring of the law and regulations.

Chapter 9
Urban Groundwater Supply

Chair: Mr. Md. Sarafat Hossain, Director General, Water Resources Planning Organization (WARPO), Government of Bangladesh

Groundwater Management Challenges in Urban Asia—Dr. Sangam Shrestha, Asian Institute of Technology (AIT), Bangkok. Urban areas are home to some 54 percent of the world's population, and urban population is expected to increase to 66 percent, or another 2.5 billion, by 2050. Around 90 percent of that will be concentrated in Asia and Africa (UN 2015[17]). The world is undergoing a great urban upsurge. Urban and rural populations of the world became equal in 2007, and urban population has been rising ever since.

Globally, groundwater is the source of one-third of all freshwater withdrawals. Approximately 36 percent, 42 percent, and 27 percent of the water is used for domestic, agricultural, and industrial purposes, respectively. Groundwater dependency is more evident in Asia, especially throughout South Asia and China. Approximately one-third of Asia's population (some 1 billion to 1.2 billion people) is reliant on groundwater. The industrial sector is a major user of groundwater in urban areas.

With increasing rate of urbanization in Asian cities, groundwater extraction will continue to be driven by economic development. Challenges for managing groundwater include unreliable data and patchy monitoring, an unconducive environment, and weak interagency coordination. Climate change will impose additional stress on groundwater. There is a lack of clear policies on groundwater management and weak enforcement of groundwater laws to address groundwater management challenges. In some cities, such as Chittagong, Bangladesh, abstraction is less than recharge, and thus it is not overexploited. However, in cities such as Lahore, Pakistan, it is overexploited and abstraction is greater than recharge, leading to a declining water table.

There is a need for a framework for evaluating groundwater resources in urban environments. Certain case studies and local examples from a broad geographical range of urban environments within Asia illustrate the challenges. Fourteen case studies reviewed by the speaker show that all cities are heavily dependent on groundwater. It is necessary to improve the understanding of the groundwater systems and build more knowledge. Bangkok is a good example of using the right instruments to manage groundwater. An enabling environment should be created through appropriate policies and financial instruments.

[17] UN, Department of Economic and Social Affairs, Population Division. 2015. *"World Population Prospects: The 2015 Revision, Key Findings and Advance Tables*." Working Paper No. ESA/P/WP.241, UN, New York.

Sustainable Groundwater Supply: Issues and Options for the Border City of Lahore—Mr. Ali Tauqeer Sheikh, Director, Asia Climate and Development Knowledge Network, Pakistan. Groundwater is key for Lahore's municipal, industrial, and commercial supply. The mandate of the Water and Sanitation Agency (WASA) includes water supply, sewage, and drainage collection and disposal services. WASA pumps about 1.45 million cubic meters of groundwater per day to meet the demand, exceeding the recharge rate.

Historically, groundwater abstraction from the Lahore aquifer was sustained by recharge from the Ravi River, the key source of aquifer recharge. Its river flows started reducing after independence in 1947 as more water was diverted through Madhopur headworks. By 2000, the Thein Dam nearly stopped the river flow. Since then the river remains mostly dry except during the monsoon season. Recharge reduction has been accompanied with increased pumping to meet the needs of a rapidly growing population and urban immigration. Declining groundwater levels and an expanding cone of depression in the city's center indicate aquifer overdraft. New WASA wells are 600–700 meters deep to maintain reliable supply.

Municipal and industrial waste in Lahore is collected through drains and canals that discharge into the Ravi River. Shallow groundwater (less than 100 feet) is known to be polluted. High arsenic levels are found in shallow groundwater. WASA pumps from deeper wells. Rapid urbanization not only reduces recharge quantity due to impervious surfaces but also contributes to deterioration of groundwater quality.

WASA faces several groundwater issues. Pumping costs are increasing as tube wells are dug deeper and demand exceeds supply, and treatment costs are increasing as groundwater becomes more polluted. Intermittent pumping due to power shortages causes stress reversals in the supply network, and results in a host of maintenance and service delivery issues.

To address these challenges and safeguard public health, there is an urgent need for a policy for and legislation on aquifer protection and management. The city must develop a plan for comprehensive mapping of contaminated sites, estimating risk posed to public health (from aquifer pollution) at each site, and developing investment needs and priorities for managing these sites. All point, linear, and diffused sources of aquifer pollution need to be identified, defined, and mapped. The city needs to develop geographic information systems (GIS) maps of the capture zones of all high-capacity public and private tube wells being used for public water supply (through analytical and numerical modeling). The city also needs to devise plans for delineation of well-head protection areas (based on capture zones) to manage and protect the vital sources of water supply.

The mean annual rainfall in Lahore is 575 millimeters, of which 400 millimeters falls during the monsoon alone. Lahore urban area is approximately 1,800 square kilometers. Two hundred millimeters of recharge captured and managed during monsoon through structural interventions in this area can add 360 million cubic meters annually to the aquifer. Total WASA abstraction of groundwater from the aquifer is 470 million cubic meters annually. The existing canal network within the urban area may also be exploited for managed recharge to make up for the shortfall. Aquifer recharge potential of the Ravi remains the biggest natural source of aquifer recharge. Managing environmental flows in the Ravi, and controlling its pollution, can further augment aquifer recharge and can potentially pave the way for sustainable groundwater pumping in Lahore.

Water Resources Management of Delhi and Groundwater Supply Challenges—Prof. Shashank Shekhar, Department of Geology, University of Delhi. Delhi is a water scarce city. It has nine districts and one river. The Delhi Jal Board (DJB) has projected water demand for 2017 as 1,140 MGD, due to rapid population growth. Delhi's present supply is only 833 MGD and faces a deficit of 307 MGD. Eighty-five percent of its supply comes from surface sources (Yamuna and Ganga rivers) and 15 percent from groundwater. Over 50 percent of river water in Delhi comes from rivers that do not flow through the city, and tube wells have doubled. All wastewater is discharged into the Yamuna. Under existing agreements, there is limited scope to increase surface supply. Under this scenario, can groundwater resources help augment the gap? Can ponds, lakes, and other water bodies of water help?

Delhi has five types of water supply areas. The first type is high-density, multistoried areas that require large volumes of water supply that the aquifer's aerial extent often cannot sustainably meet. Either piped river water or groundwater supply from nearby areas could be options with small supply deficits met through local tube wells. The second type, low-rise, widely spread urban sprawls, also requires a high volume of water. The urban sprawls' current aquifer extent is fairly good. If judiciously managed, aquifers can substantially meet the demand. Individual and DJB tube wells also supply water here. The third type is urban villages in rural belts. It requires a relatively small volume of water supply. Localities are scattered and are mostly supplied by groundwater and, if convenient, through treated river water. This type of area has many individual tube wells. The fourth type is recently regularized unauthorized colonies, requiring an even smaller volume of water supply. Scattered localities are mostly supplied by groundwater from individual tube wells. The fifth type is unauthorized colonies, requiring relatively small volume of water supply. Scattered localities lack institutional supply; individual tube wells provide water supply.

Various options were recommended for addressing Delhi's water deficit and meeting its growing demand. Demand management options could include water use efficiency enhancing measures, water efficient gadgets, water pricing, and differential block tariffs. Supply-side management options include leakage and pilferage detention and control, and distribution of dual water supply and assured and timely supply. In addition, utilities could supply groundwater stressed areas with water from surface sources or other groundwater rich areas. Other options include augmenting River Yamuna flow by ensuring environmental flow, conserving and restoring natural water bodies, conserving natural and artificial wetlands and water bodies, and harvesting floodwater and rainwater for use and for recharging groundwater aquifers. Alternate sources of supply include exploration and development of brackish aquifers, desalination of saline groundwater, and reusing treated domestic and industrial wastewater. Challenges for implementing a groundwater-based water supply management strategy were discussed.

Dhaka City Water Supply: Issues and Challenges—Dr. Anwar Zahid, Deputy Director, Bangladesh Water Development Board. Dhaka's water supply, planned over 100 years ago, started to systematically develop groundwater in 1949. Today, with over 10 million people, Dhaka uses over 2.5 million cubic meters of water to meet its municipal demand. Unchecked surface water pollution has prompted heavy dependence on groundwater and led to the rapid expansion of tube wells. Currently, pumping levels are exceeding the very limited recharge. Extended urbanization is decreasing recharge areas. Overpumping for more than three decades has caused rapid decline of the water table.

The city is vertically enlarging (with many high-rise buildings), and inhabitant concentration and density is increasing. Improper construction of wells is contributing to premature well failure. Contractor capacity to construct efficient deep wells is very limited. Groundwater monitoring, particularly for private and other agencies, is inadequate. The increase of water demand in the dry season results in adjustment of pump settings. Well spacing is not optimized because of local demand, resulting in reduction of yield. The lower the groundwater level, the higher is the electricity consumption and cost of production.

The following recommendations are made to address Dhaka's water supply challenges: (a) shifting supply from groundwater to surface water; (b) augmentation of city water supply through construction of a well field outside Dhaka and supply the city by pipeline network or transport pumped groundwater to the city by trucks as emergency supply; (c) extending groundwater monitoring, particularly for private and other agencies' wells; (d) introduction of rated drawdown concept for pumping of production well; (e) enforcement of government orders regarding rainwater harvesting from rooftop and artificial recharge to the city aquifer; (f) installation of area-wise surface-water-treatment plants, reuse of treated storm and sewage water—mainly for washing, gardening, and toilet flushing—artificial recharge by injecting treated river water and rainwater, and digging of recharge basins, which could improve the groundwater table condition; (g) storing treated surface and storm water in infiltration or retention ponds or basins or pumping into the ground through recharge wells; (h) imposing laws and regulations regarding installation of a sand pile or a recharge well to be included during construction of a new residential building; (i) assessment of groundwater recharge; (j) promoting demand management to improve water use efficiency; and (k) proper implementation of existing laws and regulations to manage groundwater.

Chapter 10
Community-Based Groundwater

Chair: Mr. Ari Nathan, Director, Regional Environment, Science, Technology and Health (ESTH), Office for South Asia U.S, Embassy, Kathmandu

Working with Communities to Tackle the Arsenic Problem in Groundwater in Bangladesh—Ms. Hasin Jahan, Country Director, Practical Action. About 20 million people are exposed to the risk of arsenic in drinking water in Bangladesh. Several policy documents, chiefly the National Policy for Arsenic Mitigation (NPAM 2004) and the Implementation Plan for Arsenic Mitigation (IPAM 2004), guide the country's approach to tackling arsenic. Currently, as of 2016, the Local Government Division (LGD) of the Ministry of Local Government Rural Development and Cooperatives (MoLGRD&C), Government of Bangladesh (GoB) is in the process of revising the Implementation Plan for Arsenic Mitigation for Water Supply (IPAM WS 2004). A baseline survey undertaken by Village Education Resource Centre, Dhaka, in 2005[18] found arsenic contamination in 78 percent and 63 percent of the shallow tube wells (STWs), respectively, in the villages of Dhalipara and Doazipara in the Sitakunda subdistrict of Chittagong.

Poor household patients were found to suffer from multiple diseases (e.g., kidney, lung, and heart diseases; diabetes; ulcers). Provision of safe water is not enough: proper treatment is also essential for arsenicosis patients. Arsenicosis patients have reduced capacity to work and earn an income, and tend to be marginalized. Project interventions included: (a) Sono filters at 194 households (arsenic removal option); (b) rainwater harvesting systems at 32 households, and (c) ring wells at four households.

Important lessons from four years of project implementation were discussed. Mobilizing people and making them aware of the problem of arsenic took time, as no one acknowledged the problem. Sono filter performance was found to be satisfactory in terms of arsenic removal. Twenty-five percent of the households did not like the taste of filtered water. Users (households) could not understand the usefulness of the filters, and doubted whether it rendered water arsenic-free or not. So the frequency or necessity of changing filter media could not be understood or maintained properly. About half of the Sono filters out of 194 filters required minor repairs. In case of major repairs, there was no skilled mechanic to repair and ultimately a number of filters were abandoned. Changing Sono filters became difficult since there was no direct connection to the product supplier. During the project it was observed that, in general, an

[18] Village Education Resource Centre. 2007. *Arsenic Mitigation Pilot Project: Bacteriological field Test Report: Dhalipara and Doazipara of Muradpur Union in Sitakunda, April 2005–March 2006*. Dhaka, Bangladesh: Village Education Resource Centre.

approach driven by a nongovernmental organization (NGO) was helpful in the beginning, but projects should not fully depend on NGOs. Participation of communities in surveys and testing helps get communities involved in the project and thus tackle the problems in a timely manner.

Deep wells are not the only means of getting safe water. Removal technology like shallow-well filters could be also used. Regardless of the technology or method, maintenance was crucial for preserving the quality of safe water. Most safe water consumers in Bangladesh belong to high- and middle-income families. Poor people often cannot afford the technology and have to wait longer, hence remain exposed to arsenic longer. Bangladesh's national cost-sharing policy suggests 20 percent cost sharing by the poor to make the technology affordable.

One of the lessons in this project was that to promote alternative technologies and incentives to tackle the arsenic problem, it is important to create an enabling environment for businesses and a mechanism to ensure quality services, service-level and post-installation services. Water quality testing facilities and a national surveillance mechanism need to explored for establishing such facilities. Also, the provision of safe water to the communities is not enough, efficient health services are required. Most important, an integrated approach is needed for working with the communities in the arsenic-affected areas linking health and safe water provisions.

Learning from the Andhra Pradesh Farmer-Managed Groundwater Systems Initiative—Dr. P. S. Rao, Director (Technical), Advanced Centre for Integrated Water Resources Management (ACIWRM), India. The successful farmer-managed groundwater systems initiative in Andhra Pradesh, Andhra Pradesh Farmer Managed Groundwater Systems (APFMGS), offers useful lessons on participatory groundwater management. Farmers face challenges pertaining to (a) increasing groundwater pollution caused by fluoride, arsenic, agricultural pesticides, industrial wastes (heavy metals), nitrates, or fecal contamination; (b) depleting groundwater levels; (c) the effects of futile investments in failed bore wells; and (d) increasing debt traps leading to migration and suicides. At the state level (in Telangana and Andhra Pradesh), the challenges to managing groundwater are due to (a) farmers' lack of information and data; (b) increased stress on existing groundwater reserves due to increased investments by individual farmers in dry regions;(c) lack of capacities and outreach by the state's groundwater department to depletion problems; and (d) lack of recognition of how groundwater could be "managed." The key strategies used in the project include (a) promoting participatory hydrological monitoring; (b) demystifying science for the benefit of farmers; (c) supporting farmer water schools (an example of community capacity building); (d) developing crop water budgeting and promoting farm-level decision making; (e) reducing the water demand for crops; (f) building linkages between farmer-scientist and farmer-government; (g) building gender-balanced and community-based institutions around groundwater management.

During the APFMGS initiative, hydrological monitoring networks were established and hydrological information was shared openly between farmers. Farmers were trained in groundwater management tasks. Farmers monitored hydrological data, conducted crop water budgets, and identified 47 over exploited aquifer zones. The project promoted extensive debates on groundwater levels, quantities, and crop-water relationship in various meetings and forums. Farmers changed pump placement based on hydrological data, cutting the costs on electricity bill and motor repairs. As part of the process of regulating water use, farmer groups also applied sanctions on excess water users and declared borehole drilling holidays to allow aquifers to recover.

As a result of APFMGS and during the duration of the project, crop diversity increased from seven to 16 crops. Paddy cultivation was reduced in around 6,000 hectares. More sustainable crops were adopted, and groundwater draft was reduced in 36 overexploited aquifer zones through (a) switching to low water-consuming crops, (b) practicing water-efficient irrigation practices, (c) use of water-saving devices, and (d) introducing organic farming. The trainees for participatory hydrological monitoring and farmer water schools were volunteers. Since it was first started, the training has been extended to larger groups of farmers with the help of NGOs. A better gender balance in the project activities was achieved, and the experience has been shared with several other states and organizations.

This APFAMGS initiative is important because it (a) puts scientific knowledge in the user's hand; (b) makes best use of traditional knowledge; (c) supports microlevel analysis of hydrological system; (d) supports farmers to collect, collate, and interpret data; (e) empowers farmers to take decisions for demand-side management and artificial groundwater recharge; (f) supports users to come together as a functional group; and (g) promotes functional linkages with relevant agencies.

Farmer Participatory Groundwater Monitoring: A Blueprint for Pakistan—Dr. Arif Anwar, Principal Researcher, International Water Management Institute (IWMI). This presentation centered around a key question: is systematic monitoring of groundwater important in Pakistan? For fresh groundwater areas, both in the Indus Basin and the mountain provinces, effective regulation is required. Achieving this in the field is a tall order. The data available on groundwater are patchy and often dated or irretrievable. Systematic monitoring is limited to the Salinity Control and Reclamation (SCARP) areas, where it is done by the Federal Water and Power Development Authority. Outside SCARP areas very little monitoring is undertaken. There is an urgent need to improve monitoring of groundwater levels and groundwater quality (van Steenbergen and Olliemans 2002[19]).

[19] van Steenbergen, F., and W. Oliemans. 2002. "Groundwater Resource Management in Pakistan." In *ILRI Workshop Report: Groundwater Management: Sharing Responsibility For An Open Access Resource,* 93–110. Addis Ababa, Ethiopia: *ILRI.* http://content.alterra.wur.nl/Internet/webdocs/ilri-publicaties/special_reports/Srep9/Srep9-h6.pdf.

Groundwater instrumentation used in Pakistan (including data loggers) are useful and robust, and capable of collecting high resolution data on groundwater level and quality. They are expensive to purchase but easy to maintain. Technology by itself, however, is not sufficient for solving the groundwater governance issue. Any solution must involve key stakeholders: farmers and farmer institutions. The tragedy of Pakistan is that groundwater is a very precious resource, yet at the same time a resource that can be exploited at very low cost (Van Steenbergen and Olliemans 2002[20]).

Successful community based groundwater monitoring program requires collection of representative samples in relevant locations in a timely manner. It hinges on the involvement of key stakeholders—farmers and farmer organizations—in the monitoring process. The scientific kits are complex and expensive to install, so installation was not left to the farmers but was supported by the government. Data are collected monthly by farmer organizations, a cheaper method than government collecting data. Government buys the data from these farmer organizations. Permanent sensors give data on water temperature, water-level elevation and depth, and water quality, which can be turned into digital photographs presenting data in an informative format. The use of these scientific kits in hard rock areas will be more challenging.

Tackling the Chronic Kidney Disease in Sri Lanka—Dr. Tushara Chaminda, University of Ruhuna, Sri Lanka. Over 75 percent of Sri Lanka's rural population depends on groundwater for domestic supply. Chronic kidney disease of unknown etiology (CKDu) appeared in Sri Lanka in the early 1990s, and the incidences gradually reached high numbers in 2002. Close to 2,000 people have died and over 35,000 patients have been registered at renal clinics of several government hospitals in the dry zone of the island. Etiology of CKDu is suggested to be a combination of environmental factors. Hypotheses for CKDu are (a) fluoride and aluminum complexes in drinking water; (b) excessive hardness in drinking water; (c) consumption of polluted drinking water by cadmium and arsenic; (d) uranium in drinking groundwater; (e) algal toxins in drinking water and rice; (f) cadmium and arsenic in rice derived from agrochemicals; (g) consumption of freshwater fish contaminated by cadmium; (h) deposition of pollutants by northeast monsoons; (i) less water consumption and more alcohol consumption; (j) DNA-related issues; and (k) malnutrition during childhood. Additional evidence suggests that CKDu may be linked to groundwater use in Sri Lanka's dry zone. Current research is focused on investigating spatial distribution of fluoride, arsenic, harness, and heavy metals to explore if there is a relationship between the prevalence of health problems (particularly CKDu) and the contamination of groundwater.

High fluoride areas overlap with CKDu-affected areas. Areas with very hard water overlap with areas with high fluoride concentration. CKDu-affected areas overlap with high fluoride- and

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[20] van Steenbergen, F., and W. Oliemans. 2002. "Groundwater Resource Management in Pakistan." In *ILRI Workshop Report: Groundwater Management: Sharing Responsibility For An Open Access Resource,* 93–110. Addis Ababa, Ethiopia: *ILRI.* http://content.alterra.wur.nl/Internet/webdocs/ilri-publicaties/special_reports/Srep9/Srep9-h6.pdf.

hardness-contaminated area. A proper mechanism for groundwater quality monitoring is needed since most of the dry zone area finds no limited potential in using perennial surface water sources. The other option is that water from moderately contaminated wells can be blended with harvested rainwater to dilute high fluoride concentration.

When the residents are not able to access wells nearby with good quality water, excess amounts of fluoride, heavy metals, and harness should be removed. Synthetic ion exchange and precipitation processes, activated alumina filters, and reverse osmosis are typically used to remove fluoride from water in the high-income countries, although there is no universally accepted or routinely used defluoridation technique. Therefore, it is important to find a simple and economical solution to remove excess amount of fluoride and heavy metals as well as hardness from well water.

Around 80 percent of the population in the area is affected by kidney disease, and there are multiple reasons suspected as the cause. Hence, it is necessary to promote a national forum to collect all the findings and promote a multidisciplinary approach to research that includes clinical records, systematic water quality monitoring, and other relevant factors. In addition, improving awareness and knowledge sharing is important. It is necessary to improve diagnostics and data collection, and more accredited laboratories are required. Systematic monitoring leading to the preparation of groundwater quality maps would help to improve and deepen the understanding of the links between CKDu and groundwater quality.

Chapter 11

Cooperative Groundwater Management—International Experiences

Chair: Dr. Bill Young, Lead Water Resources Specialist, World Bank

Lessons from Delaware: Implementation of the State Comprehensive Groundwater Protection Program, Science Support, and Data Sharing—Dr. David Wunsch, State Geologist and Director, Delaware Geological Survey. Delaware, the second-smallest state in the United States, has an area of 2,491 square miles (6,452 square kilometers); it has many commonalities regarding groundwater management challenges with many South Asian nations. Agriculture is the largest user of groundwater in both Delaware and many South Asian nations, and all have water quality issues related to agriculture, industrialization, and population. Concentrated use of groundwater has resulted in significant declines in water levels in some aquifers. All have low-lying coastal areas that may be prone to salt water contamination or intrusion due to rising sea level.

In the United States, the state has the power to adopt, enforce, and establish administrative procedures, rules, and regulations to control, conserve, and manage the waters in the public's interest as well as the power to amend or repeal permits. Water allocation permits are required for all water withdrawals greater than 50,000 gallons (190 cubic meters) in any 24-hour period. Failure to apply for a withdrawal permit before withdrawing 50,000 gallons per day may lead to forfeiture of the right to withdraw water, as well as other penalties. Water allocation permits are issued for 30 years, and reviewed every five years, with the option for renewal. Those who request withdrawals from areas of Delaware within the Delaware River Basin that average more than 100,000 gallons (380 cubic meters) per day over any 30-day period must have approval from the Delaware River Basin Commission (DRBC).

Delaware State Comprehensive Groundwater Protection Program (DSCGPP) has primacy for the following programs: (a) drinking water, (b underground storage tanks, (c) Superfund (hazardous waste cleanup), (d) septic tanks and on-site sewage disposal, and (d) sediment and storm water.

The state (DSCGPP) is linked to the national program (Environmental Protection Agency [EPA] in fundamental ways. Funding comes from the EPA, and states must report progress. There is internal sharing of records and information between state programs or sections (e.g., joint monitoring requirements). The water supply section can require, for instance, that a groundwater monitoring well be installed between a tank site managed by an underground storage tank section and down a gradient water supply well. Some programs have financial incentives (e.g., funds for cleanup of Superfund sites; funds to control storm water through long-term, low-interest loans; funds for supporting new water supplies or water treatment or for purchase of land easements or wellhead protection to protect a drinking water source for contamination). Public outreach and participation is a key part of the program. State law and rules have established a committee that has a diverse membership (e.g., water supply coordinating council members include academics, state and local officials, water purveyors, agricultural interests, and the general public).

How does science inform policy? Special projects and research conducted for regulatory agencies (e.g., the Delaware Geological Survey, the United States Geological Survey [USGS], and academic institutions such as the University of Delaware). State groundwater protection programs vary from state to state. But recently the United States has focused efforts to collect, integrate, and share data in common formats. State grant programs on water use encourage cooperation and collaboration between state agency and the USGS to improve and build better water use databases. There are now tiered criteria for major categories of guidelines to achieve the ultimate goal for site-specific, watershed- and aquifer-based data, including consumptive use of water.

Groundwater management in Kent and Sussex counties in Delaware highlights the following lessons. Groundwater policy is based on sound scientific knowledge. Policy implementation is entirely based on regulation of groundwater abstraction through permits, including ones for domestic uses. Groundwater management is linked with river basin (surface water–groundwater interaction is fully taken into consideration). It lays a big emphasis on public outreach and participation. Transparency in decision making is the key to all the issues.

Towards Management of U.S.–Mexico Aquifers—Mr. Richard Kropp, Director, USGS. The main aim of U.S.–Mexico Transboundary Aquifer Assessment Act, 2007, is to conduct binational scientific research to systematically assess priority transboundary aquifers (i.e., Hueco Bolson and Mesilla Basin for New Mexico and Texas and Conejos-Medanos aquifer in Chihuahua; and Santa Cruz and San Pedro aquifers in Arizona) and to address the water information needs of border communities. It fosters collaboration between agencies in both countries to provide new information and a scientific foundation to state and local officials facing water resource challenges along the U.S.–Mexico border.

In the case of transboundary aquifers, it is easy and effective to build trust between interested parties first at the scientific level. Joint scientific studies through the use of academic and research institutions were found effective in the case of U.S.–Mexico aquifers. Key steps were taken in building a common database with seamless access by all parties, and agreements were made for adopting a standard methodology for data collection. Important initial accomplishments achieved included a memorandum of understanding signed by all parties for sharing of information and transfer of funds to bring transparency into the system; establishment of an initial hydrogeological framework; development of a binational wells database with geologic log information; and initial modeling of geophysical data to determine structure and distribution of hydrogeologic units.

To manage U.S.–Mexico aquifers, continuous analyses of population growth and groundwater demand trends are necessary. Groundwater monitoring network needs to be expanded. It is necessary to maintain and add stream gauges on both sides of the border. Precipitation monitoring network needs to be expanded. It is necessary to process, analyze, and publish water quality data, geophysical data, and ephemeral channel stream flow data. Groundwater-level and stream-flow data should be analyzed. Development of a calibrated binational groundwater and surface-water flow model for basins in Mexico and the United States is needed. Contaminant transport modeling can be performed with new groundwater and surface-water flow models.

Recognizing, understanding, and addressing the potential organizational and scientific challenges in transboundary water management is essential for successful collaboration. There will be institutional asymmetry (agencies do not have the same authorities or functions) and organizational parity (the scientific capabilities of agencies will differ). In addition, organizational priorities may differ due to conflicting interests (e.g., U.S. legislation may not be binding in Mexico).
Scientific challenges include harmonizing approaches and process to deal with (a) different definitions of technical terms; (b) data collection (e.g., different protocols for collection, quality assurance, quality control); (c) data storage (e.g., central versus distributed databases); (d) soil mapping; (e) common (elevation) datum; (f) data sharing (e.g., institutional obstacles); and (g) publications' institutional reviews and approvals.

The importance of building relationships cannot be overstated. Building trust is key; there is a need to build relationships at the scientist level separate from government to government. Binational partnerships require (a) mapping between asymmetric institutions, (b) appreciation of cultural differences, (c) trust and respect, (d) listening (i.e., seeking to understand before seeking to be understood), (d) time to understand goals and approaches, (e) define joint programs, actions, and studies, and (f) agree on review processes and joint outputs.

Middle East Water Databanks and Groundwater Awareness for Israeli, Jordanian and Palestinian Aquifers—Mr. Daniel J. Goode, Research Hydrologist, USGS. Challenges to water resource sustainability of Israeli, Jordanian, and Palestinian aquifers are primarily caused by population growth, the need to improve standards of living, and the widespread use of well water for agricultural irrigation in the context of a semi-arid to arid climate. Water levels in wells have declined substantially in several areas due to large withdrawals. Climate change is likely to further reduce aquifer recharge and increase groundwater demand. Groundwater quality has been degraded due to water level declines, which have caused salt water intrusion in coastal aquifers and upconing of deep aquifer brines. Agricultural irrigation has likewise increased groundwater salinity and caused pollution from fertilizers and pesticides. Other groundwater pollution sources include inadequately treated domestic and industrial wastewater.

In order for decision makers to sustainably manage these shared aquifers, groundwater hydrologic information needs to be shared. Relations along borders can cause challenges to sharing data, cooperating on hydrogeologic studies, and coordinating water resource management actions. Against this backdrop, Israeli, Jordanian, and Palestinian delegates met with international partners in 1992 in Moscow to start programs of multilateral regional cooperation on five subjects, one of which was water resources. The Water Resources Working Group of the Middle East Peace Process subsequently (in 1994) endorsed several projects, including the Water Data Banks project and the Public Awareness and Water Conservation project.

The Water Data Banks project consisted of a series of specific actions by Israelis, Jordanians, and Palestinians (the parties) to foster the adoption of common, standardized data collection and storage techniques, improved data quality, and improved communication. Results of joint efforts through the Water Data Banks project ranged from design, fabrication, and delivery of three mobile water quality laboratories to development of regional guidebooks for water quality sampling and analysis methods. Regional meetings of the parties included formal exchange of hydrologic data. The parties jointly developed custom software systems for digitizing analog water charts and building a database and statistical and graphical analysis of the data.

The Public Awareness and Water Conservation project supported groundwater awareness efforts, the outcomes of which included publication of a student resource book on water—published in Arabic, English, and Hebrew—which was used in middle schools in the region. The book provided general information about groundwater and a description of regional groundwater resources in a shared geographic and sociological context.

Since 1994, these multilateral water projects improved regional capabilities to manage a shared and scarce resource, improve public and youth awareness about groundwater, and provide opportunities for peaceful cooperation among technical government officials from the parties. The participants and their respective governments demonstrated water resources cooperation under difficult circumstances. The parties, with the support of international partners, continue to work together to overcome the many obstacles to sustainable management of Israeli, Jordanian, and Palestinian aquifers.

There are important lessons to learn from this work. The rate of expansion in groundwater use for agriculture is unlikely to be sustainable within decades. Continued economic development is dependent on improved groundwater management. There is shared interest among regional parties in groundwater and in its sustainable joint management. Rather than be a cause of conflict, the need for improved management of groundwater can be catalysis for cooperation. Public awareness of groundwater issues, especially threats in common with regional parties, can be improved by developing open, technically sound hydrology.

This case study has importance relevance for South Asia. Both the Middle East and South Asia face increasing demand for scarce water resources in a changing semi-arid climate. Groundwater is an important water resource for economic development (especially agriculture) in both regions, in which aquifers are shared by regional parties across political boundaries. Sustainable management requires systemwide information and coordination. Public trust is needed to implement change, and capacity building for government science agencies is essential.

Chapter 12

Group Work II—Good Practices in Groundwater Policy, Regulations and Institutions

Facilitator: Dr. John Dore, Senior Water Resources Specialist, Department of Foreign Affairs and Trade (DFAT)

During this session, six groups focused on diverse topics to discuss success factors of good practices in groundwater policy, regulations and institutions. Key lessons are summarized below.

The Solar Tsunami: Creative Responses towards Sustainable Groundwater

- There is need for different policies for water scarce and water abundant areas.
- Economic instruments such as subsidies and feed-in tariff remain best to incentivize farmers to conserve groundwater in water scarce areas and intensify groundwater use in abundant areas.
- Countries should take advantage of carbon credit and meet their Intended Nationally Determined Contributions (INDCs) by investing in solar powered irrigation pumps (SPIPs).

Silicon Aquifer: Technology Responses towards Sustainable Groundwater

- Methods for on-site and remote monitoring of quantity of water were discussed.
- Miniaturization of tools (examples include incorporation of elementary and data loggers).
- Use of drones with similar principles may give more spatially resolved data.
- Data availability and sharing in the public domain should become an important regional objective.

Grass-Roots Voices: Enabling and Tapping Community Power towards Sustainable Groundwater

- Recognize and encourage national, state, and basin initiatives with representation and information flow upward and information sharing and resource allocations downward in accordance with national principles (e.g., equity, community participation) to empower communities and strengthen their participation.
- Make local communities a part of assessment and decision-making process.
- Communities have excellent traditional knowledge and customs to tackle their problems and build on strengths.
- Educate and build capacity of communities with modern groundwater science and technology.
- Promote village groundwater cooperatives.
- Water quality sampling at a local level should be supported by analytical capability by the government at the local level.
- Community councils can also promote conjunctive use of groundwater and surface water.

The Necessary Evil: Legal Responses towards Sustainable Groundwater Management

- A legal framework that regulates groundwater is important and necessary.
- It needs to be anticipatory.
- This domestic management of groundwater needs to be both qualitative and quantitative, with access and equity stressed and top-down as well as bottom-up considerations addressed.
- It should be area-specific.
- Along with creation and passage of laws, implementation and monitoring are equally important.
- Regional legal framework documentation is needed to guide groundwater management.
- Emerging technologies (based on information technology [IT]) can complement creation and implementation of laws and real-time monitoring.
- Identify or develop mechanisms to learn lessons from states' and countries' regulations.

Joint Management: Ideas for Improving Transboundary Management (within or between Countries)

- It is essential to determine the right level of management response to ensure that the relevant institutions have an interest to be engaged in the process, which needs to happen across multiple levels.
- It is important that entities (e.g., states, countries) identify their own issues before engaging with others.
- Coordinated management would be a credible initial goal, and the next step could be a decision about the requirement of joint management.
- Building an evidence base of data and ownership by relevant parties is important.
- Along with capacity building, correcting underinvestment in relevant agencies and addressing any power imbalances within a country or across countries is necessary.
- Existing management and governance frameworks should be considered, e.g., whether groundwater management should be integrated with surface water management.
- Other questions include the role of governmental versus nongovernmental actors: How to incentivize coordinated or joint management? How to effectively define the benefits of joint management?

Regional Symphony: Next Steps for Building a South Asian Network for Sustainable Groundwater

- Galvanize cooperation among state agencies, forum of groundwater agencies and institutions chartered by the South Asian Association for Regional Cooperation (SAARC).
- Bring groundwater into existing bilateral agendas and exchange programs among regulating agencies.

- Bring together university departments and think tanks already working on this topic on a common research agenda, e.g., learning lessons of successes and dangers from around the world.
- Promote new interdisciplinary water management by encouraging students doing thesis on diverse aspects of the problem from hard sciences (atmospheric physics, etc.) to binding emotions (arts, literature, and cinema).
- Galvanize ethics community (socioenvironmental activists) for social mobilization incentives such as presenting regional annual prizes for the most successful or the best “out-of-box” thinking.
- Encourage innovations: technical (market), managerial (state agencies) and behavioral (social, religious groups).
- Bring real economic interests to the fore for ethical resolution of problems, for example, transboundary aquifer pilots across borders that are serious but less alarming geopolitically.
- Concentrate more on water management: from common South Asian meteorology to waste management and recycling.

Day 3—Building Drought and Climate Resilience for Farmers, Cities and Communities

Local and International Groundwater Management Experiences

Chair: Dr. Ger Bergkamp, Executive Director, International Water Association (IWA)

Managed Aquifer Recharge through Village-Level Intervention in Rajasthan and Gujarat (MARVI)—Prof. Basant Maheshwari, University of Western Sydney, and Dr. Peter Dillon, Honorary Fellow, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Australia

Conjunctive Management of Murray–Darling Basin Surface Water and Groundwater—Mr. David Harris, former Executive Director, New South Wales Water Commission, Australia
Innovations to Address Groundwater Contamination—Prof. T. Pradeep, Indian Institute of Technology Madras, Chennai

A Road Map for Building Drought and Climate Resilience

Chair: Dr. Amita Prasad, Additional Secretary, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India

Is South Asia Positioned to Respond to the Effects of Climate Change?—Dr. Rafik Hirji, Team Leader, World Bank, and Mr. Geert-Jan Nijsten, Senior Researcher, International Groundwater Resources Assessment Centre (IGRAC)
A Road Map for Building Drought and Climate Resilience—Dr. Amita Prasad, Additional Secretary, MoEFCC, Government of India [[AQ: doesn't match wording in Contents and]]

Group Work III—Building Groundwater Adaptation Capacity

Closing Session

Valedictory Address: Prof. Sanwar Lal Jat, Hon'ble Minister of State, Water Resources, River Development and Ganga Rejuvenation
Summary of Key Messages: Dr. Christina Leb (World Bank)
Closing Remarks: Dr. Amita Prasad (MoEFCC), Dr. Ger Bergkamp (IWA), Dr. Bill Young (World Bank) and Mr. Ganesh Pangare (IWA)

Chapter 13
Local and International Groundwater Management Experiences

Chair: Dr. Ger Bergkamp, Executive Director, IWA

Managed Aquifer Recharge through Village-Level Intervention in Rajasthan and Gujarat (MARVI)—Prof. Basant Maheshwari, University of Western Sydney, and Dr. Peter Dillon, Honorary Fellow, CSIRO, Australia. MARVI was a participatory project for data collection on groundwater and its impact on agriculture and the lives of the villagers. In this initiative information was shared to build understanding among villagers. To create understanding and take the project forward, the facilitators of the MARVI project engaged with policy makers, government agencies, and other stakeholders.

Under this project the "Bhujal Jankaar" approach for groundwater monitoring with farmer engagement was developed and evaluated. This approach was based on the following stages: (a) get to know the people where intervention is being made and create understanding among them; (b) then, based on this understanding, design and implement adaptive actions and strengthen institutions; (c) this will lead to change in perceptions and practice at the individual level and cooperation at the village level; (d) this in turn will lead to improved livelihoods, increased incomes based on sustainable use of groundwater, and a pathway for cooperation at the basin level.

Thus, groundwater dynamics were taught at village level, using simple and cost-effective methodology, along with the importance of managed aquifer recharge (MAR) to village livelihoods and MAR maintenance requirements. The facilitators also engaged with policy makers for their input into the project and also for practical applications of project outputs.

As a result, the MARVI project helped the people involved in it understand the management of groundwater and surface water as well as recharge, discharge, and other dynamics related to drought and climate resilience in the urban and rural spaces. The other key achievements of the project were (a) developing an understanding of groundwater management as influenced by people's attitudes, constraints, and needs; (b) spreading groundwater literacy in the communities and schools; (c) influencing farmer practices through crop demonstrations; and (d) engaging with policy makers for their input into the project and for practical application and adoption of project outputs.

Conjunctive Management of Murray–Darling Basin Surface Water and Groundwater—Mr. David Harris, former Executive Director, New South Wales Water Commission, Australia. About 1 million square kilometers in area, the Murray–Darling Basin extends across four states (Queensland, New South Wales, Victoria, and South Australia) and the capital territory of

Australia. Water is shared between the states under an agreement. Around 40 percent of Australia's agricultural production and 75 percent of irrigated agriculture is supported by the water extracted from the Murray–Darling Basin.

High-level policies with respect to water distribution and basin management are made cooperatively at the apex level through the Council of Australian Governments of the territories and states. This council aids the local authorities by providing guidelines for (a) water planning and implementation, (b) water allocation, (c) water quality and salinity management, (d) trade rules, (e) maintenance of registers of water entitlements, and (f) compliance. It is the responsibility of the states to implement the policy within their respective jurisdictions. Surface water is shared between the states under the Murray–Darling Basin Agreement, however, there is no similar multilateral agreement for sharing groundwater. Where aquifers are shared across jurisdictions, these may be managed through bilateral agreements.

Groundwater resources in the basin have been split into 23 groundwater resource plan areas, which are further divided into 66 sustainable diversion resource units. Groundwater entitlements in the basin are based on volumetric entitlements, and aquifer management is planned to maintain water balance by taking into account storage capacity, recharge, river-aquifer interaction, and water quality and salinity. The authorities work with the states to monitor groundwater resources to look at the changes in the water level or pressure on the aquifer. Where there is low river-aquifer interaction, extraction limits as a percentage of long-term average recharge is set and based on the ratio of total surface water to groundwater, and extraction is regulated. In areas of high river-aquifer interaction, groundwater extraction is linked to surface water availability and setbacks from rivers are set.

New South Wales is about 56 percent of the Murray–Darling Basin. Agriculture uses 65,200 square kilometers out of which 940 square kilometers are irrigated. Irrigation uses 75 percent of the total water use: 83 percent is from surface water and 17 percent, groundwater. New South Wales groundwater management includes the following: perpetual groundwater licenses are listed on the government register; some basic landholder rights are established, and water entitlement is separated from land. Use entitlement is allowed for irrigation with conditions of use. There is full cost recovery of supply and management. Other systems that are put in place include (a) allowing permanent and annual trade of groundwater entitlements within aquifers, (b) restricting groundwater entitlement trade in areas with groundwater depletion or recharge zones, and (c) development of 10-year statutory plans to guide management actions.

Lessons learned are as follows:

- Stakeholder engagement in policy development and implementation is essential: (a) the greater their understanding of the issue the more they can be part of the solution; and (b) governments do not have a monopoly on ideas.

- Water reforms must address social, economic, and sustainability components; infrastructure and technical solutions don't work in isolation but are an important part of the reform package.
- Water reform is a process, with no defined end point, but which involves constant adaptation. Doing nothing is not an option.

Relevance to other countries:

- Most South Asian countries are undertaking significant water management reforms.
- Water reform is hard, however, doing nothing is not a viable option and there is no simple solution.

Water reforms in Australia are suited to that environment:

- Some elements of the reform are applicable to other countries.
- Demand management is a fundamental component of water management.
- Reforms have included investment in infrastructure and water use efficiency, institutional reform, and policy development and implementation.

Finally, it is important to bear in mind that it is not enough to just start the reforms. Administering reforms is a long process of continual adaptation and it needs sustained efforts.

Innovations to Address Groundwater Contamination—Prof. T. Pradeep, Indian Institute of Technology Madras, Chennai. Nanotechnology offers innovative and affordable opportunities as a revolutionary technology for dealing with groundwater contamination. Prof. Pradeep argues that advanced science using nanomaterial-based technologies can be an effective part of the solution to groundwater issues, especially those related to monitoring and filtering. Nanotechnology utilizes new nanoscale phenomenon to filter contaminants from water. Nanotechnology filtration is cheaper compared to the older generation of filters. Hence it could become a preferred option once the technology is better known, understood, and accessible.

Nanotechnologies can help deal with iron and arsenic removal in water. New generation of adsorbents using iron oxyhydroxide are changing the dynamics at the ground level with promising results (input arsenic concentrations: 168 parts per billion, and output arsenic concentration: 2 parts per billion). The new generation technologies occupy very small land areas compared to older arsenic removal technologies using activated alumina as adsorbents that require larger land areas. The performance data from pilot experiments conducted using the new generation of adsorbents from Murshidabad and Nadia were published in several journals, including the monthly newsletter *Nature Nanotechnology* (July 2014) and the *Scientific American* (May 2013), which reported on the technology that promised safe quality drinking water at affordable prices. Arsenic monitor and arsenic filter can be integrated into in-line filtration and monitoring unit to improve management of arsenic.

It is necessary to identify the pollutants that enter the system through food particles. Synthetic nanomaterials can be dangerous and should be avoided. Naturally available nanomaterials whose chemistry is well known are relatively safe to use. Nanotechnology offers solutions to address water contamination, but it is important that one uses natural nanomaterials and not the synthetic ones. *Aquananotechnology: Global Prospects* (Reisner and Pradeep 2014[21]) provides important insights about the technology and its usefulness for water filtration.

[21] Reisner, D. E., and T. Pradeep, eds. 2014. *Aquananotechnology: Global Prospects*. Boca Raton, FL: CRC Press.

Chapter 14
A Road Map for Building Drought and Climate Resilience

Chair: Dr. Amita Prasad, Additional Secretary, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India

Is South Asia Positioned to Respond to the Effects of Climate Change?—Dr. Rafik Hirji, Team Leader, World Bank, and Mr. Geert-Jan Nijsten, Senior Researcher, International Groundwater Resources Assessment Centre (IGRAC). Recent studies by the Organisation for Economic Co-operation and Development (OECD), United Nations Educational, Scientific and Cultural Organization Groundwater Resources Assessment under the Pressures of Humanity and Climate Change (UNESCO GRAPHIC), and World Bank[22] all conclude that groundwater, if well managed, can act as an effective climate adaptation option: it is a natural insurance mechanism and not just a component of freshwater supplies. In operational terms, is the region positioned to respond to the effects of climate change?

South Asia's groundwater is highly vulnerable to climate change. This high vulnerability is a function of four factors: (a) utilization is moderate; (b) impact of climate change on recharge is likely to be negligible; (c) impact of sea level rising and storms is likely to be high, especially given South Asia's very large coastline. Finally, the region's adaptive capacity—physical, administrative, and institutional—is low. Over the recent decades, as surface supplies have become less reliable, dependence on groundwater has increased substantially in South Asia. Under climate change, surface runoff will likely be impacted and make surface supplies less reliable. This will likely put extra pressure on groundwater. On the demand side, warmer temperatures will affect crop water use. Thus, under warmer conditions, crop evapotranspiration would be higher. Population growth will increase demand for water, food, and energy. Rising sea levels will impact the coastal groundwater quality. In such a scenario, managed groundwater will be central to adaptation to impact of climate change.

Recharge and discharge of groundwater is affected by changes in climate (precipitation), land use change, and human intervention (e.g., pumping). Recharge and discharge rates are also impacted by different types of aquifers, for example, shallow, fast, connected aquifers versus deep, slow aquifers. Groundwater quality also affects the supply of water for human consumption directly or indirectly.

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[22] Studies mentioned: (a) Clifton, C., R. Evans, S. Hayes, R. Hirji, G. Puz, and C. Pizzaro. 2010. "Water and Climate Change: Impacts on Groundwater Resources and Adaptation Options." Water Working Note 25, World Bank, Washington, DC; (b) UNESCO GRAPHIC. 2015. *Groundwater and Climate Change: Mitigating the Global Groundwater Crisis and Adapting to Climate Change, Position Paper and Call to Action*. UNESCO: Paris; (c) OECD. 2015. *Drying Wells, Rising Stakes: Towards Sustainable Agricultural Groundwater Use*. OECD Studies on Water. Paris: OECD.

Thus, climate change has implications for groundwater-dependent systems as well. Rural populations often depend on groundwater as a safe alternative to surface water. However, climate change is likely to have an impact on groundwater, human health, livelihoods, and food security. Even in urban areas climate change is likely to impact the use of water in the form of, for instance, unreliable reticulated water supplies, economic losses, adverse effects on human health, and social disruption. In addition, irrigation is increasingly reliant on groundwater. Reduced recharge diminishes irrigation use, whereas increased recharge leads to irrigation expansion. Irrigation may also increase salinization. Reduced recharge can affect base flow and dry up springs and wetland ecosystems. Thus, if groundwater is to become central to the adaptation mechanism for climate change impact, it is important to create a framework to build adaptation capacity based on (a) social capital (e.g., education, training, and governance); (b) information (e.g., understand climate, quantify groundwater, and monitor); (c) research and development (e.g., climate-impact assessments and adaptation methods); (d) governance (e.g., policy, regulations and institutions, conjunctive use, planning, and management of surface and groundwater, and demand management); and (e) groundwater entitlements and markets.

Central to a groundwater-adaptation framework must be management of the following aspects: recharge, storage, discharge, quality and demand. For this purpose, it is important to understand how the system works. Assessment of the complete groundwater system, including impacts of climate change and impacts of human behavior, needs to be done. Also adequate data need to be collected (e.g., classical hydrogeological data, including long-term monitoring data of groundwater levels, groundwater quality, and groundwater use [abstraction]). Analyses need to be done through modeling and conducting detailed studies to better understand crucial processes and responses and to make projections under different scenarios.

In addition, there is a need to move from assessment to management solutions. To find realistic solutions there is a need for further socioeconomic and political analyses and environmental studies. Sociocultural and political analyses need to be done to develop understanding to gauge acceptance of solutions. Finally, it is important to keep in mind that there is no "one-size-fits-all" solution in the Indian setting. Successful solutions depend on a combination of factors.

A Road Map for Building Drought and Climate Resilience—Dr. Amita Prasad, **Additional Secretary, MoEFCC, Government of India**. According to *The Guardian* (Vidal 2009[23]), climate change is expected to have the most severe impact on water supplies, shortages in future are likely to threaten food production and damage ecosystems, and climate change will cause more violent swings between floods and droughts. Global climate change is due to natural and human causes. The current water cycle and the drivers of climate change (greenhouse gas emissions and

[23] Vidal, John. 2009. "Global Warming Causes 300,000 Deaths a Year, Says Kofi Annan Thinktank." *Guardian* (blog), May 29 (accessed May 31, 2017), https://www.theguardian.com/environment/2009/may/29/1.

land cover change), lead to vulnerability of water resources. Lack of data and lack of knowledge in hydrological cycles are crucial problems.

Climate change will lead to deviation from normal conditions (climate and hydrology): it affects temperature and then meteorological drought; meteorological drought affects soil, water, and so on. All is relevant for agriculture, health, water resources, power, and ecosystems. Climate change and drought are linked. Increased evapotranspiration and reduced precipitation increase frequency and intensity of droughts. Droughts in turn can lead to desertification, land degradation, and deforestation. Srivastava and Rai 2012[24] estimate that sugarcane yields will fall dramatically. *Business Standard* (2015) reported that rice yield will drop in Odisha. The major climate change-related challenges include (a) that 16 percent of India's geographic area is drought-prone and (b) implementation of the National Action Plan on Climate Change 2008 (NAPCC 2008), which outlines existing and future policies and programs addressing climate mitigation and adaptation. The plan identifies eight core "national missions," namely National Water Mission, Green India Mission, National Solar Mission, National Mission on Sustainable Habitat, National Mission on Enhanced Energy Efficiency, National Mission for Sustaining Himalayan Ecosystem, National Mission for Sustainable Agriculture, and a National Mission on Strategic Knowledge for Climate Change.

Institutional and policy framework supports coordinated action, preparation of the District Agriculture Contingency Plan that was launched in 2010[25], mitigation of adverse impact through efficient water management practices, and the promotion of knowledge sharing and capacity building. The main recommendations include (a) supporting better water management, (b) promoting climate-resilient agriculture, (c) imparting skills and education, (d) strengthening systems and effectiveness in data collection, (e) focus on agro-forestry, and (f) watershed management.

The *proposed national level actions* include (a) strengthening of the observational network for drought monitoring, (b) capacity enhancement for medium- and long-range drought forecasting, (c) developing mechanisms for context-specific and need-based forecasting, (d) improvement in information and communication technologies (ICTs), (e) dissemination in local languages for better understanding of the people. The *proposed regional level actions* include (a) enhancement of real-time monitoring capabilities through training and joint monitoring programs, (b) improvement in methodologies and analytical tools for drought analysis and vulnerability

[24] Srivastava, A. K., and M. K. Rai. 2012. "Sugarcane Production: Impact of Climate Change and Its Mitigation. *Biodiversitas 13* (4): 214–27.

[25] DACP are technical documents aimed to be ready reckoners for line departments and farming communities on prevailing farming systems and technological interventions to manage various weather aberrations such as droughts, floods, etc. The contingency plans are useful for drought preparedness.

assessment, (c) capacity building through joint training programs in improved resilience toward drought, and (d) effective and collaborative implementation of drought relief programs.

Chapter 15

Group Work III—Building Groundwater Adaptation Capacity

Chair: Dr. Amita Prasad, Additional Secretary, Ministry of Environment, Forest and Climate Change (MoEFCC), Government of India

The third breakout session focused on identifying climate change adaptation policies and actions for sustainable use of groundwater drawing from 10 diverse cases of urban, rural, and agriculture water supply contexts. The cases were from various parts of South Asia facing a variety of groundwater management challenges (e.g., depletion, depletion and pollution, depletion and saltwater intrusion, salinity control, arsenic control, irrigation and fluoride, salinity control in irrigated areas). The group discussion was centered around six areas: building adaptive (administrative, technical, and management) capacity, managing groundwater recharge, protecting groundwater quality, managing groundwater storage, managing demand for groundwater, and managing groundwater discharge.

Forum Recommendations

Adaptive groundwater management requires implementing a variety of policy reform options. The forum participants from discussions from 10 groups converged towards the following water policy reform actions to address the region's groundwater management challenges in a more concerted manner with surface water through adopting integrated water resources management:

- Invest in groundwater knowledge and science to support evidence-based decision making
- Elevate political/public awareness of the value of groundwater and opportunities it presents
- Develop, strengthen, and implement groundwater policies and legislation
- Prioritize training and capacity building for farmers, professionals and policy makers
- Scale up community-based groundwater management and collection action initiatives
- Build technical and administrative capacity, empower and fund groundwater institutions
- Build and strengthen groundwater regulatory capacity
- Invest in demand management, including improved irrigation water use efficiency
- Promote planned MAR and conjunctive management of surface and groundwater
- Develop groundwater management plans
- Encourage cooperative monitoring, assessment, and management of transboundary aquifers
- Act now to take the necessary decisions to address what is known
- Organize and mobilize support for addressing complex and longer term actions and reforms

Chair Dr. Prasad, in her concluding remarks on "Group Work III," was pleased to note that the groups were able to identify, acknowledge, and accept the problems across the region unanimously. Groups adopted practical ways of looking at these problems. Along with many other solutions, the need for collecting adequate and reliable data collection and its easy accessibility was stressed. However, Dr. Prasad suggested going beyond data accessibility. She suggested the need to adapt cutting-edge approaches and techniques for data analytics (e.g., modeling, simulation). She recommended the continuation of the dialogue on groundwater and drought and climate resilience and noted the need to relook at water polies, legislation, institutions, and capacity building with a strong groundwater lens. And she recommended more detailed research to better understand the role of groundwater for drought and climate resilience through improved groundwater governance and management.

Chapter 16
Closing Session

Moderator: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA

Valedictory Address—Prof. Sanwar Lal Jat, Hon'ble Minister of State, Water Resources, River Development and Ganga Rejuvenation, Government of India. In his valedictory address, the Hon'ble Minister of State thanked the participants to have spent such a considerable time deliberating on various aspects of groundwater management. In light of the water scarcity being faced across several parts of India, he noted the timeliness of the forum to lead to reflecting and addressing the challenges at hand. He also extended a welcome and thanked all participants from neighboring nations—Pakistan, Afghanistan, Bangladesh, Bhutan, China, Nepal, and Sri Lanka—along with experts from all over the world.

Prof. Jat called for action and reminded the audience that the traditional knowledge and wisdom of the people of India may have some answers to managing water sustainably. He stated, "One important aspect of traditional wisdom on water management was that water bodies recharged the groundwater, which was used in the summer months. One of the reasons for groundwater depletion is that we have forgotten the basic principles of conservation and rejuvenation of our water resources."

Prof. Jat emphasized the need to integrate ancient wisdom with modern science and technology. "My ministry is a great repository of scientific information and knowledge on groundwater," noted Prof. Jat. However, the government alone cannot tackle the crisis; he called for engaging in participatory, multisectoral approaches to managing groundwater. The efforts of the government, such as legislation and programs, have to be complemented with inputs from and support of people and partners such as the ones at the forum. Groundwater is directly linked to livelihoods; therefore, it impacts whether the socioeconomic condition will improve for millions of people across South Asia. Thus, the deliberation at this forum will be very important for the ministry to take forward the work on managing groundwater sustainably. He said that the momentum and wisdom generated at the forum will result in a mass movement for groundwater management and sustainable use across the region.

Summary of Key Messages—Dr. Christina Leb, World Bank. The objectives of the forum were to (a) elevate, at the policy level, the vital role groundwater plays in the water sector across South Asia; (b) build a community of practice—a network of technical expertise—to guide improved groundwater management in South Asia; (c) share knowledge and experiences in groundwater management and governance; and (d) discuss opportunities for local, national, and regional action to achieve sustainable groundwater use and build drought and climate resilience. The three days of discussions were structured around three themes to understand: (a) the value and limits of this vital yet hidden resource; (b) the foundations for sustainable groundwater management and use; (c) how to build drought and climate resilience for farmers, cities, and communities.

Groundwater plays a vital role in the economies of South Asia. Around one-fourth of the global abstraction is in the Indo-Gangetic plain. In South Asia, the "silent revolution" of groundwater development has lifted millions out of poverty, making farmers, previously dependent on rainfed agriculture, resilient to hydrologic variability. Groundwater has provided food and income security. It has been the driving force for agricultural "revolution" with change of irrigation from Type I (surface water, kinetic energy, and public investments) to Type II (groundwater, private development, and mechanical energy and electricity).

Thus, the groundwater-energy-food nexus needs to be looked as an important driver of the economies in South Asia. Because of the invisible nature of groundwater and because it is relatively cheap to develop and requires little infrastructure investments, across the region, government policies have encouraged its reckless mining with subsidized power. Now, changing farmer behavior is seen to be politically difficult.

Use of modern technology such as solar pumps may be helpful in its outreach to the poor at a large scale. However, the "solar tsunami" represents a bundle of threats, potentially creating a similar challenge as subsidized electricity. There is an increasing risk of overpumping, unless monitored and managed properly, as noted by Prof. Tushaar Shah. Prof. Shah added, "Democratization of energy grid independence creates a formidable challenge for groundwater management" and needs to be handled with caution.

Recommendations from the urban groundwater use session are for urgent actions in major cities to deal with the deteriorating groundwater situation. Rapid urbanization has increased the demand for water. There is a correlation between population growth and groundwater dependency. How hydrologic variability and climate change are likely to intensify the groundwater management problems further was also discussed.

Regional differences were discussed during the session on country perspectives. There are regional differences within countries, for instance, in east India (good recharge but arsenic contamination), in west India (arid, recharge challenges, and overexploitation) and in southeast India (coastal aquifers and saline intrusions). The differences in geological characteristics determine the aquifer resilience to change and ease of abstraction and recharge.

The challenge of recharge is a complex issue. Recharge structures such as check dams need to be sited and designed on the basis of sound hydrogeological conditions; they have their own complexity, including, for instance, downstream impacts. The possibility of conjunctive use of surface water and groundwater was discussed and recommended.

It is not adequate to focus on groundwater quantity alone, groundwater quality is equally important. Geogenic and anthropogenic pollution is both a quality and quantity challenge.

Overpumping induces transport of contaminants such as arsenic. Water quality risks from on-site sanitation and leakage can be significant. The health impact due to contamination affects economic opportunities.

A key message from the forum is the need to shift from groundwater development to groundwater management. Unfortunately, reforms start only with crises. Today the region has reached a state of crisis that in the future could lead to risk of conflicts between farmers, cities, villages, districts, states, provinces, and nations. It is critical to learn to live within the available means.

Governance is challenged by lack of policy and legal frameworks or outdated the laws (with the exception of Bhutan). For example, the Easements Act (India, Pakistan, and Bangladesh), 1882, leads to limited responsibility at the federal level and makes top-down and national approaches to water resource management difficult, especially with interconnected systems. Thus, there is a need for better regulation in almost all the countries. Better regulation requires clear definitions, identification of issues, and adequate and strong institutions for enforcement.

Aquifer protection plans are required to avoid overabstraction. Pollution control and managed recharge should be carried out with land use planning and zoning. Communities should be trained to use technology for monitoring purposes. For example, color-coded systems developed for drillers to show the arsenic content of sediment to indicate the security and safety of groundwater should be implemented. Smart fines, subsidies, and price incentives should be used to control groundwater use, and licenses based on “safe yield” determination and capacity building and stakeholder participation need to be prioritized.

A combination of policy interventions and balance of subsidies, incentives, and regulation adapted to local conditions can make positive changes for sustainable management. Management approaches need to be based on an understanding of aquifer hydrogeology and should be customized to the local socioeconomic and institutional and governance context. Principles of national framework and water acts need to be operationalized through secondary legislation and institutions (put in place before legislation is enacted). It is necessary to build capacity of communities before management and monitoring responsibilities are transferred to communities. Thus, it is vital to involve communities in designing monitoring programs and in enacting regulations to ensure implementation. It is necessary to provide practical knowledge in an accessible form to communities.

Case studies from Gujarat and Rajasthan on community recharge show the importance of the process of integrating stakeholders (Maheswari et al. 2014[26]). International case studies from the United States experience show that the process is the same, whether at local, national, regional or cross-border levels. Participatory collection of good quality data is necessary to acquire knowledge of aquifer characteristics. Building shared data is vital and efforts need to be put into it in future. Few solutions are purely technical in nature; most solutions need a sound understanding of the socioeconomic and regulatory environments.

Closing Remarks—Dr. Amita Prasad, Additional Secretary, Ministry of Environment, Forest and Climate Change (MoEFCC). Dr. Amita Prasad expressed her appreciation to the efforts made by the forum organizers, and observed that the forum had brought together a diverse group of professionals from across the region, from China to all the South Asian countries, and had succeeded in giving voice to all major issues pertaining to groundwater across the region. She hoped that the dialogue on groundwater, which began through the workshop, will continue and be followed by actions. She suggested that a forum for South Asia should be created in which exchange of ideas can take place. At the end she requested the World Bank and IWA to organize follow-up workshops for technical partnership and knowledge exchange in the near future.

Dr. Ger Bergkamp, Executive Director, IWA. Dr. Ger Bergkamp said that IWA has been working on bringing people together from all over the world to build cooperation to solve issues pertaining to water. This forum was yet another example of the creative experiences that IWA is bringing to the world, and thus he was thankful and happy to have been instrumental in organizing this conference. He expressed the need to continue this conversation further. He added that "when you bring top professionals together and begin a dialogue, the churning starts, giving rise to ideas for positive outcomes: to build a water wise world, to reduce inefficiency and waste, and to recycle".

Dr. Bergkamp noted that "All over the world there is a need to improve accessibility to clean water, to replenish water resources, and to prevent, stop and reverse depletion of water quantity and quality. For this, we need to discuss not only policies and regulations but also specific activities; we need to think not only of the long run but also about things of immediate consequence: what we can do immediately with communities at the grassroots level?" Dr. Bergkamp expressed his appreciation of the fact that the forum had succeeded in bringing together representatives from various government departments and states all across the region.

Dr. Bill Young, Lead Water Resources Specialist, World Bank. Dr. Bill Young, in conveying his vote of thanks, stated that the World Bank has been convening dialogues and events to promote water

[26] Maheshwari, B., M. Varua, J. Ward, R. Packham, P. Chinnasamy, Y. Dashora, S. Dave, P. Soni, P. Dillon, R. Purohit, and T. Shah. 2014. "The Role of Transdisciplinary Approach and Community Participation in Village Scale Groundwater Management: Insights from Gujarat and Rajasthan, India. *Water 6* (11): 3386–08.

cooperation in South Asia for the last 10 years. However, in the past the events were narrower in scope. Increasingly, the World Bank has been broadening the scope, moving to basin level. Today, conversations around water are becoming more and more important due to additional challenges like the looming threat of the impact of climate change. Thus it is important to take these conversations forward at the national level and then at the local level. He expressed his hope that the conversation started at the conference will inspire a generation of dialogue at the national level, and the World Bank will be happy to support such efforts.

Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA. Mr. Ganesh Pangare, at the end of the forum, made the following announcements that (a) the proceedings of the conference will be sent to all the participants; (b) an email list of all the participants will be circulated; (c) IWA would launch a global website through which everyone can remain connected for a better future. He concluded the conference with the final vote of thanks.

Appendix A

PROGRAM
South Asia Groundwater Forum:
Regional Challenges and Opportunities for Building Drought and Climate Resilience for Farmers, Cities and Villages
Jaipur, Rajasthan
June 1–3, 2016

DAY 1—*Understanding the Value and Limits of a Vital Hidden Resource*

Time (in hours)	Program
0830–0915	**REGISTRATION at the Mandani**
0920–1000	**Inaugural Address**: Master of Ceremony: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA Lighting of the lamp *Welcome and Setting the Scene*, Mr. Shashi Shekhar, Secretary, MoWRRDGR, India *Welcoming Remarks*, Ms. Jennifer Sara, Senior Director for the Water Global Practice, World Bank *Groundwater Megatrends in South Asia*, Mr. Jeremy Bird, Director General, IWMI
1000–1150	**SESSION 1: Political Economy of Groundwater** **Chair: Mr. Shashi Shekhar, Secretary, MoWRRDGR, India**
1005–1025	*Groundwater Policy Implications for Building Drought and Climate Resilience in South Asia*, Dr. Rafik Fatehali Hirji, Team Leader, World Bank
1025–1045	*The Political Economy of the Groundwater-Energy-Food Nexus: Towards Drought and Climate resilience*, Prof. Tushaar Shah, Senior Fellow, IWMI
1045–1105	*Direct Delivery of Power Subsidy to Manage Groundwater-Energy-Food Nexus*, Mr. Mohinder Gulati, former CEO, UN Sustainable Energy for All
1105–1135	*High-Level Panel Discussion: Groundwater Policy Implications for Drought and Climate Resilience* Moderator: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA Panelists: - Mr. Shashi Shekhar, Secretary, MoWRRDGR, Government of India - Mr. Nisar A. Memon, former Federal Minister, Pakistan/Chairman, WEF - Mr. Dipak Gyawali, Chair, NWCF, Nepal - Dr. Bill Young, Lead Water Resources Specialist, World Bank
1135–1150	**Q&A**
1150–1205	**TEA/COFFEE BREAK**
1205–1305	**SESSION 2: Regional Groundwater Management Perspectives**

	Chair: Mr. Jeremy Bird, Director General, IWMI
1205–1225	*Groundwater Resilience to Climate Change and Abstraction in the Indo-Gangetic Basin*, Prof. Alan MacDonald, Principal Hydrogeologist, British Geological Survey
1225–1245	*Groundwater Quality Challenges in South Asia and Options for Management*, Prof. Kazi Matin Ahmed, Dhaka University
1245–1305	**Q&A**
1305–1415	**LUNCH at the Aarogosa**
1415–1530	**SESSION 3: Panel—Country Groundwater Priorities** **Co-chairs: Mr. Nisar A. Memon, former Federal Minister, Pakistan/Chairman, WEF, and Ms. Mieke van Ginneken, Manager, World Bank**
1415–1505	Country Presentations: • Mr. Sayed Sharif Shobair, Coordinator and Chief Engineer, FAO/IRDP, Afghanistan • Dr. Anwar Zahid, Deputy Director, Bangladesh Water Development Board, Bangladesh • Mr. G.K. Chhopel, Chief Environment Officer, Water Resources Coordination Division, National Environment Commission, Bhutan • Prof. Guangheng Ni, Director, Institute of Hydrology and Water Resources, Tsinghua University, China • Mr. Dipankar Saha, Member, CGWB, India • Mr. Dhana Bahadur Tamang, Secretary, Water and Energy Commission Secretariat, Nepal • Mr. Muhammad Riaz, Director, Program Monitoring and Implementation Unit, Punjab Irrigation Department, Pakistan • Mr. Ranjith Seevali Wijesekera, Chairman, Water Resources Board, Government of Sri Lanka
1505–1530	**Q&A**
1530–1550	**TEA/COFFEE BREAK**
1550–1800	**SESSION 4: Group Work I—Tackling Irrigation and Domestic Water Supply Challenges** **Facilitator: Dr. John Dore, Senior Water Resources Specialist, DFAT**
1550–1700	Six groups
1700–1800	Group Presentations
1900–2100	**RECEPTION at pool lawns**

DAY 2—*Foundations for Sustainable Groundwater Use and Management*

Time	Program	
0900–1000	**SESSION 5: Groundwater-Energy-Food Nexus: Policy Implications Chair: Mr. Dipak Gyawali, Chair, NWCF**	
0905–0925	*Food-Irrigation- Energy Nexus in the context of Groundwater Use in India*, Dr. Aditi Mukherji, Theme Leader, Water and Air, ICIMOD	
0925–0945	*Managing Groundwater Use in Agriculture Sustainably: Lessons from OECD Nations*, Dr. Guillaume Gruere, Senior Policy Analyst, OECD	
0945–1000	**Q&A**	
1000–1110	**SESSION 6: Lessons on Regulating Groundwater Chair: Justice Madan B. Lokur, Supreme Court of India**	
1005–1025	*Groundwater Regulation and Implementation: An Overview*, Mr. Stefano Burchi, Executive Chairman, International Association for Water Law	
1025–1040	*Model Bill for Regulation of Groundwater Development*, Mr. Y. B. Kaushik, Regional Director, CGWB, India	
1040–1055	*Groundwater Management Legislation in the Indus Basin*, Ms. Hina Lotia, Director, Programs, LEAD Pakistan	
1055–1110	**Q&A**	
1110–1130	**TEA/COFFEE BREAK**	
1130–1300	**SESSION 7a: Urban Groundwater Supply Chair: Mr. Sarafat Hossain, Director General, WARPO, Government of Bangladesh**	**SESSION 7b: Community-Based Groundwater Chair: Mr. Ari Nathan, Director, Regional ESTH, Office for South Asia US Embassy, Kathmandu**
1135–1150	*Groundwater Management Challenge in Urban Asia*, Dr. Sangam Shrestha, AIT, Bangkok	*Working with Communities to Tackle the Arsenic Problem in Groundwater in Bangladesh*, Ms. Hasin Jahan, Country Director, Practical Action
1150–1205	*Sustainable Groundwater Supply: Issues and Options for Border City of Lahore*, Mr. Ali Tauqeer Sheikh, Director, Asia Climate and Development Knowledge Network, Pakistan	*Learning from the Andhra Pradesh Farmer-Managed Groundwater Systems Initiative*, Mr. P. S. Rao, Director (Technical), ACIWRM, India
1205–1220	*Water Resources Management of Delhi and Groundwater Supply Challenges*, Prof. Shashank Shekhar, Department of Geology, University of Delhi	*Farmer Participatory Groundwater Monitoring: A Blueprint for Pakistan*, Dr. Arif Anwar, Principal Researcher, IWMI

1220–1235	*Dhaka City Water Supply: Issues and Challenges*, Dr. Anwar Zahid, Deputy Director, BWDB	*Tackling the Chronic Kidney Disease in Sri Lanka*, Dr. Tushara Chaminda, University of Ruhuna, Sri Lanka
1235–1300	**Q&A**	**Q&A**
1300–1400	**LUNCH at the Aarogosa**	
1445–1545	**SESSION 8: Cooperative Groundwater Management—International Experiences** **Chair: Dr. Bill Young, World Bank**	
1445–1505	*Lessons from Delaware: Implementation of the State Comprehensive Groundwater Protection Program, Science support and Data sharing*, Dr. David Wunsch, State Geologist and Director, Delaware Geological Survey	
1505–1525	*Towards Management of U.S.–Mexico Aquifers*, Mr. Richard Kropp, Director, USGS	
1525–1545	*Middle East Water Databanks and Groundwater Awareness for Israeli, Jordanian and Palestinian Aquifers*, Mr. Daniel J. Goode, Research Hydrologist, USGS	
1545–1600	**TEA/COFFEE BREAK**	
1600–1730	**SESSION 9: Group Work II** **Facilitator: Dr. John Dore, Senior Water Resources Specialist, DFAT**	
Six Groups		
1930–2230	**DINNER at the Village**	

DAY 3—*Building Drought and Climate Resilience for Farmers, Cities and Communities*

Time	Program
0900–1030	**SESSION 10: Local and International Groundwater Management Experiences** **Chair: Dr. Ger Bergkamp, Executive Director, IWA**
0905–0925	*Managed Aquifer Recharge through Village-level Interventions in Rajasthan and Gujrat (MARVI)*, Prof. Basant Maheshwari, University of Western Sydney, and Dr. Peter Dillon, Honorary Fellow, CSIRO, Australia
0925–0945	*Conjunctive Management of Murray–Darling Basin Surface Water and Groundwater*, Mr. David Harris, former Executive Director, New South Wales Water Commission, Australia
0945–1005	*Innovations to Address Groundwater Contamination*, Prof. T. Pradeep, IIT Madras, Chennai
1005–1030	**Q&A**
1030–1050	**TEA/COFFEE BREAK**

1050–1300	**SESSION 11: Group Work III—A Road Map for Building Drought and Climate Resilience** **Chair: Dr. Amita Prasad, Additional Secretary, MoEFCC, Government of India**
1055–1110	*Is South Asia Positioned to Respond to the Effects of Climate Change,* Dr. Rafik Fatehali Hirji, Team Leader, World Bank, and Geert-Jan Nijsten, Senior Researcher, IGRAC
1110–1230	*A Road Map for Building Drought and Climate Resilience*—Dr. Amita Prasad, Additional Secretary, MoEFCC, Government of India
1230–1300	Presentation of Group Work II and Group Work III discussions
1300–1400	**LUNCH at the Aarogosa**
1400–1500	**SESSION 12: Closing Session** **Facilitator: Mr. Ganesh Pangare, Regional Director, Asia-Pacific, IWA**
1405–1415	*Valedictory Address*, Prof. Sanwar Lal Jat, Hon'ble Minister of State, MOWRRDGR, Government of India *Summary of Key Messages*, Dr. Christina Leb, World Bank
1415–1500	*Closing Remarks,* Dr. Amita Prasad, Additional Secretary, Ministry of Environment, Forest and Climate change • Dr. Ger Bergkamp (IWA) • Dr. Bill Young (World Bank) • Mr. Ganesh Pangage (IWA)
1500–1530	**TEA/COFFEE**

Appendix B

Participants

[[AQ: this was not fact-checked or cross-checked against same names elsewhere in document]]

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Note: n.a. = not applicable; — = not available.

Appendix C

PowerPoint Presentations