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Rural Development Ensuring Protection of Water

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Water quenches our thirst, grows food, produces energy, and sustains the earth's ecosystems. But water scarcity is increasing, and water quality is under severe pressure. Appropriate rural development with respect to water resources is a key to alleviating water scarcity and the degradation of water quality. This paper will address three dimensions of rural development that have direct impact on water resources, namely (a) development of agriculture (or on-farm activities); (b) development of industry and services (off-farm activities); and (c) development of infrastructure and settlement patterns. Development in each of these dimensions needs to promote sustainable use of water and protection of waterbodies. This paper will first introduce the Sustainable Development Goals (SDGs) and Aichi Target 11 that are related to water; discuss the current status and challenges across agriculture, industry and services, and infrastructure and settlements; and will assess strategic options for each of them and explore scenarios that seek to improve performance toward the water-related SDG goals. Then research priorities are identified to assist in effectively addressing the challenges and implementing the technologies, policies, and strategic options that are identified in this chapter. The chapter concludes with priority strategies.

Water and the Sustainable Development Goals and Aichi Target 11

Water is an important element in SDG2, SDG6, SDG 15, and Aichi Target 11, and plays a role in other SDGs as well. Improved technology, management, and policy for water for rural development in agriculture, industry and services and infrastructure and settlement patterns can contribute to meeting the SDGs and Aichi Target. The key water-related SDGs and Aichi Target 11 are discussed in this section.

SDG2: End hunger, achieve food security and improve nutrition and promote sustainable agriculture

Progress on ending hunger is importantly influenced by progress in ensuring availability and sustainable management of water in agriculture and urban areas and sanitation. SDG2 and SDG6 are inextricably linked, with some targets in each of the SDGs enabling the achievement of others, while others are constraining and yet others are in conflict. For example, increased agricultural productivity can be boosted by expanded access to irrigation and increased use of fertilizers and pesticides. But unless appropriately managed, both activities have the potential to undermine the availability, sustainability, and quality of water for agriculture and for other water users. Ensuring sustainability of water in agricultural production systems can help address this constraint.[1]

Ending hunger requires access to safe drinking water (SDG6.1) and equitable sanitation and hygiene (SDG6.2). The underlying productivity (SDG2.3) and sustainability (SDG2.4) of agricultural systems is dependent on adequate water availability of good quality; more specifically, in much of the world irrigation is a key contributor to increased productivity, and lack of access to water is a key determinant of low yield growth in Sub-Saharan Africa, for example. Moreover, water and related agro-ecosystems embedded in sustainable landscapes are an important contributor to sustainable agriculture (SDG2.4).[2]

The latest Food and Agriculture Organization (FAO) assessment of progress on SDG2 shows that progress on the primary target 2.1 to end hunger has been inadequate. In fact, the number of people affected by hunger globally has been slowly on the rise since 2014. Current estimates are that nearly 690 million people are hungry, or 8.9 percent of the world population – up by 10 million people in one year and by nearly 60 million in five years. The world is not on track to achieve the SDG 2.1 Zero Hunger target by 2030.[3]

SDG6: Ensure availability and sustainable management of water and sanitation for all

The most directly water-focused SDG is primarily targeted to non-agricultural water, with targets of universal and equitable access to safe and affordable drinking water for all (6.1); by 2030, achieve access to adequate and equitable sanitation and hygiene for all and end open defecation, paying special attention to the needs of women and girls and those in vulnerable situations (6.2); by 2030, improve water quality by reducing pollution, eliminating dumping and minimizing release of hazardous chemicals and materials, halving the proportion of untreated wastewater and substantially increasing recycling and safe reuse globally (6.3); by 2030, substantially increase water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity and substantially reduce the number of people suffering from water scarcity (6.4); By 2030, implement integrated water resources management at all levels, including through transboundary cooperation as appropriate (6.5); by 2030 protect and restore water-related ecosystems, including mountains, forests, wetlands, rivers, aquifers and lakes (6.6).

UN Water states that SDG6 "is alarmingly off track. At the current rate of progress, the world will not reach the SDG 6 targets by 2030."[4] Trends in progress towards universal basic drinking water services (2000–2015) among countries where at least 5 per cent of the population did not have basic services in 2015, shows that only one in five countries below 95 per cent coverage in 2015 is on track to achieving universal basic water services by 2030. Progress is too slow in 68 countries to achieve universal access to drinking water, and in ten countries access to basic drinking services is decreasing. Progress is even slower in access to sanitation. The global population using at least a basic sanitation service increased slowly from 59 to 68 per cent between 2000 and 2015, and just 1 in 10 countries below 95 per cent coverage in 2015 is on track to achieve universal basic sanitation by 2030.[5]

FAO monitors progress on target 6.4. Indicator 6.4.1 is showing progress toward substantially increasing water use efficiency across sectors measured in $/m3. For the world, water use efficiency rose from US$12.58/m3 in 2000 to US$18.17/m3 in 2017. Agriculture tends to have a much lower water use efficiency compared to other productive sectors, particularly in economic value, so a country's economic structure affects its overall water use efficiency. Increasing agricultural water productivity is therefore a key intervention for improving water use efficiency. With respect to water scarcity (Indicator 6.4.2), their 2020 update notes that globally, water stress remains at a safe 17 percent. However, the world average masks huge regional variations, and there is a gradually increasing trend of global water stress over the past 20 years reflecting increasing stress in several regions of the world, which are not fully compensated by decreases in other areas of the world.[6]

Achieving targets 6.1, 6.2, and 6.3 will require much faster progress in the effectiveness of water technology, management, and policy in the industrial and service sectors and in the development of rural settlements and infrastructure. Less obviously, but very importantly, the effectiveness of water technology, management, and policy in the agricultural sector also influences the outcomes for these three targets. Well-managed agricultural water can free up water for the non-farm and rural settlement water uses that support sustainable water and sanitation. And better water management in agriculture is essential for target 6.4. Targets 6.5 and 6.6 are primarily addressed through protected areas and area-based conservation measures and are measured by progress in protecting land, as with Aichi 11 discussed below.

SDG15: Protect, restore, and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss

Water is explicitly included in target 15.1: by 2030, ensure the conservation, restoration and sustainable use of terrestrial and inland freshwater ecosystems and their services, in particular forests, wetlands, mountains, and drylands, in line with obligations under international agreements. Indeed, water is needed to sustain terrestrial ecosystems, and at the same time, terrestrial ecosystems underpin the availability of water and its quality. As with Aichi 11 (discussed below), SDG 15.1 has focused on protected areas, with progress being measured in terms of quantitative area-based measures. For example, indicator 15.1.1 is the forest area as a proportion of total land area. These area-based goals, targets, and the policies to achieve them are most directly addressed by protected area policies, not water policies. Progress on target 15.1 has been inadequate. Forest area has continued to decline: the proportion of forest area of the world's land area has gradually decreased from 31.9 percent in 2000 (4.2 billion hectares) to 31.5 percent in 2010, then down to 31.2 percent (4.1 billion ha) in 2020.[7]

This chapter focuses on other measures (not area-based) that can save water and more effectively manage water. Thus, there are direct links between SDG6 and the issues and policies that are the focus of this paper. This focus—agricultural water, industry and services water, and rural settlements and infrastructure—is also important to reach the 15.1 targets by reducing some of the pressure on freshwater ecosystems and creating synergies with area-based programs. Progress on meeting SDG 15.1 (and Aichi 11) through area-based measures is influenced very importantly by these non-area-based interventions and outcomes, including patterns of rural development, technology, management, and policy for water, which are addressed in this chapter.

Aichi 11: By 2020, at least 17 percent of terrestrial and inland water and 10 per cent of coastal and marine areas are conserved through effectively and equitably managed, ecologically representative and well-connected systems of protected areas and other effective area-based conservation measures and integrated into the wider landscapes.

As explicitly stated in Aichi 11 (and like SDG15), the terrestrial water targets are to be met through protected areas and area-based conservation measures and are measured by progress in protecting land. These mechanisms are not the focus of this chapter but are important complementary interventions. As of 2019, there had been good progress to meeting these area-based targets, as summarized by Gannon et al. (2019):[8] By September 2019, terrestrial protected area coverage had reached 15.0 per cent (UNEP-WCMC, 2019),[9] with protected area coverage of at least 17 per cent for 344 out of 823 terrestrial ecoregions, while 102 had less than 2 per cent coverage, as of January 2019. JRC, 2019).[10] Marine protected area coverage for the global ocean was 7.8 per cent (coverage is 18.1 per cent for areas under national jurisdiction and 1.2 per cent for areas beyond national jurisdiction,[11] significant improvement since 2010.

As described above for SDG15, this progress on area-based protection of water can be importantly enhanced by the water-saving improvements in technologies and policies for agriculture, industry and services, and development of infrastructure and settlements, which are analyzed in this chapter, beginning in the next section.

Current Status and Challenges for Water in Agriculture, Industry and Services, and Infrastructure and Settlements

Agriculture

Withdrawal of fresh water to produce crops and livestock accounts for the largest percentage of water usage among all sectors (71 percent), followed by industrial use (20 percent), and then domestic uses, including drinking water and sanitation (9 percent).[12] Competition for water resources is increasing between people and the natural environment and between cities and rural areas, risking the prosperity of both. Overuse of water due to wasteful irrigation management is worsening water scarcity. Aquifers are being depleted of groundwater, and the quality of both agricultural and non-agricultural water supplies is declining. Global demand for water will continue to increase, adding to the pressure on supplies: demand is projected to increase by 30 to 50 percent by 2050, driven by population growth, rising consumption, urbanization, and energy needs.[13] Accounting for constraints in future water supplies, it is projected that agricultural water consumption will grow 21 percent by 2050, with a 29 percent increase in total *consumptive use* of water across all sectors between 2005 and 2050.[14] Total water withdrawals are projected to increase by 45 percent from 3,800 km^3 in 2000 to 5,500 km^3 in 2050, falling thereafter to 5,000 km^3 by 2100.[15]

Pollution of water from agriculture is degrading water and the environment. Inorganic fertilizer has been a major driving force in agricultural production growth. Together with irrigation expansion and crop productivity growth from investment in agricultural research and development, increased fertilizer use has been essential for rapid growth in agricultural production and farm income. However, in many regions in the world, fertilizer is excessive or poorly managed, causing runoff that can pollute irrigation and drinking and cause eutrophication, which results in excess algae growth and oxygen depletion in lakes and stream. Because polluted water is less productive than fresh water and requires the use of fresh water to leach the pollutants, water pollution also reduces the effective water supply.[16]

Simultaneously reducing the use of water in agriculture and cutting agricultural water pollution would require significant improvements in technology and water management. Strategic options to address these challenges are discussed below.

Industry and Services

Sustainable water development and management for off-farm areas, covering industry and services, including wastewater treatment and domestic water for drinking and other household purposes is also critically important. This sector is often called the water, sanitation, and hygiene (WASH) sector. It faces difficult challenges. Typically, only a portion of the population is covered by a water utility and water supply is inadequate. Water supply provided by the utility is frequently intermittent, non-revenue water is high, water is often not potable, asset management is poor or lacking, and low tariffs for water for higher income consumers hamper investment in water supply connections to the poor.[17]

Poorly run systems in this sector create dangerous pollution and often produce unsafe water for drinking and cooking. Water and sanitation services are inadequate for billions of people, threatening health, and nutritional status. More than 80 percent of wastewater is discharged without adequate treatment or reuse, threatening supplies for agriculture and other sectors.[18] The crop area irrigated with unsafe wastewater is estimated to be ten times larger than the area using treated wastewater, causing fecal contamination and accumulation of microbiological and chemical pollutants in crops, livestock products, soil or water resources and leading to severe health impacts for consumers and farm workers.[19]

Globally, about 3 in 10 people worldwide, or 2.1 billion, lack access to safe, readily available water at home, and 6 in 10, or 4.5 billion, lack safely managed sanitation. Of the 2.1 billion people who do not have safely managed water, 844 million do not have even a basic drinking water service. This includes 263 million people who must spend over thirty minutes per trip collecting water from sources outside the home, and 159 million who still drink untreated water from surface water sources, such as streams or lakes.[20] Unsafe drinking water combined with poor sanitary conditions in households and communities is a major contributor to disease and malnutrition in developing countries, particularly among children. The burden of disease from unsafe water, coupled with time spent collecting water, negatively affects the economies of developing countries. Women and girls are disproportionately affected, since they often bear primary responsibility for providing drinking water and sanitation to their families and for taking care of the sick.[21] Poor sanitation, water, and hygiene lead to about 675,000 premature deaths annually and estimated annual economic losses of up to 7 percent of GDP in some countries.[22] The World Health Organization (2012)[23] estimated the total global economic losses associated with inadequate water supply and sanitation to be US$260 billion annually in 2010.

Of the 4.5 billion people who do not have safely managed sanitation, 2.3 billion still do not have basic sanitation services. This includes 600 million people who share a toilet or latrine with other households, and 892 million people – mostly in rural areas – who defecate in the open. Due to population growth, open defecation is increasing in sub-Saharan Africa and Oceania. In 2015, 892 million people worldwide still practiced open defecation and 2.3 billion people lacked adequate sanitation facilities. Twenty-three percent of people in East Asia and the Pacific, 54 percent in South Asia, and 72 percent in Sub-Saharan Africa, have access only to open defecation, unimproved, or limited sanitation.[24]

Strategic options to address these water challenges for industry and services are discussed below.

Infrastructure and Settlements

Investment in rural infrastructure is essential for small farmers in developing countries. Expanded and improved rural roads reduce marketing costs, providing lower prices for farm inputs and higher prices for farm outputs, thereby improving farm income. Investment in energy is also important, including hydropower and access to a source of energy for irrigation. Energy is often needed to pump water from the ground and from surface sources and to distribute water in the field, and for many applications in the agricultural value chain.

But expansion of rural infrastructure, especially roads, can also create problems for water resources. Filling up of wetlands and other water bodies and misalignment of roads, highways, and railways with rivers and streams can reduce the availability of water. Rainfall runoff from roads and highways frequently washes harmful pollutants into nearby rivers, streams, and lakes because the surface of roads is impervious to water. Therefore, rain that falls on roadways is not able to soak into the ground as it would naturally, instead generating runoff into local water bodies, carrying with it any polluting substances that may be present on the road's surface.[25]

In conjunction with new infrastructure, the creation of new rural settlements or expansion of existing settlements creates several challenges for water resources. As settlements develop, trees and vegetation are removed, and houses and commercial and industrial buildings are built with sewers and septic tanks. This development creates more storm runoff and erosion because there is less vegetation to slow water as it runs down slopes. More sediment is washed into streams and flooding can occur because water-drainage patterns are changed. More wastewater and sewage are discharged into local streams, potentially causing erosion of the banks and floods. Some stream channels are changed to accommodate building construction. Rural industries might drill some deep, large-capacity wells. The use of too many large wells in new settlements can lower the underground water table, causing other wells to run dry, and saltwater can be drawn into drinking-water wells and can cause land that was formerly "held up" by underground water to subside, resulting in sinkholes and land subsidence.[26]

Dams for hydropower and irrigation

The other major rural infrastructure that has the most impact on water resources are dams for agriculture and hydropower. Hydropower emerged as a major source of energy during the 20th century. More than 45,000 large dams have been constructed around the world to generate electricity, irrigate crops to produce food, supply water to industry, and control floods. Dam have generated large economic benefits. Many smaller dams also have been built to meet similar objectives.[27]

Hydropower is a major source of electricity, accounting for about one sixth of the global electricity supply.[28] It is a renewable energy, with significantly lower greenhouse gas (GHG) emissions compared to fossil fuels. Importantly, because potential energy is stored as water in a reservoir, hydropower provides an option for energy storage (i.e., prior to generation), which optimizes electricity generation. A secondary benefit is flexible timing for energy generation. The World Bank[29] has estimated an absolute level of feasible hydropower capacity in developing countries at more than 1,900 gigawatts, with 70 percent of the total yet to be tapped.[30] The untapped amount is not quite double the currently installed hydropower worldwide. Regionally, the unexploited potential is greatest in Africa (93 percent of potential), East Asia and the Pacific (82 percent), Middle East and North Africa (79 percent), South Asia (75 percent), and Latin American and the Caribbean (62 percent).[31]

But expansion of hydropower from dams faces many challenges also. Dam installations can force large-scale resettlement of human communities while flooding biodiversity hotspots and fertile lands. Failure to consider and address resettlement issues and develop programs for the displaced communities has caused impoverishment and suffering. Dams can also seriously disrupt river systems and permanently alter or destroy their ecology by changing the volume, quality, and timing of water flows downstream, and by blocking the movement of wildlife, nutrients, and sediments.[32] Hydropower development can also impact fish and fisheries. During construction and filling, the river habitat is lost, which is detrimental to fish resources. For hydropower facilities that use large reservoir storage, altering the natural river cycle adversely affects habitat availability and stability during periods of spawning and incubation.

Strategic options for infrastructure, settlements, and hydropower that seek to overcome the challenges and generate benefits to move the world closer to achieving the SDGs and Aichi Target 11 are discussed in the following sections.

Strategic Options for Water in Agriculture

This section identifies strategic options, including technologies, in which the use of both surface and groundwater for agriculture can be reduced; and in which both surface and groundwater resources can be protected from pollution in the most cost-effective and sustainable manner.

Increasing the productivity of water in agriculture

New irrigation technology

New technologies combined with appropriate management and policy can conserve water and increase water productivity. Existing irrigation technologies with potential to reduce water use include small-scale pumps, solar irrigation pumps, above-ground drip irrigation, and micro-sprinklers. Advanced irrigation technologies generate many potential benefits, including increased income from higher value crops; more precise irrigation applications at critical crop growth periods resulting in higher yields; farmer convenience and labor savings; and lower pumping costs. However, major reductions in basin-wide consumptive water use should not be expected due to new technologies alone given the interconnectedness of water within the basin.[33] An increase in water use efficiency for an individual farmer may not save water in the river basin or irrigation system. Much of the water that is "wasted" by farm-level upstream irrigation is recovered through downstream use of drainage water and recharge of groundwater that can be used for irrigation.[34] The adoption of new technologies can even induce increased water use by making irrigation more profitable for individual farmers who expand its use rather than save water.[35] However, appropriate physical controls on water usage, which could include rationing or quotas through enforcement of water rights that are based on consumptive use, can maintain or reduce basin-wide water use after introduction of new technologies.[36]

Water rights

Secure and well-defined water (and land) rights provide incentives to farmers to adopt and invest in more effective irrigation technology and improved water management. With strong rights, farmers know they can retain their additional income in the longer term from investing in new irrigation technologies, new crop varieties, and improved crop management.[37] Making those water rights tradable provides additional incentives to optimize the economic value of water, but fully tradable water rights are likely a longer-term prospect for most developing countries. In addition to the potential benefits described above, secure water rights can play an important role in establishing incentives for improved irrigation management and for adopting more advanced technology. They empower water users by requiring user consent to reallocation of water by public authorities and compensating the user for any water transferred. If well-defined rights are established, water users have the incentive to invest in water-saving or income-enhancing technology.[38]

Technology for rainfed agriculture.

Investment in technology to generate higher production from rainfed agriculture boosts farm income and can reduce pressure on the use of water in irrigated areas. Water harvesting through storing water in surface areas, in the soil profile, or by facilitating recharge of aquifers can reduce vulnerability to dry spells, can increase crop yields and reduce yield losses in dry weather and allow farmers invest in other inputs, such as fertilizers and high-yielding varieties.[39] Water harvesting concentrates and collects the rainwater or runoff for productive purposes. The runoff can either be diverted directly and spread on the fields or collected and stored locally to be used later. Local water harvesting techniques include external catchment systems, micro-catchments, rainwater harvesting, and rooftop runoff collection. Most techniques, such as water harvesting systems, focus on capturing more water. Others focus on increasing water productivity (e.g., drip-irrigation from local ponds and mulching).[40]

Investment in agricultural research and development

Investment in agricultural research and development to generate productivity gains for irrigated and rainfed agriculture as well as livestock has been major contributors to water use productivity. While improved water basin efficiency has contributed to the increase in water productivity (crop yield per meter of applied water), a major contribution over previous decades has come from breeding that increased crop productivity per unit of water and land.[41] Progress on irrigated and rainfed crop yield per hectare and per unit of water would not only improve rainfed water efficiencies, but also reduce pressure on irrigated production. Although they are challenging crop breeding goals, improvement in crop yield per unit of water use and in development of drought tolerant varieties continues and has further potential.[42]

Achieving productivity gains in the livestock sector is also important. The sustainable expansion of livestock production to meet the growing demand for animal-source foods must allow poorer consumers to benefit from a nutritional perspective while reducing the impact on the environment. This means balancing trade-offs among food and nutrition security, poverty, equity, environmental sustainability, and economic development. Key innovations are needed in breeding and feeding programs that will focus not only on productivity but also on product quality, animal welfare, disease resistance, reduced water and land use, lower greenhouse gas emissions, and reduction of other environmental impacts.[43]

ICT in agriculture

In addition to modern irrigation technologies, other advanced technologies are emerging that are being adapted for use by small farmers. Satellite-based ground water mapping, remote sensing of water productivity (crop yield and consumptive use), sensors and measuring devices for soil water status, and integrated information processing and dissemination that facilitate real-time management and governance of water and cropping decisions can have major benefits, although more development of these technologies is required, especially for small farmers.[44] Remote sensing applications are in development or being used in areas such as the measurement of water quality, water surface mapping, monitoring of area under crops and crop health, and adoption of good agricultural practices. For example, the *Africa Regional Data Cube* is a tool that harnesses the latest Earth observation and satellite technology to help Ghana, Kenya, Senegal, Sierra Leone, and Tanzania address food security and issues relating to water access, agriculture, and deforestation.[45]

Advanced technology offers the potential for developing countries to leapfrog older technology and develop faster. Mobile phones are transforming the delivery of market information, and financial, weather; agricultural, health, and educational services that reach the poor.[46] Nearly 70 percent of the bottom fifth of the population in income in developing countries own a mobile phone. The number of internet users more than tripled in a decade, from 1 billion in 2005 to an estimated 3.2 billion at the end of 2015.[47]

Precision agriculture guided and managed by advanced digital technologies is another technique that is developing steadily. Aided by remote sensing and big data, continued development of precision agriculture will allow farm management based on observing and responding to in-field variations. With satellite imagery and advanced sensors, farmers can optimize returns on inputs while preserving resources. Further field-level understanding of crop variability, geolocated weather data, and precise sensors for soil water availability and nutrients should allow improved decision making for improved crop productivity. However, precision agriculture has mainly been for large-scale farming and has the potential to further disadvantage smallholder farmers due to lack of expertise and financial startup costs. It is crucial to develop precision technologies that are suited to smallholder farmers.[48]

Some applications for small farmers have already been developed, as summarized by Rosegrant (2019):[49] *Zenvus*, a Nigerian precision farming startup, measures and analyzes soil data including temperature, nutrients, and vegetative health to help farmers apply the right fertilizer and optimally irrigate their farms. *Zenvus* seeks to improve farm productivity and reduce waste of water and fertilizer by using analytics to facilitate data-driven farming practices for small-scale farmers. *UjuziKilimo*, a Kenyan startup, seeks to use big data and analytic capabilities to transform farmers into a knowledge-based community with the goal of improving productivity by adjusting irrigation. *SunCulture*, which sells drip irrigation kits that use solar energy to pump water from any source, has the potential make irrigation more affordable.[50] *FruitLook*, which is used by farmers in the Western Cape in South Africa as information technology that helps deciduous fruit and grape farmers become water efficient and climate-smart. In trials, the *Chameleon and Wetting Front Detector Sensors* have enabled small-scale farmers in pilot studies in Mozambique, Tanzania, and Zimbabwe to cut irrigation frequency and double productivity.[51]

In addition to providing production support services, advanced technologies can help value chains better serve small farmers in other ways. Sensors linked to digital information systems have the potential to improve links between farmers and processors; reduce postharvest losses (with consequent reduction in the water used in producing the food) with digitally enabled harvest loans and digitally warehoused receipts; inform on-farm harvest practices; monitor storage conditions along the value chain; track provenance for supply chain optimization and grading; reduce the cost of transport; increase transport options for farmers; and increase access to timely information so that farmers know if and when transport is arriving.[52] An example of promising ICT in the value chain is *DrumNet* in Kenya, which has helped link financial institutions, smallholder farmers, retail providers and agricultural product buyers through a cashless microcredit program. Farmers gained access to inputs such as seeds, fertilizers, and pesticides from local input providers by using a pre-established line of credit from banks, where *DrumNet* provided the bank with a credit rating score for each farmer.[53] *Esoko* in Africa uses mobile and web services and advisory call centers to improve access to extension services.[54] The *e-Choupal* trading platform in India, reduces transaction costs by connecting buyers with farmers, using internet kiosks.

Through its ICT-kiosk platform, *e-Choupal* provides additional services to farmers, including sharing of best practices to improve productivity, and price benchmarking to increase sales prices.[55]

Finally, enabling conditions also need to be in place for effective adoption of both existing technologies and the advanced technologies that are coming. Enabling conditions that need improvement for small farmers are the availability of credit, low-cost weather insurance, and market accessibility. Initial costs of new technologies are often too expensive for small farmers. A reorientation of general subsidies to limited smart subsidies targeted to encouraging purchase and sustainable operation of new technologies could be helpful.[56]

Reducing water pollution from agriculture

Many strategic options for reducing water pollution are the same or complementary to the options described above for reducing water use in irrigation. Technologies and policy that reduce the quantity of water use also contribute to reducing pollution in most cases. To reduce excessive use of water and fertilizer that creates water pollution as the fertilizer is washed away with irrigation runoff, large-scale fertilizer and water subsidies should be reduced or eliminated. More efficient application of fertilizer and management of water can greatly reduce both water and fertilizer loss. Various fertilizer technologies are available to help increase the efficiency of fertilizer application, including deep placement and timed-release fertilizer formulations. Breeding crops for nitrogen use efficiency also has great promise.

In contrast to regions in much of the world, low levels of inorganic fertilizer use in much of Sub Saharan Africa have contributed to soil infertility as nutrients are lost over the harvest period through leaching, erosion, or other means, and not replenished with fertilizer. Increased levels of use of inorganic fertilizer use, together with organic fertilizer applications would improve nutrient management and generate higher crop yields. Promising organic technologies include incorporation of leguminous trees and shrubs into improved fallow systems, planting of leguminous cover crops, and application of manure and compost. These techniques should be complemented with higher inorganic fertilizer use.

Strategic Options for Water in Industry and Services

This section identifies strategic options, including in terms of choice of technologies, in which the use of both surface and groundwater for industry and services can be reduced; and in which both surface and groundwater resources can be protected from pollution in the most cost-effective and sustainable manner.

Wastewater reuse

Reusing wastewater for both municipal purposes and for agriculture means less pollution, more water conservation, and additional water for recharging aquifers. The use of treated wastewater for peri-urban irrigation has the most potential in rural towns and villages, where wastewater is more easily available and reliable and where there is a market for agricultural produce. But if wastewater is used in agriculture without the necessary safety precautions, the effects are detrimental. However, if adequately treated and safely applied, wastewater is a valuable source of both water and nutrients, contributing to food and nutrition security and the improvement of livelihoods.[57] The use of wastewater can encounter strong public resistance due to a lack of awareness and trust with regard to human health risks. Other factors include different cultural and religious perceptions about water in general and/or using treated wastewater. Whereas public health and safety concerns have traditionally been the main reason for public resistance to wastewater use, cultural aspects and consumer behavior seem to be the overriding factors in most cases today, even if the reclaimed water resulting from advanced treatment processes is safe.[58]133 Increased efforts by large corporations to enhance wastewater reuse in high water risk areas may alleviate some of these concerns. For example, in several of PepsiCo's manufacturing facilities in Mexico, the company has installed membrane bioreactors coupled with reverse osmosis wastewater treatment technology, which enables water reuse and helps to deliver greater water-use efficiency.[59]134 34

Water recycling

Water recycling also can provide opportunities for water supply expansion and water resource recovery, both at the large-scale, for example in industrial parks where synergies in water recovery and recycling can be achieved, and at small-scale. Large scale recycling plants tend to be energy intensive, and produce sludge that is difficult to dispose.[60] Newer technologies may be able to alleviate these problems by developing new sludge byproducts and moving toward recycling at net zero energy cost by capturing biogas.[61] Biogas, a by-product of the treatment process, is captured and used to offset the energy consumption of the facility.[62] New sludge by-products under development to reduce pollution include fertilizer, cement, and fuel.[63] These advances offer exciting opportunities not just for closing the water cycle but also for reducing carbon emissions, energy costs, and environmental contaminants. Additional research will determine the commercial viability and real-world opportunities to scale up these new technologies (Damania 2017).[64]

An example of smaller-scale recycling is the wastewater collection and recycling in the greenhouses of Sher Ethiopia, which produces roses for export and employs around 10,000 local people. Prior to recycling, wastewater was discharged directly into a nearby lake. With implementation of the recycling project, Sher Ethiopia has collected wastewater and treated it in constructed wetlands. The effluent is then stored in reservoirs and eventually added to the irrigation water of the greenhouses dramatically reducing the environmental impact of the company.[65]

Improved treatment and delivery of drinking water

Improved access to safe water supply and improved sanitation and hygiene practices can decrease the incidence of diarrhea in young children. A systematic review and meta-analysis of health impacts of water and sanitation interventions show reductions in diarrhea morbidity, with evidence supporting greater reductions in diarrhea for households with piped water connections and higher community coverage of improved sanitation.[66]

The World Bank (2017)[67] identifies three delivery segments for rural water supply. First are highly dispersed rural populations. In this case, service levels are basic, typically provided by public or private waterpoints. Service providers include community-based organizations, mostly waterpoint user groups; self-supply (individual, and shared by households); and occasionally local government provision. Second is rural villages and growth centers, which are served mainly by networks with standpipes, but transitioning to household connections. Service providers are community-based organization and more aggregated management forms, such as through aggregation or federation of service providers with professional supervision; small-scale private providers; and direct local government provision. Third are concentrated peri-urban populations and rural towns served by piped networks with household connections. Service providers include expanding public utilities and professionalized (private) operators.[68] Even in these more concentrated populations, coverage is often incomplete and of poor quality.

Several measures should be taken to address challenges of providing clean drinking water and sanitation systems. Large additional public and private investments in water supply, water treatment and sewage disposal plants will be required to bridge the current financing gap in the sector to provide clean water for drinking and household use (see below in the scenarios section). Improved regulations, incentives, and enforcement must be put in place and appropriate technologies for clean water implemented.

Municipal-level development of water sources and delivery of water is critical for larger rural settlements and towns. Combined with development of the water source and delivery to households, municipal-level treatment can achieve economies of scale in delivering clean water to households. Municipal management of drinking water requires improvement in water sources and treatment of the water for delivery to homes. Ideally, households in rural settlements would have in-house connection to clean water provided by utilities. But as noted above, in much of the developing world household connections are not available, especially to lower income households. In the longer term, additional investment in connecting households to water are needed. With limited available financial services, in the short term, a greater focus on standpipes rather than household connections can increase coverage more quickly at lower cost.[69]

In more dispersed rural populations and in niches within more concentrated populations, community-level initiatives and small-scale private business can help to fill gaps and coverage and service. Community-level water supply is becoming increasingly important, aided by new technologies. Solar water pumps are a key emerging technology for small-scale water supply, able to pump larger volumes of water at greater depths and with higher efficiency than previous generations of solar pumps. Solar pumping is now cost-competitive with diesel and wind pumps in all size ranges. The highest potential demand is within rural off-grid areas, currently underserved, or served by costly fossil fuel-driven pumps. Applications include potable water supply for institutions such as schools and health clinics and community-scale water supply schemes.[70]

Household-level treatment is especially critical when municipal and community water treatment is inadequate. Appropriate technology options for household water treatment can be grouped either as filtration methods, in which water passes through a porous barrier (filter) that traps tiny particles including pathogenic microorganisms and other impurities, and disinfection methods, in which contaminants are removed by the use of various chemicals or by energy from the sun.[71] Most household treatment designs need additional testing for technical efficacy and economic viability. Additional pilot testing of these technologies is essential to scale up household treatment technologies to reach large numbers of low-income households on a sustainable basis. Few if any household-treatment technologies have reached significant scale thus far.

Small-scale commercial water treatment in the form of water treatment kiosks is reaching increasing numbers of people in low-income countries, particularly in South and Southeast Asia. While quality control and quality assurance in such locations may be variable, initial assessments of vended water quality have been encouraging. These water kiosks often use advanced technology (such as membrane filtration combined with UV irradiation, multi-stage particle filtration, and ozonation, and membrane filtration) is applied with increasing frequency. Such microenterprises can vend water at low prices and have been shown to reduce incidence of diarrhea.[72] Scaling up of these enterprises could be highly beneficial.

As in the case of agricultural water, management of water for efficiency and quality in industry and services requires improved enabling conditions. Regulatory and incentive reforms are also needed to improve water quality, sanitation, and wastewater treatment. The 2017 UN *World Water Development Report*[73] shows that the first and perhaps most important step in improved wastewater management is reducing pollution at the source. The three other key steps are removing contaminants from wastewater flows, reusing reclaimed water, and recovering useful by-products. Together, these four actions generate social, environmental, and economic benefits for all society, contributing to overall well-being and health, water and food security, and sustainable development. Policy approaches need to be developed that combine regulations, economic incentives, and information dissemination to address water delivery and pollution. Enforcement of existing regulations is essential and can prioritize major polluters and water bodies with the highest pollution and largest potential adverse impact on nutrition and health, and pollution taxes could be implemented in the industrial and domestic water sectors. Improvement in the monitoring and tracking of the status of water quality and spatial and temporal distribution patterns of pollutants in water environments is also needed. Effectively enforced regulatory and economic instruments will provide incentives for adoption of better technologies to provide clean water and treat and recycle wastewater.

In addition to the role of technologies and policies such as those discussed above, more extensive use of ICTs in the industrial and service sector can help manage water. Governments and water utility companies need to be able to accurately assess water resources, to manage current demand and plan for future growth in demand. Networks of sensors can be used to measure groundwater levels, and satellite imaging gives a clearer picture of how water systems are prepared to respond to people's needs. For example, satellite remote sensing of groundwater in Somalia is being used to accurately gauge water quality.[74]

ICTs can also be effective in improving the treatment and recycling of wastewater. At the household and community level, ICTs can help reduce water use, reduce the waste contributed to the water system, maintain household sanitation facilities, and reuse water where it is safe to do so, for example through the use of smart water meters and apps to monitor home usage and for people living in informal urban settlements with no connection to sewerage networks, using apps and text messages to alert local latrine emptying services, so waste is properly disposed.[75]

Strategic Options for Water Related to Rural Infrastructure and Settlements

This section identifies strategic options in which infrastructure and settlement patterns can be promoted in a way that help to protect waterbodies. Many of the strategies described in the previous section on water in industry and services are also applicable to protect water bodies, through the policies and technologies to improve service, conserve water, and reduce pollution. Additional strategies are discussed here.

Options for roads and settlements

To reduce the added runoff caused by new settlements that was describe above, improvements in the storm drainage system should be made. Ecologically designed recharge ponds disperse some storm drainage to artificially recharge shallow aquifers. New storm-drainage systems reduce flooding during storms, reducing damage to basements, yards, and streets. Wells can be drilled to recharge underground aquifers, and water can be injected into these recharge wells to put water back into underground aquifers.[76]

More broadly, rural areas and communities can avoid many of the costly impacts of water pollution by preventing road runoff through stormwater control measures, including structural (engineered devices) and nonstructural measures—used to manage the quantity and improve the quality of stormwater runoff. Structural or engineering controls include treatment systems, erosion and sediment controls, and integrated volume reduction devices. Typical structural controls include grassy swales, infiltration trenches and basins, sand filters, bioretention cells, wet and dry retention ponds, constructed wetlands, and porous pavement. Non-structural controls include land-use planning and conservation of natural areas. Combinations of these practices have proven quite effective in many cases. Among the most effective practices are green infrastructure that are infiltration-based and help maintain or restore the natural hydrology of the watershed.[77]

Another important initiative to protect water resources is climate proofing of rural infrastructure such as roads. Climate proofing of new investment projects includes both protecting the road infrastructure from the impacts of climate change and ensuring that the road infrastructure does not increase the vulnerability of the surrounding area to climate change. As with existing roads, climate proofing involves both engineering options and planning and ecosystem approaches. Ecosystem-based climate adaptation strategies can focus on environmental or green planning for to improve flood and drought management (i.e. increasing ground cover to improve infiltration of floods and water retention during droughts, which has the added co-benefits of improving rural livelihoods by improving the soil structure for agriculture). For example, planting climate change resilient trees along road embankments can reduce runoff and erosion.[78]

Options for dams for hydropower and irrigation

Strategic approaches are also needed for the future of dam infrastructure, to balance the benefits with economic, social, and environmental costs. Because new investments in irrigation and water supply are increasingly expensive and politically sensitive, large-scale infrastructure investment is likely to have a reduced role globally compared with past decades when dam building and expansion of irrigated area drove rapid increases in crop yields. To the extent that some new large-scale dams remain feasible, decision-making processes for the large-scale projects should be broadened sufficiently to include all relevant social and environmental effects and actors, especially including the impacts on water resources. A more inclusive approach, and improved communication between developers and people affected, would help increase confidence in the legitimacy of the processes for decision-making and development.[79]

Moreover, there is substantial potential for small-scale hydro and irrigation dams. Small-scale hydro offers a number of advantages, including a more concentrated energy resource than wind or solar power, predictable energy availability (usually continuous and available on demand), limited maintenance, long-lasting technology, and minimal environmental impact.[80] Similarly, a hydropower resource assessment for Africa projected substantial potential for small hydropower in the region due to low investment requirements, low environmental impacts, and viable technologies.[81] Small-scale hydropower can also be designed to run "in-river" rather than creating storage, which is considered more environmentally friendly because it does not interfere significantly with the flow of the river.[82]

Scenarios for Better Performance on the SDGs

This section explores whether plausible scenarios for implementation of the strategic options in agriculture, industry and settlements, and settlements described above can substantially improve outcomes on outcomes related to the SDG6. Progress on SDG6 in turn assists in achieving SDG15 and Aichi 11 by reducing pressure on water and land ecosystem to make the area-based targets more feasible to achieve. In particular, the scenarios assess the potential for contributing to goals for SDG6.2, 6.3. and 6.4 (described above) for achieving access to adequate and equitable sanitation and hygiene for all; improving water quality by reducing pollution and untreated wastewater; substantially increasing water-use efficiency across all sectors and ensure sustainable withdrawals and supply of freshwater to address water scarcity; and substantially reduce the number of people suffering from water scarcity. Can combinations of these policies, technologies, and investments lead to a better performance on SDGs than has occurred so far? How much would it cost?

Water use efficiency and water productivity

The first three studies reviewed here use comparable modeling methodologies but with somewhat different assumptions about water use efficiency to shed light on the potential for water conservation and saving by 2030 and 2050.

Scenario 1: Agricultural water use, productivity, and industrial and services sector efficiency

Rosegrant et al. (2013)[83] and Rosegrant (2015)[84] simulate a reference or business as usual (BAU) scenario and an alternative scenario for water and food security that combines water use efficiencies in the domestic, industrial and irrigation sectors to reflect direct water-saving effects, together with higher crop productivity growth per unit of water consumed, and the resultant higher GDP growth stimulated by higher agricultural productivity. The analysis utilizes IFPRI's International Model for Policy Analysis of Agricultural Commodities and Trade (IMPACT) model, an integrated modeling system that combines information from climate models (Earth System Models), crop simulation models (for example, Decision Support System for Agrotechnology Transfer), and river basin level hydrological and water supply and demand models linked to a core global, partial equilibrium, multimarket model focused on the agriculture sector. (See Robinson et al. 2015[85] for a detailed description of IMPACT). CGE models (GTEM[86] in this study and GLOBE[87]) in the second scenario study described below were used iteratively with the IMPACT model to generate the multiplier effects from agricultural and water sector productivity growth to GDP growth. The model offers high level of disaggregation with 159 countries, 154 water basins, and 60 commodities.

The assumptions about efficiency gains for industrial and residential water use under high efficiency model are taken from the WaterGAP model[88]. The concept of WUE in the IMPACT model is based on the concept of basin-level effective irrigation efficiency, which represents the ratio of irrigation water utilized by crops for evapotranspiration to total irrigation water consumption.[89] The effective irrigation efficiency concept is applied to irrigation at the river basin scale in the IMPACT model. The underlying drivers for water use efficiency gains for this scenario, as described in Global Environment Outlook V

(GEO5) report[90] include stringent efficiency measures are taken in industry and residential water use and climate policies lead to a reduced demand for thermal cooling in power generation as fossil-fuel-powered plants are partly replaced by renewable energy sources. For agriculture, basin water use efficiency gains are based on more efficient transpiration (including drought resistant varieties and other advances in research as described above), reduced non-beneficial evapotranspiration (ET) and reduced losses to water sinks (e.g. due to water-conserving irrigation and crop management technologies and reduced evaporative losses during conveyance).

The results show projected average global basin-level water use efficiency gains of 8.8 percent by 2030 and 14.5 percent in 2050 compared to the BAU scenario. The simulated improvements in efficiency result in an improvement in irrigation water supply reliability (IWSR), which is defined as the annual ratio of irrigation water supply to demand in each river basin. The degree of improvement varies by country and regions, but globally, IWSR is 0.619 under the BAU scenario and 0.726 under the higher efficiency and productivity scenario. This improvement results in higher reliability than in the 2000 base year, while accommodating significant increases in irrigated area, an important gain given the increasing variability in rainfall and runoff.[91]

Scenario 2: Agricultural water use efficiency

In a second quantitative scenario study, focusing on water use efficiency in the agricultural sector, the IMPACT suite of models is used to assess the impact of irrigation efficiency increases and improvements in on-farm water and soil management compared to the baseline scenario.[92] In the water use efficiency (**WUE)** scenario, improvement in WUE is achieved through modernization of irrigation systems, including investment in improved water delivery infrastructure; improved management such as enhancing groundwater governance, farmer-led irrigation management, water user associations; and greater adoption of farm level irrigation technology (e.g. micro-sprinklers, and drip irrigation), which can also improve effective efficiency if combined with appropriate management, regulation, and incentives. The **WUE** scenario is projected to reduce water use in 2030 relative to the baseline by 9.5 percent and by 2050 by 10.4 percent while raising agricultural production and income. These results are comparable to the first efficiency scenario summarized above, although with smaller improvements in 2050 since non-agricultural efficiencies are not included. The increases in water use efficiency also raise agricultural production and income and reduce the number of hungry people in 2030 by 19 million, thus contributing to SDG2 as well.

The integrated soil and water management (**ISW)** scenario simulates the benefits of technologies such as no-till agriculture, water harvesting, and integrated soil and water management that increase the water holding capacity of soil or otherwise make precipitation more readily available to plants. The **ISW** scenario saves 1.5 percent of water in 2030 compared to the reference scenario and 2.9 percent in 2050 and results in increases in agricultural production and income, and a reduction in hunger by 13 million people.[93]

This study also estimated the cost of the **WUE** and **ISW** scenarios, as well as for more rapid irrigation expansion compared to the reference scenario. The investment cost of **WUE** improvement is therefore calculated as the increase in irrigated area modernized multiplied by the unit area cost of irrigation modernization. The cost of implementing **ISW** is estimated by applying the cost per hectare to projected area of cropland across developing regions. Irrigation expansion cost is estimated as the cost per hectare of new irrigation times the projected additional irrigated area. The average annual costs on top of the reference scenario costs of these three scenarios is $4.96 billion/year for **ISW**, $3.52 billion/year for irrigation expansion and $4.58 billion/year for **WUE**.[94] Combining these additional expenditures with the reference scenario expenditures for the three interventions combined of $11.84 billion/year gives a total investment of $24.90 billion annually.

How can these investment levels be achieved? In the irrigation sector of developing countries, private sector financing or investment has been limited mainly to groundwater development and, to a lesser extent, smaller commercial surface water systems growing high-valued crops. Private sector funding is limited by relatively low rates of return; high financial risks; political interference during project management that leads to water fees below sustainable levels for private investors or banking sectors; and failure to consider the irrigation sector as a commercial venture.[95] It is likely that public financing of larger-scale systems will continue to dominate. However, broader private funding in irrigation should be possible through public-private partnerships (PPP). Private involvement in the planning, design, financing, construction, and operation stages could be beneficial. The potential advantages of PPP include the mobilization of private capital, relieving pressure on public development budgets; incentives for efficient and cost-effective design, construction and operation; and incentives to recover capital and operational costs.[96] Where there are good prospects of profitability, there may be scope for using risk-sharing instruments (e.g. guarantees by public agencies) to stimulate private lending and investment.[97] In any type of PPP, contracts need to be designed and regulated so as to protect small farmers.

Scenario 3: Efficiency with emphasis on the industrial and services sector

A third set of scenarios includes a 'Blue' scenario which focuses on high water use efficiency gains (and corresponding energy efficiency gains) across all water-using sectors, including agricultural efficiency improvements comparable to the ones described above, but with an emphasis on the domestic sector through improvements in leakage reduction and water efficiency gains; and on the industrial sector, with substantial total water productivity potential achieved through water recycling and reuse and a shift to biomass produced from waste material or otherwise without water impacts.[98]

In this analysis river basins are considered "water scarce" and under water stress when withdrawals more than 40% of total renewable water in the river basin. Under these conditions, local adverse impacts of withdrawals are common, and withdrawals are often unsustainable. Under a business as usual scenario, the number of people impacted by water stress will double from 2.4 billion people to 4.8 billion – 52 percent of the world's population. Approximately half (49 percent) of global grain production and 45 percent of total GDP ($63 trillion) will be at risk of water stress by 2050.[99]

Under the Blue water scenario, with high but feasible improvements in water productivity across domestic, industrial, and irrigation uses, 1 billion people fewer would be at risk from water stress in 2050 compared to BAU. Moreover, under this scenario, US$17 trillion GDP (at USD 2000 prices) or 12 percent less than BAU in 2050 would be produced in areas facing high water stress, compared to BAU.[100] Implementation of sustainable water management practices would also reduce by 21 percent the number of children projected to suffer from malnourishment compared to a business-as-usual approach.[101]

Scenario for Sanitation and Water Quality

As was summarized above, unsafe drinking water combined with poor sanitary conditions in households and communities is a major contributor to disease and malnutrition in developing countries, particularly among children, and the economic and environmental costs of these poor service levels costs high. This section explores whether plausible improvements in water and related policies in agriculture, industry, can stop growth in pollution.

Scenario 4: Reduction of pollution related to water

Human activities contribute large amounts of Biochemical Oxygen Demand (BOD), Nitrogen (N) and Phosphorus (P), which make their way into water bodies around the world. High risks from water pollution means that adverse impacts on humans, the environment and the economy are likely to occur. Can interventions in agriculture, industry and services, and human settlements such as the strategic options described above alleviate this pollution? This question is explored using IFPRI's global water quality model (IGWQM). Global agricultural non-point source N and P loadings were estimated for the base year on a half-degree latitude-longitude grid, accounting for both crop production and livestock production systems. Projected loadings for crops are a function of growth in fertilizer use and rates of change in fertilizer use efficiency. The total quantities of livestock excreta and the quantities of excreta recycled to cropland as manure and resultant N and P loadings are simulated according to projected livestock animal population size in 2050, recycling rate, and efficiency of management of livestock waste. [102]

Scenarios for point-source BOD, N and P mainly consider loadings from domestic sources and account for loading changes over time caused by population increase and abatement level improvement. Industrial BOD loading estimate for the base period (2000-2005) are derived from the World Bank,[103] but data is lacking to project BOD in future years, so industrial BOD loading estimates are assumed unchanged over time and added to the projected BOD loadings from domestic sources. This assumption implies substantial improvements in industrial recycling, reuse and treatment since industrial growth is sizable over the projections period. Projections of BOD, N and P point-source loading is a function of base period loading per capita (g/person-day), population, and the fraction of BOD, N or P loading removed through wastewater treatment. Projections are made under alternative assumptions about improved coverage and quality of wastewater treatment.[104]

The estimated total annual loadings of BOD, N and P during the base period are 209, 131 and 10 million mt per year, respectively.[105] Agricultural non-point loadings were 46 million mt for N and 2.7 million mt for P.[106] Of this, 36.4 million mt of N and 1.8 million tons of P were from crops and 9.6 million tons of N and 0.8 million tons of P were from livestock. The largest amounts of these pollutants are discharged in northern and eastern China and in the Indo-Gangetic plains in South Asia. High levels of N and P are also emitted in the midwestern United States, in central Europe, and in central-eastern South America. These regions are densely populated, are large agricultural production centers, or both.[107] In a medium or BAU scenario, BOD increases to 254 million mt (21.5 percent increase from the base period) by 2050, N to 200 million mt (52.7 percent increase), and P to 13.6 million mt (36 percent increase).[108] Growth in GDP, population, income, crop and livestock production, and fertilizer use drives these substantial increases in pollution.

We develop an alternative scenario with more aggressive investment in wastewater treatment, improved design of households and industry to minimize pollution, and increased recycling and reuse compared to the BAU scenario. In this scenario, all developing countries are projected by 2050 to reach

90 percent connection to sewerage systems, with 50 percent of connected households receiving primary waste treatment, 20 percent receiving secondary treatment, and 10 percent receiving tertiary treatment. With these projections, there is a 32 percent reduction in point-source BOD, N, and P loadings. In the agricultural sector, the scenario assumes a 40 percent improvement in N use efficiency and 24 percent improvement in P use efficiency, through increased investment in breeding for enhanced nutrient use efficiency; adoption of sustainable agricultural methods such as nutrient efficient crop varieties and fertilizers formulated increase nutrient uptake; adoption of advanced irrigation technology and improved water management, no-till or reduced tillage and other conservation measures; phased out fertilizer subsidies; and improved management of the nutrient cycle for recycling and re-use in the livestock sector. The improvements in pollution control under this scenario result in projected loadings in 2050 of 173 million mt of BOD, 130 million mt of N, and 9.5 million mt of P, each of which is lower than the corresponding values in the 2000-05 base period. Thus, with major investments and improved policies, technologies, and management, it is possible to achieve zero-growth and even reductions in water pollution.

How much investment would be required to overcome the current shortcomings in the industrial, services, and sanitation or WASH sector? Available evidence shows that substantial improvement of the WASH sector will require massive additional investments in coming years. There are many estimates of future requirements for water infrastructure, using many different definitions of scope and geographical coverage. The most appropriate for this analysis is the cost of achieving the SDG6 goal of achieving universal and equitable access to safe and affordable drinking water for all. Huge additional investments in water treatment and sewage disposal plants are required. The WHO (2012)[109] estimated that the amount of investment to reach universal access to drinking water and sanitation by 2030 is US$536 billion. Of this amount, 36.7 percent is in rural areas. A subsequent World Bank assessment estimated that US$570 billion is required for basic universal access to water and sanitation, and that the higher standard of achieving universal and equitable access to safe and affordable drinking water for all will cost approximately US$1.7 trillion.[110]

Raising these large sums of money for investments in the WASH sector will be difficult because the big gap between current financing and future requirements is the result of several barriers, as pointed out by OECD (2018):[111] "Water services are underpriced, resulting in a poor record of cost recovery for water investments; Water infrastructure is typically capital intensive, long-lived with high sunk costs. It calls for a high initial investment followed by a very long pay-back period; Water management generates a mix of public and private benefits in terms of valued goods and services as well as reduced water-related risks. Many of these benefits cannot be easily monetized, undermining potential revenue flows; Lack of appropriate analytical tools and data to assess complex water-related investments, and track record of such investments can deter financiers; Water projects are often too small and too context specific. This raises transaction costs and makes emerging innovative financing models difficult to scale up; Financial flows may benefit projects which are bankable but may not maximize benefits for communities and the environment."

Private sector investments will be critical to meeting the investment targets, but as noted above, significant constraints are holding back private participation. Investments in water security compete with other sectors based on the attractiveness of the risk-return profile. This depends a stable revenue stream; and how the range of risks related to water security investments are shared between public and private actors. To make better progress on mobilizing commercial finance, water pricing and policy reforms are needed in the water sector to promote equity, affordability, efficiency, cost reduction, cost recovery, as well as improving the balance of tariffs and taxes as sources of finance.

A range of policy instruments are available to recover the costs of investment from those who benefit and provide a revenue stream for investors (e.g. tariffs for water supply and sanitation, abstraction charges, pollution taxes, value capture mechanisms, payments for ecosystem services). At the household level, the removal of subsidies and increased tariffs in some areas can have a substantial impact on water use. Increased water prices and pollution restrictions have led to significant reductions in industrial water use through conservation and water recycling. Targeted subsidies are justified to protect the poor from excessive water prices. However, urban water subsidies in most developing countries go disproportionately to the better off: urban water users connected to the public system and irrigated farmers. The urban poor, many of whom must rely on water vendors, often pay many times more for water than the generally better-off residents who receive subsidized water from the public systems. [112]

To improve both efficiency and equity in such situations, urban water prices should be increased to cover the costs of delivery and to generate adequate revenues to finance the needed growth in supplies. Generalized subsidies could be replaced with subsidies targeted to the poor. A uniform volumetric charge with financial rebates would accomplish these goals, meeting the needs for cost recovery, if tariffs are set at an appropriate level and revenues adjust automatically to changing consumption; providing economic efficiency with tariffs set at or near marginal cost of water; promoting equity, with people paying according to how much water they actually use and targeted compensation for people with lower incomes; and affordability, with effective tariffs differentiated by ability to pay.[113]

Several financial mechanisms for investment in WASH are promising if these types of reforms are implemented. These include green and blue bonds, payment for ecosystem services, and blended public and private finance. Blended finance, which strategically uses development finance or public funding to mobilize of additional finance towards sustainable development in developing countries – is a promising approach to scale-up private sector financing for water.[114]

Research Priorities

This section outlines research priorities that would assist in addressing the challenges and implementing the technologies, policies, and strategic options that have been identified in this chapter. The proposed research emphasizes problem-focused analytics by exploring the impacts from multiple and interrelated interventions. The research priorities focus first on households and small farms, to understand the incentives facing households and farms and how they interact with water systems. Second, and closely related, the research aims to provide decision-makers at community and national levels with a better sense of the impact and tradeoffs of policy and technology options and tradeoffs in order to guide decisions for more sustainable use of water. The priorities are primarily for applied and action-oriented research. Meta-analysis is proposed for some topics to better understand the lessons from previous experience and research that can be implemented and can drive future research. In these areas, considerable work has been done, but clear guidelines for implementation are not yet apparent. The research priorities are provided below. The order and numbering do not represent assignment of priorities across these items; the specific priority of this research will vary by country, sectoral priorities, and other factors.

1. Pilot studies on the impact of precision agriculture in the context of small farms, including the potential for consolidated management of multiple small farms to enhance the efficiency of precision agriculture.
2. Identification, piloting, and upscaling of cost-effective technologies and management for soil erosion prevention, improved soil nutrition, quality, and moisture-holding capacity.
3. Research on continued improvement of remote sensing and small-scale sensors for improved monitoring and management of crop water use, soil moisture and quality, and plant and animal health.
4. Research for development of low-cost technologies that are affordable for marginal and remote farmers, such as cheap, reliable solar irrigation pumps, and technologies that improve water control at field level addressing both drought and flood risks.
5. Assessment of water allocation systems, including devolution of water rights and water trading within farmers and farmer groups, through randomized control trials or other controlled experiments.
6. Implement and evaluate pilot programs phasing out general fertilizer, water, and energy subsidies with direct compensation payments to small farmers through mobile phone/mobile banking systems.
7. Meta-analysis of the impacts of integrated soil and water management and low-external-input agriculture to identify under what conditions (e.g. agro-climatic, labor and input costs) these are effective.
8. Research and investment in upper watershed restoration and management for increased resilience under more uncertain climate futures and increased climate extremes.
9. Meta-analysis of the impact and success factors for payment for ecosystem services and other market-based policy instruments in agriculture, livestock, fisheries, forestry, agroforestry, to guide design and implementation of targeted pilot programs.
10. Expanded crop breeding research for increased plant transpiration efficiencies and tolerance to drought, submergence, alkalinity, and soil and irrigation water salinity.
11. Increased use of social learning interventions to change community attitudes toward enhanced governance of drinking water and waste treatment and ground and surface water.
12. In rural settlements and the WASH sector, research on preparedness for water extremes (floods and droughts) such as urban wetlands; and assessment of increased greening of cities and rural settlements together with rainwater collection systems
13. Research on best technologies and management for wastewater treatment and for disposal of untreated waste, including small-scale community level methods.
14. Research and evaluation of pilot programs on tariff and subsidy policies in the domestic and industrial water sector for more equitable and efficient water use.

15. Research to develop dynamic modeling to monitor, evaluate, and provide foresight on progress toward the SDGs. This modeling would evaluate relative benefits of new technologies and other innovations, with projection of SDG outcomes in future years under alternative scenarios of policies, investments, and technologies, together with monitoring of progress.

Conclusions: Priority Strategic Options

Water scarcity will be increasing in much of the world, and business-as-usual strategies and policies in agriculture, industry and services, and rural infrastructure and services will exacerbate slow progress in meeting the SDGs and Aichi Target 11. But the scenarios summarized above, based on a set of water allocation reforms, new water technologies and farming systems, investment in agricultural research to increase yield with respect to water, selective new investments in irrigation, and major investments and policy reform in water sanitation and sewage, can significantly improve the water-related outcomes in the SDGs and Aichi Target 11. This includes improving the underlying productivity (SDG2.3) and sustainability (SDG2.4) of agricultural systems through increased water use efficiency, and improvement in water quality. Improved water sector performance also contributes to reduction of hunger (SDG2.1) and malnutrition (SDG2.2). The scenarios summarized above also show that appropriate interventions (a) directly promote universal and equitable access to safe and affordable drinking water (SDG6.1); (b) boost access to adequate and equitable sanitation and hygiene for all (SDG6.2); (c) improve water quality by reducing pollution and untreated wastewater and substantially increasing recycling and safe reuse (SDG6.3); (d) substantially increase water-use efficiency across all sectors; and (e) reduce the number of people suffering from water scarcity (SDG6.4). These scenarios, based on developments in agricultural water, industry and services water, and rural settlements and infrastructure, also contribute indirectly to SDG15.1 and Aichi 11 targets by reducing pressure on freshwater ecosystems through conservation of water and improvement in water quality, thereby creating synergies with the area-based programs featured in SDG15.1 and Aichi 11.

In the remainder of this section, the findings regarding the priority strategic options for each of the three priority dimensions—agriculture, non-agricultural activities (rural services and industry), and infrastructure and settlements—will be summarized.

Agriculture

1. Adoption of advanced technologies, such as drip and sprinkler irrigation, precision farming, ICT and remote sensing can provide substantial benefits from increased income from higher value crops, convenience in farming operations, reducing labor use, and cutting pumping costs. In conjunction with implementation of improved water management to improve incentives and regulations, new technologies can also contribute to conserving water. Well-specified water rights that establish a cap on system- or basin-wide water use, can transform local irrigation efficiency gains to broader water savings.

Improved management of groundwater needs to be pursued to reduce over-exploitation of groundwater. Successful groundwater management requires both regulatory and incentive-based tools. Regulatory tools include limits on new wells or irrigated acreage, permitting of pumping rights that cap usage, and metering of wells. Incentive-based tools include water pricing, land retirement payments, trading of groundwater storage credits or use permits, and cost-sharing to provide farmers incentives to adopt improved technologies and management practices.[115]

2. Higher nutrient use efficiency should be promoted in crop production to reduce nitrogen and phosphorus runoff. Nutrient use efficiency is a trait that is under development for key staple crops, which are the major consumers of fertilizers. Other strategies in this area include more efficient fertilizer management, with practices such as deep placement of urea and timed-release fertilizers; increased use of precision agriculture methods, such as yield monitors, to apply fertilizers and water where they are needed most or where they generate the highest yield impacts; and replacement of furrow irrigation with drip irrigation, which allows direct fertilizer application to the crops and their root systems.[116]

3. Generalized water, energy, and fertilizer subsidies incentivize the overuse of water, fertilizer, and other inputs, with resultant environmental degradation. In addition, subsidies are often ineffective at reaching the poor, i.e. they tend to mostly support richer farmers, who are least in need of such support. These should be phased down or eliminated with the budget savings invested in agricultural and water research and development, compensatory income support to small farmers, and targeted smart subsidies to achieve specific water management goals. Additional research funds should be allocated to breeding for yield per unit of water and land, including more efficient transpiration and photosynthesis and drought and heat tolerance.

4. Investment in new irrigation systems is more costly and difficult than in previous decades, but selected cost-effective investments should be pursued, with an emphasis on small-scale irrigation driven by farmer investment. As discussed above, investment in new technologies and management techniques can also benefit rainfed agriculture by capturing more rainfall and runoff (water harvesting systems) or increasing water productivity (supplemental drip irrigation from local ponds and mulching). Technical support and targeted subsidies for construction of water harvesting structures should be provided in areas where rainfall would otherwise be lost to unrecoverable runoff. Smart subsidies could cover labor as well as installation costs.

Industry and services (off-farm activities)

1. Massive increases are needed in investment for the provision of water for industry and services (including drinking water) and for wastewater. The expansion of water supply and connectivity for rural industry and services, especially drinking water, should be supported by improved incentives for efficient use of water and cost recovery, including higher tariffs for water supply and sanitation for wealthier consumers and targeted subsidies for the poor. The widespread development of wastewater collection and treatment can efficiently remove various pollutants before discharge into the environment. Improved management of wastewater requires the planning and construction of new treatment facilities combined with better regulation of pollution and taxes on polluters.

2. Investment and policy support are also required in rural areas and small settlements to improve service and to potentially transition toward more advanced connected water and sewerage systems. Expansion adoption of small-scale technology including standpipes, private small-scale water kiosks, and household-based water filters and purification devices is needed. While such small-scale water businesses have developed on their own, public support could be provided for credit for these small

enterprises; public funding for maintenance support; registration and legal recognition of service providers, with clear asset ownership that can provide collateral for credit; and targeted household subsidies to support purchase of in-home water filtration and purification technologies.[117] As in agriculture, adoption of ICTs can promote effective use of water in the WASH sector by improving monitoring of water supply, demand, and quality and improving the efficiency of water management.

3. Nutrient cycles should be closed where feasible through expanded recycling and reuse of water. Treated wastewater for peri-urban irrigation has potential in rural towns and villages, where wastewater is more readily available and there is a market for agricultural produce, but appropriate treatment is essential. Rural industries, including agribusiness, can develop smaller-scale systems for recycling and reuse of their own byproducts and pollution. Industries and households produce large quantities of these pollutants, which can be recovered from effluents and sewage and treated and reused in agriculture. New technologies for recycling and reuse need to be developed and adopted.

Development of rural infrastructure and settlements

Strategic options for infrastructure and settlements overlap with agriculture options (investment in irrigation) and off-farm services (investment in water supply and sanitation). Key priorities in these areas were described above. Additional priorities are as follows.

1. Adoption of green infrastructure for roads and settlements should be prioritized. Urban forests and constructed wetlands can improve pollution control in rural settlements. Planting ground cover would improve and infiltration of floods and water retention during droughts and planting climate change resilient trees along road embankments can reduce runoff and erosion. These initiatives need to be supported by improved management of stormwater runoff to avoid contamination of treated water supplies. Infrastructure should be climate proofed, for example by changing the composition of road surfaces so that they do not deform in high temperatures and using permeable paving surfaces to reduce run-off during heavy rainfalls.[118]

2. Governments should provide support for local development and management of small-scale hydropower. Additional research can improve equipment design, materials, and control systems, particularly for low-cost technology for small-capacity and low-head applications to match with the available (and smaller) resource sites. Public resources should be also be allocated for technology transfer of appropriate turbines to local manufacturers; loans for developing sites; technical support for developers; and training in operation, maintenance, repair, and business management.[119]

Implementation of these priority strategic options for agriculture, industry and services, and rural settlements and infrastructure must be adapted to specific countries, and will vary across underlying conditions and regions, including levels of development, agroclimatic conditions, relative water scarcity, and level of agricultural intensification. Implementation of these strategic initiatives are not easy, and they take time, political commitment, and money. Some of these initiatives will be politically and technically difficult and, in some instances, will need to be phased over several years, conditioned on national and local capabilities. But it is urgent to get started on this reform process to accelerate progress on the water-related SDGs and Aichi targets. The challenges are formidable and will only become more difficult if not addressed.

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