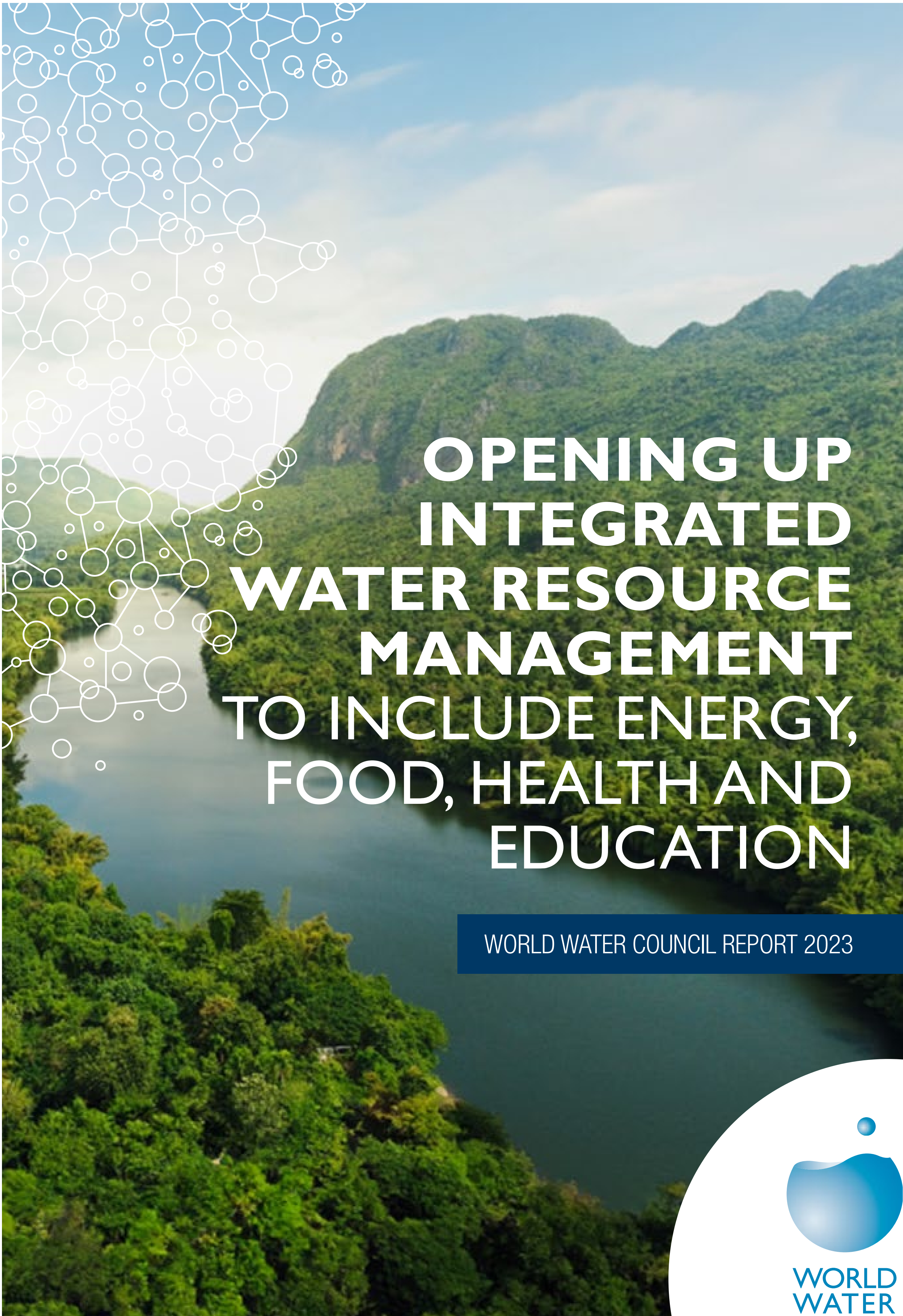

OPENING UP INTEGRATED WATER RESOURCE MANAGEMENT TO INCLUDE ENERGY, FOOD, HEALTH AND EDUCATION

WORLD WATER COUNCIL REPORT 2023

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Report of the World Water Council Task Force on IWRM

This Discussion Paper was developed based on inputs received from IWRM-Task Force members, IWRM-related sessions, and the High-Level Panel at the 9th World Water Forum.

June, 2023

CONTENTS

ANNUAL REPORT 2023

MESSAGE FROM THE PRESIDENT

Recent global crises have demonstrated that important aspects of our lives are interlinked and that events can be unpredictable. Water is no exception: it is a common thread that connects humans, animals, and nature, from beginning to end.

Now more than ever global water security is threatened by the issues that impact people's lives: rapid urbanization, climate change, ageing infrastructure, increasing demand for food and energy supply are examples of these threats that are exerting constant and increasing pressure on our global water resources. However, water is not always appreciated: the current challenges facing the world often omit water as a political priority despite the priceless benefits water carries. Water is an invaluable resource, essential for life, food, education, and indeed, peace. Water is an increasingly essential component of geopolitics and hydrodiplomacy. Nothing significant can be achieved without political will from the highest levels of decision making.

Since its creation, the World Water Council has seized every opportunity to call on political leaders to take bold action and to create enabling environments that encourage the necessary and concrete responses to good water management as a multifaceted, complex matter, and shared responsibility. The recent pandemic served as a painful reminder that water connects everything, and that the issues related to water, and the consequences of those issues, are also inter-connected: if water is in danger, the world is in danger. Therefore, we must stop addressing water issues in silos. It is more than time that we approach water in a more holistic and cross-cutting way.

The Integrated Water Resources Management (IWRM) framework, which is a vertical approach, must be associated and completed by a more transversal approach for the benefit of enhanced water security.

Our common goal is the guaranteed access to essential services for everyone in the world. Achieving this goal demands that we must push for the indissociable connections between water security, equitable access to electricity, food security, health protection, and education for all. For many years the World Water Council has been advocating for the Five Fingers Alliance in which water is inseparable from energy, food, education, and health.

Accordingly, to be efficient, solutions for water must be considered through a different lens. Challenges are to be seen as a balance between water for human development, water for mankind and dignity, and water for nature. We understand that water is the key. To deliver on our ambitions, water must be the centre of our attention, of our thoughts, and above all, of our actions.

Loïc Fauchon, President
World Water Council

MEMBERS OF THE TASKFORCE

The IWRM Task Force aims to impact sustainable water management, identify the barriers to scaling up, and provide a systemic vision and clear direction towards equity of allocation of water across and among sectors. This will be achieved through dialogue and trade-off discussions with stakeholders.

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INTRODUCTION

SUMMARY AND OBJECTIVES

The objectives of this report are to identify and analyse key success stories, facilitate IWRM thinking, and encourage implementation of sustainable water management at multiple levels (data, finance, institutional arrangement, enabling environments and technologies, research, and education) and globally (Asia, Africa, Americas, Europe, Oceania, Middle East). The goal is to empower and enable the application of systems level approaches to water management and the implementation of system level solutions in a manner that places greater inter-sectoral emphasis on the achievement of improved water management strategies by offering a systems-vision of clear pathways to equity in water allocation across its related sectors: water, energy, food, health, and education.

The introduction to the report includes a brief history of Integrated Water Resources Management (IWRM): its origin, key dimensions (enabling environment, institutions and participation, management instruments, and financing), principles (social equity, economic efficiency, environmental sustainability), and extension over time. The report explores the interlinkages between water and other sectors (food, energy, health, education, agriculture, industry) to better understand those links and promote synergies between the sectors. The status of implementation of IWRM in multiple countries across the globe was studied. Based on the collected success stories of effective implementation of solutions, and in the contexts of the integrated approaches to the linked resource systems (water, energy, food, and health) and the circular economy approaches to achieving the Sustainable Development Goals (SDGs), the report presents a vision and roadmap to optimize IWRM implementation at appropriate scales and to accelerate achievement of the SDGs through improved integration of water and non-water sectors. This is followed with examples of the successes and shortcomings of current water management approaches and the need for a more systems-oriented approach. The report then develops an implementation strategy for identifying and assessing those potential trade-offs and synergies and proposes integrative solutions for the entire system. The concept of a new vision is elucidated with several case studies, one of which, San Antonio, Texas, USA, also focused on the dissemination of the knowledge of systems thinking. This concept was tested through a series of stakeholder dialogues and the development and implementation of graduate courses in systems integration. The lessons learned encourage the importance of systems thinking to integrated water management (WEFNI 2015-18).

While emphasizing greater inter-sectoral achievement of the SDGs, the report explores the interlinkages between water, energy, food, health, and education. The report recognizes that there is no single, fixed strategy for implementing IWRM: each nation must create and adapt its methods based on its own political, social-economic, and cultural circumstances. The integrated systems-approach to water management emphasizes the importance of inter-sectoral coordination to achieving those goals and provides a comprehensive water management platform that is compatible with IWRM practices and accounts for the close interlinkages between sectors while addressing the challenges of sustainably fulfilling these simultaneous, often competing, demands. The systems-approach offers a strategy for planning, policy development, and technological decisions through analysing possible trade-offs and investigating potential synergies in their production and use while also considering natural resource assets and climate issues (Flammini et al 2014, GIZ 2018). Such an integrated, systems approach addresses many of the key development challenges of our age: increasing demand due to population growth, rapid urbanization, changing diets, and economic development through fair and effective resource management within planetary bounds and in the context of climate change (Flammini et al 2014).

BRIEF HISTORY, PRINCIPLES, INTERLINKAGES OF IWRM

The World Economic Forum (WEF) conducts an annual global survey of risk perception among representatives from business, academia, civil society, governments, and international organizations. Since 2014, WEF has listed water scarcity as a global systemic risk of high concern. In its Global Risk Report of 2022, water continues to be referenced as a primary global risk trigger (WEF 2014; WEF 2022). Freshwater scarcity continues to manifest itself in declining groundwater tables, reduced river flows, shrinking lakes, heavily polluted waters, increasing costs of supply and treatment, intermittent supplies, and conflicts over water (Hoekstra 2014). Future water scarcity will grow due to drivers such as population and economic growth, increased demand for animal products and biofuels, and climate change (Ercin & Hoekstra 2014).

The Dublin Principles for Sustainable Water Management, an outcome of the 1992 International Conference on Water and the Environment, advocated innovative methods for the evaluation, development, and management of freshwater resources (Figure 1). Traditional water management systems that focus solely on water supply without considering social or ecosystem implications were recognised as no longer sufficient.

◇ Figure 1 Dublin Principles for sustainable Water Management, 1992

- Freshwater is a finite and vulnerable resource, essential to sustain life, development, and environment
- Water development and management should be based on a participatory approach, involving users, planners and policy-makers at all levels
- Woman play a central part in the provision, management and safegarding of water management and safeguarding of water
- Water has an economic value in all its competing uses and should be recognized as an economic good

Water professionals use the concept of integrated water management to address concerns posed by aging infrastructure, climate change, and population increase while balancing environmental, social, and economic demands. Although the idea dates to early basin planning efforts in the United States, the term IWRM gained popularity in the late 1990s with the efforts of Global Water Partnership (GWP) and others to promote its use (Biswas 2004). Based on the Dublin Principles, the Technical Committee of GWP defined IWRM as: "a process that encourages the integrated development and management of water, land, and associated resources in order to optimize the resulting economic and social welfare in an equitable way while protecting key eco-systems." IWRM is a comprehensive approach to water resource management extensively supported across the world to assist in better understanding, preserving, and developing water resources in a coordinated manner and to contribute to long-term development. Social equity, economic efficiency, and ecological sustainability are the principles of IWRM (GWP 2000), and create a framework for analyzing and managing water resources in a way that achieves coordinated results. Figure 2 depicts the interplay of these principles.

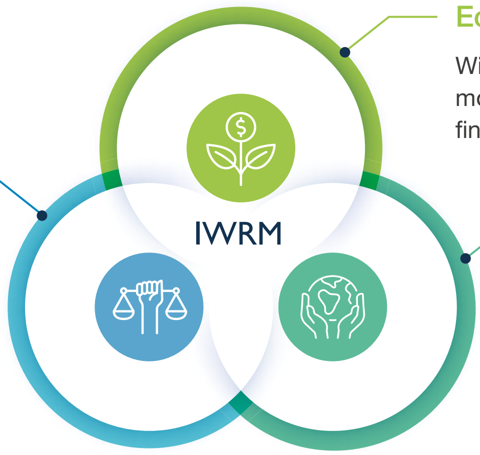
◇ Figure 2 IWRM Principles & Interaction (GWP 2000)

Economic Efficiency

Will my decision/action result in the most efficient use of the available finalical and water resources?

Social Equality

How will my decision/action affect access for other users to water or benefits from its use?



Ecological sustainability

How will my decision/action affect the functioning of natural systems ?

Economic Efficiency refers to the necessity to make the most cost-effective use of water resources to maximize value returns and to benefit the largest number of people. This value should encompass present and future social and environmental costs and benefits, in addition to price.

Social Equality is the essential right to sufficient quantity and quality of water. It emphasizes ensuring fairness in access and use of water resources and the benefits that result for all users.

Ecological sustainability acknowledges the environment as a user and the need to preserve ecosystem services: natural processes or human intervention should not deplete water supplies beyond their replenishment limits.

The Global Water Partnership identified three practical aspects to define implementation of the IWRM agenda (GWP Technical Committee 2005). UN Member States committed to SDG target 6.5, to implement by 2030 “integrated water resources management at all levels, including through transboundary cooperation as appropriate”. SDG target 6.5 has two indicators: 6.5.1 - the degree of integrated water resources management and 6.5.2 - the proportion of transboundary basin areas with an operational arrangement for water cooperation. In this context, IWRM is defined in the SDG 6.5.1 survey instrument as having four dimensions: 1. Enabling environment: policies, laws and plans to support IWRM implementation. 2. Institutions and participation: the range and roles of political, social, economic, and administrative institutions and other stakeholder groups that help to support implementation. 3. Management instruments: the tools and activities that enable decision-makers and users to make rational and informed choices between alternative actions. 4. Financing: budgeting and financing made available and used for water resources development and management (apart from drinking water supply and sanitation) from various sources. (UNEP-DHI Data Portal; Lenton & Muller 2012).

The global request for IWRM deployment, issued in 1992, acknowledged the need for an effective IWRM strategy. However, in 2021, 87 nations (47%) still reported «poor» or «medium-low» IWRM adoption. The UN reports that IWRM implementation has progressed to 54%, although achieving and maintaining sustainable water resource management remains an ongoing process. Between 2017 and 2020, 55 countries made little or no progress, 52 made moderate progress but need to accelerate efforts, 22 made significant progress that must be sustained until 2030, 44 countries are close to target but must sustain their efforts, and that globally, the world must double the current rate of progress to achieve the 2030 target (UN Water, 2021). In 2015, Smith & Claussen proposed the addition of the fifth and sixth elements focused on IWRM implementation (5 - Dynamic Management of Change, 6 - Bridge Strategy and Problem Solving) (Smith & Clausen 2015).

IWRM earned international acclaim as a critical technique to better manage precious water resources. Many nations have embraced and implemented IWRM as a strategy for long-term water management, and several international and national development groups continue to advocate its adoption. The IWRM SDG 6 Support Programme (SDG 6-SP) addresses this challenge by supporting implementation of IWRM to achieve SDG6. The programme assists governments in the design and implementation of country-led responses to indicators of SDG 6.5.1, the degree of implementation of IWRM, as an entry point to accelerate progress toward the achievement of water-related and other SDGs in line with national priorities. (GWP SDG 6-SP).

IMPLEMENTATION OF IWRM

Implementing an IWRM strategy was expected to improve planning and management of water quality and supply, allow more cost-effective management, and improve allocation of water between ecological demands and consumptive users. Despite its potential benefits, implementation of IWRM is hampered by the lack of a uniform definition that can be operationalized with quantitative criteria. Real-world political, social, and physical issues also challenge implementation. New water management practices, most notably climate change adaptation and the water-energy-food-environment-health system, have arisen as water experts seek a greater emphasis on refining concepts and principles via research and on quantifying outcomes of successful implementation and lessons learned.

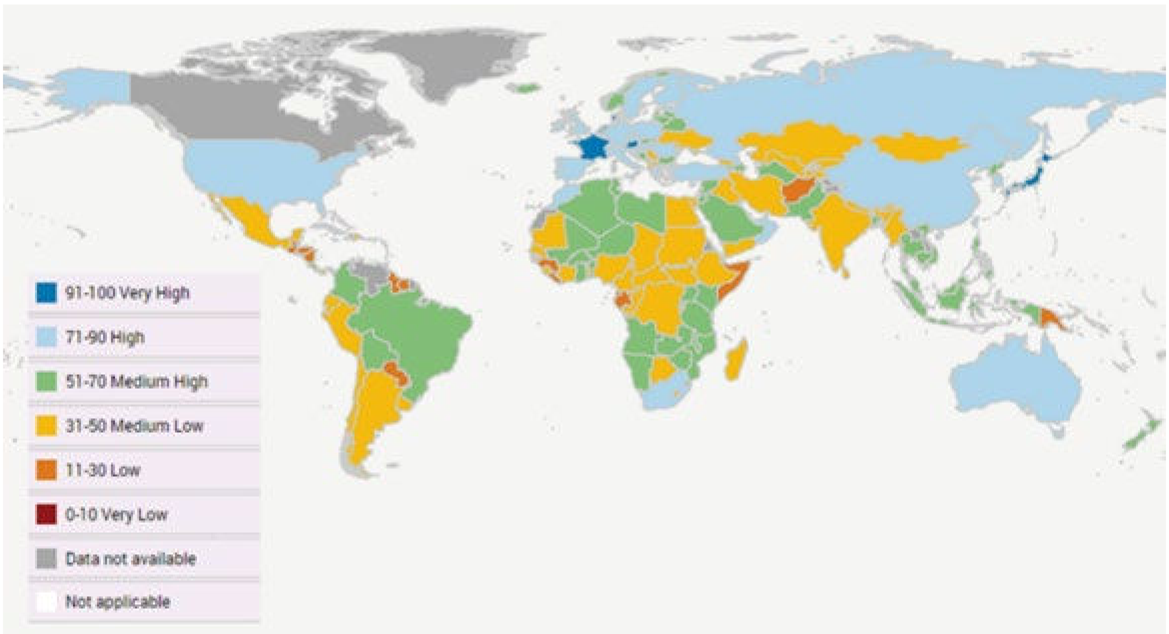
Table 1 The pillars of an Integrated Water Resource Management Framework

Enabling Environment	Institutions & Participation	Management Instruments	Financing	Dynamic Management	Bridge Strategies
Laws and policies • Frame water resources management within a country and between countries Water User • Cross-sectoral and upstream - downstream dialogues • Basin committee Co-operation • Within international river basins (transboundary)	• Basin and other water sector organizations at different levels in the government, NGO's and private sectors • Effective co-ordination mechanisms • Planning process	• Assess water resources • Set up communication and information systems (Data & Info sharing) • Resolve conflicts in allocation of water • Establish regulations • Undertake development works • Ensure accountability Develop organizational capacity • Co-ordinate	• Financing organizations and investment Cooperation • Revenue Raising • Establish financing arrangements Establish self-regulation Research and develop	• Learning, adaptive, deliberative, for complex systems change • Social learning processes backed by data, communications, and empowerment	• Problem solving under a guiding strategy, enabling collective action to solve priority problems • Platforms that bring sectors and stakeholders together

Source: GWP Technical Committee 2005; Smith & Clausen 2015

Globally, nations have adopted IWRM as a core concept that provides a beneficial framework for water resource management. The concept is included in major government papers that guide and regulate the use, conservation, and preservation of a country's water resources. The GWP Toolbox provides an online list of several national and regional IWRM collaborative efforts throughout the world. It is suggested that the reader refer to the GWP online toolbox for further details of projects and for strategic water plans that record the use of IWRM principles as early as the mid-1990s to address transboundary and local water resource issues (Figure 3). The International Waters Learning Exchange and Resource Network's (IW: LEARN) project was established to strengthen transboundary water management by collecting and sharing best practices, lessons learned, and innovative solutions to common problems across the Global Environmental Facility's International Waters portfolio.

Figure 3 IWRM Implementation Status-Global



Data source: Exported from UN-Water https://sdg6data.org on 11 apr 2022

STATUS OF IWRM IMPLEMENTATION

The United Nations Status Report on IWRM used data monitoring SDG 6.5.1 from 186 countries to assess its implementation against the four pillars of enabling environment, institutions and participation, management instruments, and financing. Between 2017 and 2020, the worldwide average indicator score grew from 49 to 54 out of 100. The global implementation rate for IWRM was 54% by 2021 (UN Water 2021). This global rate of progress needs to double. Acceleration is needed in all regions, but is most urgent in South and Central America, the Caribbean, Oceania, South and Central Asia, and Central and West Africa.

The most significant indicators of development are changes in governance, institutional improvements, transboundary collaboration, water resource assessment, and knowledge of the need to accommodate different users in planning for water resources. The least developed nations are also those most in need of solutions-oriented progress in overcoming multiple challenges (financial restrictions, infrastructure development, coordination across sectors, application of management instruments, aquifer management, ecosystem management, and data information). The IWRM agenda is focused on priority problems and must be driven by local demand. Achieving and maintaining the demands of sustainable water resource management is an ongoing process. The degree of IWRM implementation in Brazil, Senegal, Lebanon, Asia, Europe, and North America is presented in Table 2. Europe and North America have the highest overall score (72) and Lebanon has the lowest overall score (25).

Table 2 IWRM Implementation Status

Country (or area), region, world	Year	Degree of integrated water resources management implementation (0-100)				
		Overall	Enabling environment	Institutions and participation	Management instruments	Financing
Brazil	2020	63	71	71	57	53
Senegal	2020	50	57	50	56	37
Lebanon	2020	25	37	26	24	13
Central and Southern Asia	2020	43	43	45	46	39
Eastern and South-Eastern Asia	2020	62	67	62	61	55
Europe and Northern America	2020	72	75	75	74	65

Source: UNEP-DHI - Water SGD6 Data Portal

IWRM IMPLEMENTATION

Blue Peace in the Middle East Initiative (SUEN 2019)

Implementing Agencies: Swiss Agency for Development and Cooperation (SDC), Turkish Water Institute (SUEN)

Description: With the long-term vision of using concrete action to transform water from a source of potential conflict into an instrument of cooperation and peace, a new structure was established for the Blue Peace in the Middle East Initiative: a structured, dynamic network of prominent institutions from partner countries in the region. The Blue Peace Community in the Middle East is a soft infrastructure for dialogue whose long-term objective is to enable water cooperation in the Middle East through an institutional cooperation mechanism for sustainable management of water resources. Blue Peace in the Middle East is focused on contributing to peacebuilding through integrated political and technical dialogues substantiated in concrete regional projects, data collection, and capacity building programs. It combines hydro-politics with hands-on technical expertise. The initiative consists of several studies, field visits to various transboundary basins around the world, workshops, and similar significant efforts to find solutions to three main challenges for sustainable water management in the region:

- Closing the knowledge gap regarding reliable data on water resources,
- Enhancing capacity and confidence building,
- Developing dialogue among partner countries.

A basis for cooperation must be established for IWRM to be implemented, especially in our region. The BPME initiative, established with the purpose of transforming water into an instrument for collaboration, promotes development of cooperation and dialogue between the member states.

Unique Features: Representatives of the collective leadership from Iraq, Jordan, Lebanon, Turkey, Iran, and, to a limited extent Syria have been involved since January 2019. Concerned parties designated SUEN to act as the Coordination Office for the initiative from 2019–2022. The project aims to support the Blue Peace Initiative's new governance structure, including the work of the Coordination Office, the Management Committee, and the creation of a regional Policy Advisory Committee. Additionally, representatives of the regional network of water institutes will collaborate on water-use efficiency in agriculture to stimulate regional food security by promoting knowledge exchange, capacity building, and enhanced communication among countries.

Key Messages: There is growing consensus on the imperative of transboundary cooperation. Growing scarcity of water and its implications for food and human security explain why water protection and its optimal use are increasingly critical in shaping the foreign policy and international affairs of Middle Eastern countries. In the future, the key geopolitical resource in the Middle East will be water due to increasing populations and the subsequent water and food demands.

As irrigated agriculture represents the bulk of the region's demand for water, it is generally the first sector impacted by increased water scarcity, resulting in a reduced capacity to maintain per-capita food production while meeting water needs for domestic, industrial, and other purposes. To sustain their needs, these countries should focus on the efficient use of all water resources (ground, surface, and rainfall) and water allocation strategies that maximize their economic and social returns.

The Middle East has become a hotspot of unsustainable water use, with more than half of current water withdrawals in some countries exceeding the amount naturally available. This could have serious long-term consequences for the region's development and stability. Solutions for narrowing the gap between the supply of and demand for water are of urgent priority.

There are two main options for improving water use efficiency in agriculture: reduce water loss and increase water productivity. Technically, 'water use efficiency' is a non-dimensional ratio that can be calculated at any scale, from irrigation system to point of consumption. Increasing crop productivity involves producing more crop value per volume of water applied. The working area can cover issues such as changing cropping patterns, introducing more efficient irrigation techniques, and recycling wastewater for agriculture. Thus, any work on the issue of water use efficiency in the agricultural sector can be an area of cooperation with regional and transboundary dimensions that can produce large benefits for all countries involved. Working on irrigation water use has direct implications for other important areas like food security. Finally, sharing knowledge and best practices that lead to building trust among countries has the utmost importance under the umbrella of developing dialogue.

Fergana Valley, Central Asia - Improving water accessibility through IWRM (Abdullaev et al., 2009)

Implementing Agencies: International Water Management Institute (IWMI), Interstate Commission for Water Coordination of Central Asia (ICWC), Swiss Agency for Development and Cooperation (SDC).

Description: The Fergana Region, formerly Central Asia's most productive valley, suffers from high levels of soil salinization: crops farmed there are no longer sufficient to sustain the population of around ten million. State borders between Uzbekistan, Kirgizstan, and Tajikistan complicate transboundary management and provoke internal and interstate conflict. More than 60% of the population lacks access to clean drinking water and basic sanitation, resulting in prevalent water-borne infections in rural regions. Irrigation infrastructure is deficient and water consumption is inefficient.

Unique Features: Water resource management was improved using IWRM principles, with an emphasis on greater efficiency and justice. Capacity building for IWRM in river basin management was implemented, engaging river commissioners, provinces, municipalities, and businesses. Bottom-up techniques were shown to be beneficial, and measures to improve water use efficiency were implemented.

Key Messages: Fergana Valley's water management players came together to form a partnership. Twenty-eight communities with a total population of 80,000 received safe drinking water; 320 ecological sanitation toilets were built on a cost-sharing basis. Despite widespread poverty, water-borne infections have fallen by an average of more than 60%, newborn mortality has been nearly eliminated in all communities. Twenty-eight Water Committees were formed to efficiently administer and maintain the water systems, and women comprise more than 30% of those active in village committees. Crop yields and water productivity improved by up to 30%. Irrigation techniques were expanded and enhanced by implementing novel irrigation canal management systems. There is now sustainable financing at canal, water-user association, and farm levels.

Morocco – Management of scarce water resources in urban water supply (Ben-Daoud et al., 2021)

Implementing Agencies: Moroccan State Secretariat for Water and the Environment (SEEE), Agence de Bassin Hydraulique (ABH), Souss-Massa-Drâa and Oum Er-Rbia basins, and GIZ on behalf of the German Federal Ministry for Economic Cooperation and Development (BMZ).

Description: Water has been a critical problem due to scarce water resources, fast population growth, urbanization, and industrialization: 42% of the rural population lack access to drinking water and agriculture consumes 92% of water resources. Water resource variability in time and place makes sustainable water resource management a critical concern. Among the challenges is the gradual implementation of a water reform that decentralizes financial and planning power for water resources to nine river basin authorities.

Unique Features: Improvement of water resource management institutions and policies based on IWRM concepts. Water resource management best practices are established and communicated. Participation of nongovernmental organizations in water resource management has expanded. Among other things, wastewater pilots were carried out.

Key Messages: The Souss-Massa-Drâa River Basin Agency was founded and is run in accordance with IWRM principles. There is multi-agency collaboration and participation of private water user organizations in management decisions. Institutional duties at national and regional levels are defined and unified. Water allocation procedures, technological capacity to assign and monitor water quantity and quality, and communication channels across sectors and authorities were created. Fez, Al Attaouia, and Draga pilot projects featured the installation of innovative wastewater treatment plants. Soil conservation methods dramatically decreased watershed soil loss in Nakhla.

Senegal – Establishing a transboundary organization for IWRM (Sall et al., 2021)

Implementing Agency: Organisation pour la Mise en Valeur du Fleuve Senegal (OMVS).

Description: The Senegal River is approximately 1800 kilometers, with a basin size of 289.000 km2 and annual flow of 24 billion m3. The basin's population accounts for about 16% of the overall population of the three nations. Due to increased drought and desertification, the region has experienced significant migration. Annual rainfall ranges between 200 and 800 mm, with large variations between wet and dry seasons and from year to year. Environmental problems include drought, desert encroachment, loss of arable and pasture lands, and pollution from industrial and residential wastes. The basin's potential comprises 375,000 acres for irrigation, 200MW for hydropower generation, and 900 km of navigation.

Unique Features: In 1972, three of the four riparian governments formed the Senegal River Development Organization (OMVS) to solve difficulties and fulfill the basin's potential. The objectives were to promote inter-country cooperation, to coordinate technical and economic studies and activities related to Senegal river development (i.e., navigation, irrigation, hydropower generation, environmental protection, conservation), and to regulate river flow for irrigation, navigation, flood control, power generation, domestic and industrial water supply, and other purposes. The three nations jointly fund the Secretariat. Loans for the two dams are returned using a formula based on the proportion of project benefits shared by the three nations. Power is generated and delivered to Mali and on its way to Mauritania and Senegal. Irrigation is managed by local communities organized and provided with financial and other resources to carry out farming tasks.

Key Messages: Environmental considerations should encompass the preservation of aquatic ecosystem integrity and specific environmental consequences from infrastructure. A river flow simulation model is important for planning and optimizing facility operations and can be utilized by the permanent water commission as a decision-making tool. If all riparian states are unable to participate in the program, it is preferable to begin with those who can, with the goal of eventually attaining full involvement. Projects will take time to become commercially and financially sustainable: member states must recognize that they will be responsible for servicing any debts owed by the organization. Knowledge, infrastructure, information, markets, and financing are critical for local people to prosper and should be considered in the institutional frameworks to include water users such as farmers.

Brazil – Strengthening institutional capacity and participation (Ioris, 2008)

Implementing Agencies: Ministry of Environment (MMA), National Water Agency (ANA), National Agency for Electrical Energy (ANEEL) and Regulatory Agency for Water, Energy and Basic Sanitation of the Federal District (ADASA)

Description: Brazil's water resources are usually abundant, though unevenly distributed. Water is crucial to the economy for hydropower generation, rain-fed and irrigated agriculture, residential and industrial consumption, and river traffic. One of two major difficulties is reconciling the needs of these sectors. Consensus, critical for the nation's economy and the well-being of Brazilian society, was used to accomplish reconciliation. The second concern stems from Brazil's population, concentrated in quickly growing cities that frequently lack suitable infrastructure for water delivery, sanitary disposal, protection against urban flooding, and landslides on the steep slopes where irregular settlements exist. Pollution from home and industrial waste, sediment, and solid waste are major issues in urban areas. The solution has been to form river basin committees, however where rivers flow through many states, there may be some conflict of interest among committees.

Unique Features: It was important to create legislation to define methods for establishing the ANA, which has performed well since its creation. The case of Brazil exemplifies several important aspects of IWRM, including the need for unambiguous laws governing water resource development and control; strong, well-funded executive agencies capable of putting laws into action; charging for water as a public good; involving other users and the public at large when decisions are made; basin-wide planning; and wide consultation on decisions made regarding upstream basins.

Key Messages: The primary takeaway from the Brazilian experience is that reforms to the water sector's structure and progress toward IWRM were achieved through non-partisan talks amongst experts free to express opinions within a maturing democracy. The establishment of the legal and administrative framework required for water resource management followed the growth of democracy, which allowed for broad public engagement. It cannot be assumed that IWRM would be difficult in a less democratic society, but in the instance of Brazil, democracy has clearly aided.

Jordan - IWRM in the Lower Jordan Valley (Klinger et al., 2016)

Implementing Agencies: Jordan Valley Authority (JVA), Turkish Water Institute (SUEN), European Investment Bank (EIB), Jordan Water Institute.

Description: Since its inception in the early 1950s, the Jordan Valley Authority (JVA) is the preeminent water development body in the Jordan Valley. Rising capabilities and engagement of other groups and Ministries, changing Valley requirements, and new laws necessitated a shift in JVA's purpose and in the type and quality of services provided. JVA was chosen to go through a rigorous, public strategic planning process to build a new future. A steering committee comprised of all essential parties and working groups directed the planning process. Before finishing the strategy, a series of information sessions and workshops were held to collect opinions and feedback from stakeholders. The outcome was a clear, extensively examined, written strategic plan.

Unique Features: The JVA needed reform to satisfy new needs. A steering committee comprised of all essential parties and numerous working groups led a public strategic planning process. The example demonstrates how an integrated strategic planning process can establish circumstances that enable all stakeholders to participate in the proposed institutional transformation. The case also demonstrates how the JVA worked to guarantee water supply and solve inequities in water allocation to satisfy customer expectations effectively and cheaply.

Key Messages: The strategic planning process established the circumstances for all stakeholders to participate, express viewpoints, and negotiate acceptable answers to proposed institutional transformation. Other Ministries, farmer groups in the valley, and current and future landowners were among the relevant parties. Increasing private sector engagement necessitates proper government regulation and an institutional structure that allows public and private partners to work together to accomplish a common goal. The private sector has a significant role to play in delivering water services: management contracts must be designed to provide sufficient incentives for the private sector to assume responsibility for existing assets, operations, investments, and customer service. On the other hand, the government's power to control the private sector must not be weakened. The successful integration and adaptation of the JVA Strategic Plan depends on continued participation from JVA policy leaders and senior management, and active engagement of regional stakeholders, particularly farmers in the Jordan Valley who rely most directly on JVA for water management and distribution.

Kazakhstan – Project for a National IWRM and Water Efficiency Plan (Zinzani, 2015)

Implementing Agencies: Committee for Water Resources (CWR), Ministry of Agriculture of the Republic of Kazakhstan, Global Water Partnership (GWP).

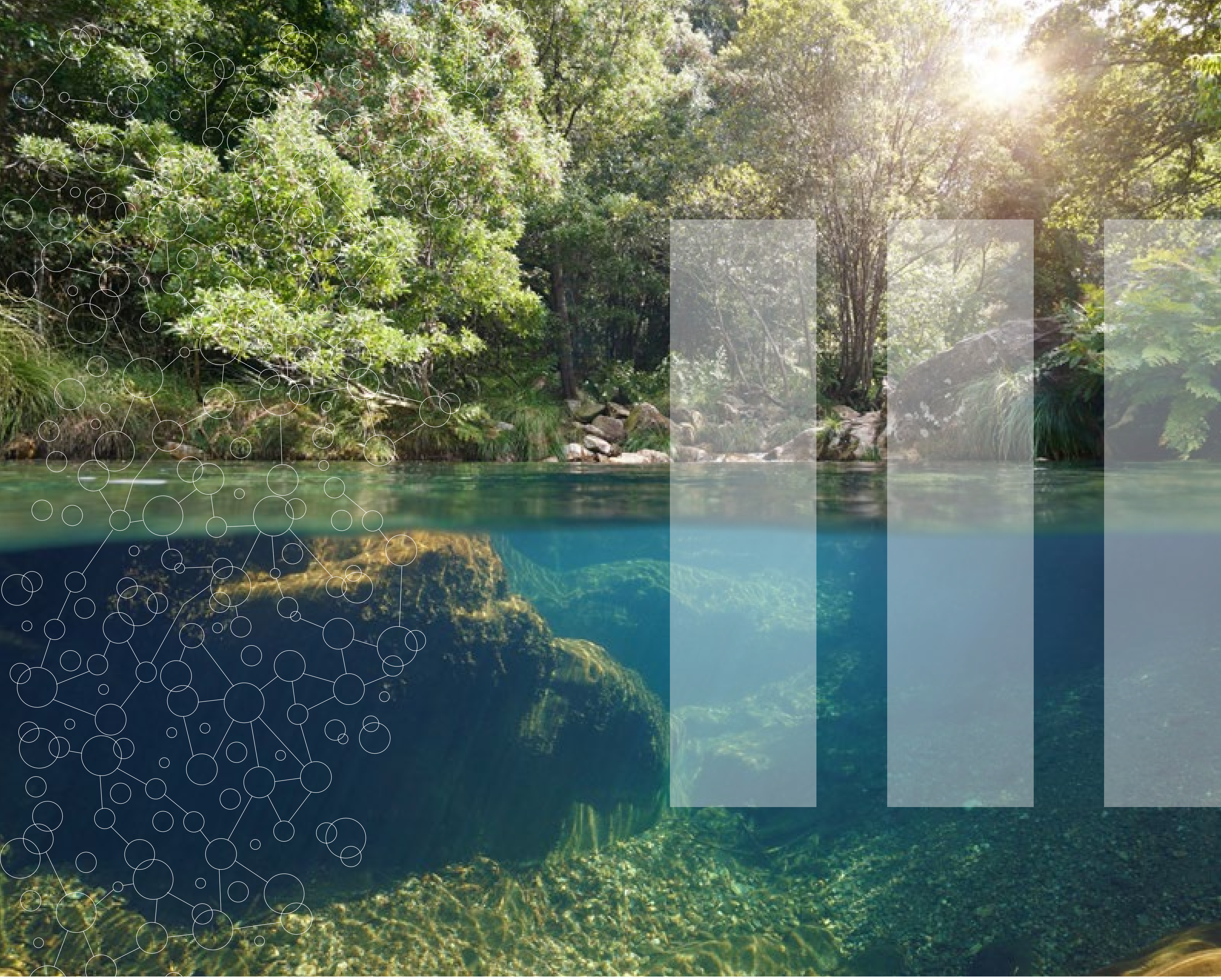
Description: Growing water deficit, pollution of open and underground water, massive over-norm water losses, exacerbation of quality drinking water supply to population, problems with interstate water apportionment, and deterioration of the technical state of dams, waterworks, and other installations are all obstacles. The situation with water management is tight throughout the republic's territory: environmental calamity has engulfed all the country's major river basins.

Unique Features: According to the Republic of Kazakhstan's Water Code, the Water Resource Committee of the Ministry of Agriculture is tasked with managing, regulating, and protecting water resources, including renewable water resources. Since June 2004, the Committee is developing an Integrated Water Resource and Water Efficiency Management Plan with the goal of enhancing water resource management and introducing worldwide best practices. Transitional legal and organizational prerequisites for integrated water resource management (IWRM) have also been developed. Basin Councils, which serve as the foundation for IWRM Plan implementation, have been developed to improve the participation of interested parties in water resource management.

Key Messages: Kazakhstan has developed the appropriate legislative framework, including the Water Code, Land Code, and Forestry Code (2003), and the Law «On Sanitary-Epidemic Security of Population» (2003). River Basin Organizations, especially Basin Councils, are being formed to carry out the IWRM Plan. In terms of territorial division, basin councils are established in Kazakhstan's eight hydrographic basins and in independent water bodies.

LESSONS LEARNED FROM CASE STUDIES OF IWRM IMPLEMENTATION

As we reflect on these case studies, many of the lessons learned lend themselves to a systems approach to water management. We conclude that planning and executing successful water projects needs the participation of all key stakeholders. In this regard, river basin planning works best when an appropriate institutional framework is in place. Because of the extended healing period following stress in lakes, prevention and preparation are far more beneficial than restoration. We also learn from the watershed perspective that effective water management must address the entire hydrological cycle: surface and subsurface waters cannot be managed independently of the ecosystems upon which they rely. When it comes to groundwater, good management necessitates avoiding an imbalance between groundwater pumping and aquifer recharge. Water management is also about partnerships across and within watershed boundaries where the potential benefits of collaborative water resource management can act as accelerators for larger regional collaboration, economic integration, development, and conflict avoidance. During these collaborative processes, economic analysis can help make the case for international river cooperation by identifying and measuring the potential incremental benefits of cooperation, determining the distribution of benefits among riparians, and assessing the feasibility and fairness of alternative management and investment scenarios. Regarding public sector involvement, the participation of government officials is important for galvanizing local political support, advocacy efforts, and increasing trust in research findings. Trust is earned through sharing decision-making authority and the willingness of bureaucratic administrations to negotiate. Finally, addressing resource management and allocation needs to move from a sectoral-silo approach to a systems approach that integrates all the affected sectors and stakeholders and makes them cognizant of cross sectoral synergies and tradeoffs.



THE NEED FOR A SYSTEMS APPROACH IN WATER MANAGEMENT

The current approach to water management is largely sectorally siloed and has proven unsuccessful in holistically addressing the resource allocation crisis. It fails to predict emerging hotspots and regions with impending resource allocation challenges. Nor does the current approach consider the impact of or on multiple sectors and stakeholders. It fails to consider associated trade-offs between resource allocations in given scenarios. It lacks the analytical methodology to identify holistic solutions and capitalize on synergies between multiple sectors. As the impacts of unprecedented challenges like climate change and economic growth continue, effective IWRM must provide an opportunity for all involved stakeholders to be part of an equitable decision-making process that frames long term sustainable policies.

In 2004, Biswas wrote that the "concept of integrated water resources management (IWRM) has been around for some 60 years. The definition of IWRM continues to be amorphous, and there is no agreement on fundamental issues like what aspects should be integrated, how, by whom, or even if such integration in a wider sense is possible." IWRM recognizes the importance of the complete water cycle and its interactions with other ecological cycles in the natural ecosystem. IWRM also recognizes the diverse interests of all water users across society, including integration with food and energy, the often-uneven distribution of water resources across socioeconomic sectors, the need for equity in decision-making processes and use, and the importance of affordable pricing of water resources.

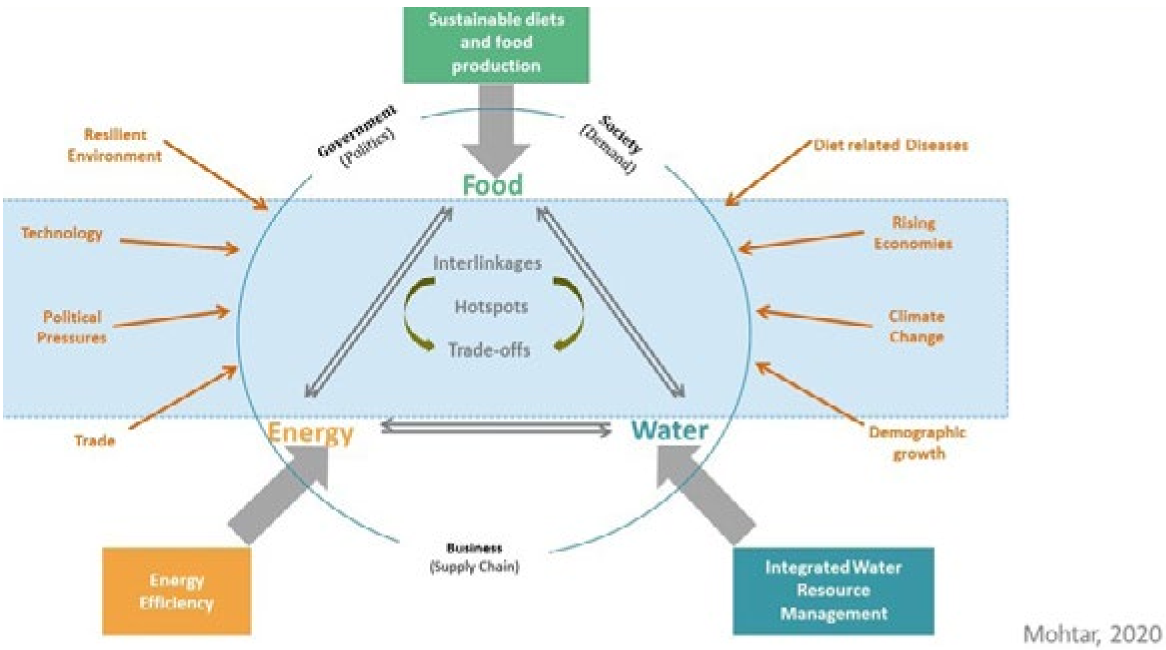
In its March 2023 report, the Global Commission on the Economics of Water (GCEW) outlines a seven-point call for collective actions. These include global water as a global good that connects the global community through the sustainable development goals. GCEW highlighted the fact that water plays a key role in human well-being and includes a multiplicity of stakeholder, scales, and fields. Water economic and non-economic values must be accounted for; subsidies that encourage waste and limit conservation must end. The report calls for investments in water for low- and middle-income communities. Water governance must become coherent and address water storage, conservation, reuse, improved water use efficiency, particularly in agriculture water use. Essentially, the GWEC's call for action is a call for a system view of water management (GCEW 2023).

It is in this spirit of a system view of water management that, the Taskforce of the 9th World Water Forum proposes changes in relation to the complex social and political contexts of IWRM, whose concepts and processes must relate to real actions and offer solutions to pragmatic problems at the systems level. A comprehensive systems approach to these objectives is essential for effective, integrated water resource management and decision-making. Such a systems approach includes these important components:

- Integration of the environment (ecology) and socio-economic issues,
- Integration of water use, functions, and values,
- Integration of water, energy, ecology, and health systems,
- Integration of all stakeholders in the multiple decision-making processes.

An inter-sectoral systems approach to water resource management is shown in Figure 4. To be effective, such an approach necessitates commitment from all sectors, effective collaboration, multi-sectoral coordination, and awareness of the water resource demands of all stakeholders (Stephan et al. 2018).

◇ Figure 4 Systems Approach Illustration (modified after Mohtar 2022)



HOTSPOTS AND SYSTEMS ANALYTICS

In 2017, 844 million people lacked access to safe drinking water; 1.1 billion lacked access to energy; about 815 million lacked secure access to food (WHO 2022; FAO 2022; IEA 2022; Stephan et al. 2018). With global population projected to reach 10 billion by 2050 (UN-DESA 2017), growing economies (World Bank 2018), and stresses caused by the impacts of climate change (IPCC 2015), resource systems are and will remain under pressure (Daher et al. 2019). Great variability in resource distribution and competing resource demands across cities will result in the emergence of distinct hotspots, each with unique characteristics that will require multiple, localized, interventions (Mohtar and Daher 2019). A "hotspot" is a vulnerable sector or region of defined scale that faces stresses in one or more of its resource systems due to resource allocations that are at odds with the interconnected nature of their food, energy, water, and health resource systems (Mohtar and Daher 2016). A business as usual allocative model for these resources will be insufficient to address current or anticipated complex, highly interconnected resource challenges. Adopting new paradigms for resource management and allocation, moving from away silos toward systems integration by identifying cross-sectoral synergies are modes of addressing these challenges that will result in expanded opportunities for business growth, economic development, and improved social well-being (Mohtar 2017; Mohtar and Daher 2017). Solutions and interventions must be multi-faceted (Daher et al. 2018). Opportunities must be identified in light of holistic, systems level trade-offs (Daher and Mohtar 2015; Mohtar and Daher 2014). While the understanding and quantification of water, energy, food, and other interconnected systems is similar across hotspots, the solutions and responses for each hotspot are bound by local knowledge, physical resource constraints, and governance challenges (Mohtar and Daher 2019). Addressing these systemic hotspots requires accounting for the interconnections between them by developing the analytics to catalyze a dialogue about the trade-offs associated with future resource allocation pathway options (Mohtar and Daher 2016).

BENEFITS OF THE SYSTEMS APPROACH

The systems approach provides multiple benefits, some of which are listed in Table 3.

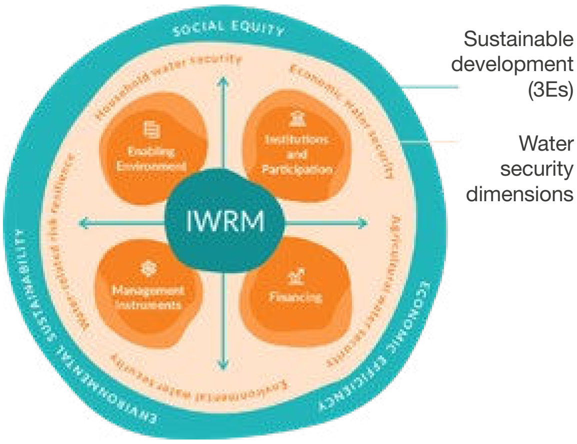
Table 3 Benefits of Systems Approach in IWRM (Biswas 2004; Stephan et al. 2018)

Type of benefit	Benefits Provided
Economic	Equitable, efficient water supply for industry and agriculture
	Water recycling, reuse, and waste reduction
	Sustainable sanitation (minimization of pollution and waste reduction)
	Efficient irrigation systems
	Fishing and other natural resources for economic activities
Ecological	Maintaining the natural water cycle and other natural nutrient cycles
	Ecosystem role in erosion regulation
	Ecosystem role in replenishing subterranean and surface water resources
	Ecosystem role in water purification and pollution regulation
	Ecosystem role in flood regulation
	Ecosystem role in climate regulation
	Ecosystem role in air quality regulation
Social	Water of high quality for human consumption, health, and sanitation demands
	Waste transportation by water
Ecosystems	Natural & cultural heritage: water resources & ecosystems for recreation, tourism, and sports
	Conservation of sacred sites and rare species
Political	Democratic processes to ensure equitable participation, distribution of water rights and responsibilities
	Inclusion of women in water resources planning and decision-making
	Stakeholder cooperation, collaboration in water resource development, use, management
	Financial Support

BILATERAL CONNECTIONS OF THE WATER SYSTEM

Cross-sectoral integration can be a catalyst for sustainable development. A multidimensional model with a triple bottom line of environment, economy, and social dimensions of water distribution emerges and includes water as it relates to and is impacted by energy, food, health, industry, climate change, municipalities, education, peace, equity, and access. Indeed, bi- and multi-lateral connections comprise the pillars of the system. "Systems thinking" means putting all topics at the same level rather than focusing on individual connections. The GWP Toolbox Explained notes that "IWRM offers a comprehensive framework to catalyze water governance toward achieving this vision of a water secure world… The integrated approach seeks to identify win-win water investments to increase economic productivity and growth that contribute to overall socio-economic well-being and ecological sustainability." Using IWRM to achieve SDG 6 and its sub-targets of equitable access to affordable drinking water, sanitation and hygiene, improved wastewater treatment and water quality, enhanced water-use efficiency and minimized water stress, implement integrated water resources management at all levels, including through transboundary cooperation. It protects and restores water related ecosystems, expands international cooperation, community participation and capacity building. UN-Water offers an SDG6 tracking portal that helps follow global progress toward each of these goals (UNEP-DHI). Figure 5 summarizes the water security framework. Let us consider some of the interlinkages of these targets in greater detail.

◇ Figure 5 **IWRM Water Security Framework**



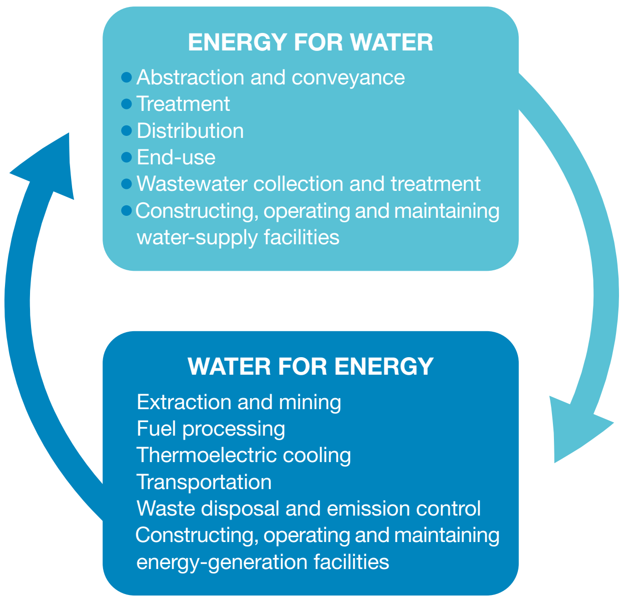
Source: GWP Toolbox IWRM explained

Water and Energy

Water and energy are essential resource inputs for economic expansion. Economic development and energy demand are correlated: water, a crucial component in most energy production processes, is used to meet the energy demand. The production of fossil fuels requires water for extraction, transportation, and processing. Thermoelectric generation based on nuclear, fossil fuels, or concentrated solar power requires water for cooling. Hydropower can only be produced if water is easily accessible in rivers or reservoirs. The production of feedstock for biofuels may depend on water for irrigation. Renewable energy sources such as solar and wind power require water for cooling and cleaning panels or collectors for improved efficiency The impact of energy on the extraction, use, and quality of water resources depends on the technological choices, water sources, and fuel type (World Bank 2013; IRENA 2015; IEA). Energy inputs are required throughout the water supply system. Groundwater is pumped, treated, and transported before being used for its intended household, irrigation, commercial, or other purposes. The used water is returned to the environment through discharge (with or without treatment) or evaporation. Sometimes, reusing treated water is possible (Fahlund et al 2013).

The water-energy system is the relationship between energy and water resources (Figure 6). This system represents an increasingly recognized critical security, business, and environmental issue (IRENA 2015). A survey of 318 companies listed on the FTSE Global Equity Index Series (Global 500) was conducted by the Carbon Disclosure Project and showed that 82% of energy companies and 73% of utilities identified water as a substantial risk to business operations. 59% of energy companies and 67% of utilities experienced water-related business impacts (Deloitte and CDP 2013).

◇ Figure 6 **Illustration of the water-energy nexus**



Source: World Bank, 2013

Water for Energy

Energy production, the use of water to generate electricity, uses 580 billion m3 of freshwater annually, about 15% of the world's annual total freshwater withdrawals (IEA). Approximately 66 billion m3 (11% of total water withdrawn) is not returned to the source and considered consumed (Lavelle & Grose 2013). The proportion of water withdrawn and consumed for energy differs greatly throughout the world: in the United States, over half of freshwater withdrawals are used to generate thermoelectric power, and China has the highest portion of industrial water consumption - one-fifth of all water nationwide is used for mining, processing, and consuming coal (Schneider 2011).

Hydropower is the best illustration of the need for water in the production of energy. A significant portion of the world's electricity production, almost 16%, comes from hydropower, which accounts for approximately 75% of Brazil's 2012 total electricity generation (REN21 2014; IRENA and IEA-ETSAP 2014). Global energy demand is projected to increase up to 35% by 2035, which means that meeting the rising demand could increase water withdrawals in the energy sector by 20%, and water consumption in the sector by 85% (World Bank 2013). The energy sector influences water quality in multiple ways: crude oil, natural gas, oil and shale extraction, water drainage from coal and uranium mining operations have large impact; coal fired power plant emissions impact surface water quality.

Energy for Water

Global data are limited on energy used in extracting, producing, treating, and delivering water. This is primarily due to large variations in the energy intensity of delivering water as a result of differences in water sources (groundwater vs. surface freshwater), water quality (high-salinity seawater is the most energy intensive to treat and use) and the efficiency of water delivery systems. However, some national and regional estimates exist. In the United States, for example, water related energy use accounts for 13% of total annual energy consumption (Griffiths-Sattenspiel et al. 2009; Sanders and Webber 2013).

As easily accessible freshwater resources are depleted, energy-intensive technologies such as desalination or more powerful groundwater pumps are expected to expand rapidly (Hoff 2011; WEF 2011; World Bank 2013). MENA (Middle East and North Africa) is among the regions with the lowest renewable water resources in the world and is home to most of the world's desalination capacity. MENA's capacity is projected to increase more than five times by 2030, thereby tripling total electricity demand for desalination in the region (IRENA and IEA-ETSAP 2012). Around 2–3% of world energy is used for water supply and sanitation purposes.

In industrialized countries, energy is the second highest cost, after labor, in the water and wastewater industry. However, it should also be noted that end user energy consumption of water significantly exceeds the energy used in the rest of the urban water cycle. Consumption of electrical energy can be compensated for by the recovery of energy from water and wastewater: organic content of wastewater can be used to produce biogas, which in turn can generate both heat energy and electrical energy. The heat content of water can be extracted to heat buildings and processes and can be used as environmentally friendly air conditioning. Treating water to drinking standards requires energy and as the raw water source becomes more contaminated, traditional methods are no longer sufficient: more energy will be required to treat water to drinking standards using membrane technology. The intensity of the water–energy system is a regional characteristic dependent on energy mix, demand characteristics, resource availability, and resource accessibility. The choice of fuel and of technologies used in power production hold significant impacts for the quantity of water required (IEA 2012; World Bank 2013). Where water resources are limited, technologies that impose less strain on water resources may be preferable. The risks posed by the water–energy system affect all essential elements of water and energy security (Table 4). These risks not only confront governments, but also stakeholders who engage in activities directly or indirectly affected by the availability, accessibility, and affordability of water or energy. Consequently, the risks and associated impacts manifest at regional, national, and local levels causing governments, communities, and businesses to increasingly consider the system as a key variable impacting the socio-economic sustainability of operations and long-term objectives.

Water and Food

The availability of water resources in quality and quantity is closely intertwined with food security and safety. Water resources are essential to food systems activities such as agricultural production, aquaculture, food processing, food consumption, and achieving food security, the Zero Hunger Sustainable Development Goal (SDG2) (FAO 2017(b). Food system activities also affect water resources by depleting groundwater, non-point source pollution from agriculture or discharges of untreated or poorly treated wastewater (FAO and IMWI 2017). Water and food are vehicles of transmission for agents of disease and continue to cause significant outbreaks of disease in developed and developing countries worldwide (Kirby et al. 2003). Accessibility and availability of water resources greatly influence evolution of agricultural practices globally. The type of crops grown, crop cycles, irrigation methods adopted vary from arid to wet parts of the world. This interlinkage of water and food symbolizes vulnerability on two fronts: changing patterns of water supply influence the reliability of water-intensive sectors including agriculture; increasing competition for limited water resources influences meeting the projected increase in food demand (IRENA 2015). Fertilizers and agro-chemicals that release chemical compounds that percolate to the groundwater has grown considerably under usual agricultural practices (IRENA, 2015).

Table 4 Summary of risks and impacts within the water–energy system

Risks		Impacts
Water-related risks to energy security	Shifts in water availability and quality due to natural or human-made reasons (including regulatory restrictions on water use for energy production/fuel extraction)	Reduced reliability of supply and reliance on more expensive forms of generation Possibility of economic pricing of water and therefore higher costs of energy production
	Increase in energy demand for water production, treatment, and distribution	Strains on the energy system and reduced efficiencies given the different demand profiles for water and energy
Energy-related risks to water	Limited or unreliable access to affordable energy necessary to extract water Re-allocation of water resources from other end-uses to energy	Disruption in water supply to end-users or diversion of resources away from other core activities such as agriculture Changes in delivery cost of water due to fluctuating costs of energy inputs
	Contamination of water resources due to energy extraction and transformation processes	Water resources, including for drinking purposes, rendered unsuitable due to contamination, often requiring additional treatment

Source: IRENA 2015

Water Quantity and Agriculture

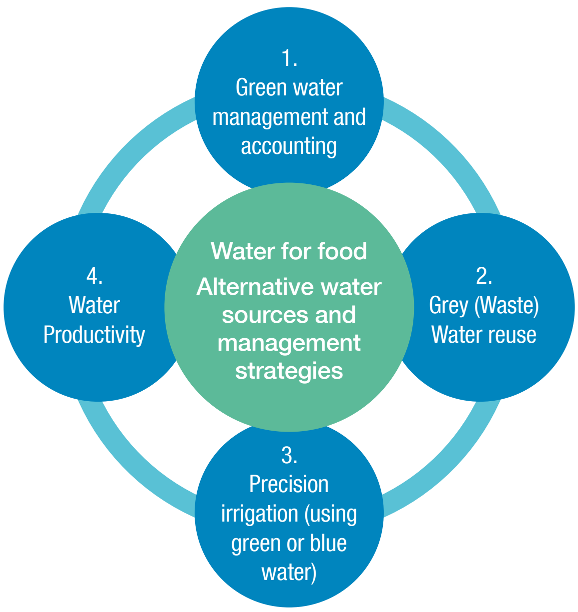
Agriculture is the world's largest consumer of water, accounting for over 70% of global freshwater withdrawals (up to 90% in some countries). Water is used throughout the agri-food chain in processing, distribution, retailing, and consumption. By 2050, a projected 60% increase in agricultural production, will cause water consumption for irrigation to rise by 11% and withdrawal by 6%, despite accounting for modest gains in water efficiency and crop yields (FAO 2009, FAO 2017). Although a seemingly modest increase, much of it will occur in regions already suffering from water scarcity and witnessing intense competition with other sectors, including manufacturing, electricity production and domestic use. In the face of these competing demands, increasing allocation of water for irrigation will be challenging (OECD-FAO 2012). Irrigation will play an important role in increasing food production and growth in agricultural production to feed a projected human population of over 9 billion in 2050 will come from increasing crop yields, and expanding arable land area, together with increases in cropping intensities (i.e., by increasing multiple cropping and/or shortening fallow periods) (IRENA 2015). To achieve increased production, the expansion of harvested irrigated land area is estimated to rise nearly 12% to 2050, compared to a 9% rise for rain-fed harvested land area (Alexandratos and Bruinsma 2012).

Water for Food

At the same time, alternative water resources and new management strategies must together with water efficiency and water productivity. Green-water management and accounting, wastewater reuse, water use efficiency, precision irrigation, and approaches to increase water productivity (Figure 7) are the four ways by which a transformative approach to future of food can be brought about (Mohtar and Fares 2022).

It is estimated that 60% of global food production comes from rain-fed (green water) agriculture. Irrigation (blue water) represents, globally, 20% of the arable land but produces 40% of the global food. Analysis of global consumption of green and blue water highlights that green water is much more significant than blue water in many dryland regions. The difference between the two is that blue water is the surface water found in lakes, rivers while green water is the ground water pumped from aquifers for irrigated agriculture) or in soils, a storage reservoir for the green water (Cosgrove and Rijsberman 2010; Siebert and Döll 2010; Sulser et al. 2010). Green water lacks a unified definition and hence poses a challenge in its accounting.

Figure 7 Alternative water management approaches to support food security



Source: R. H. Mohtar & Fares, 2022

For centuries, several soil, water, and crop management practices and technologies have been used to improve green water resources because in many areas, particularly in arid and semi-arid regions, blue water resources are limited. Rain harvesting technologies and conservation agriculture address water shortage and increase soil fertility and crop yield, thereby improving the efficiency of green water, enhancing its contribution to food security. Another very important element in effective water management is wastewater reuse and the long-term impact on soil from exposure to different types of water for irrigation.

A case study conducted in San Angelo, Texas, offers an example. A specific block of land whose groundwater is very salty was irrigated for 10 years with good quality wastewater. Results showed that, in this case, irrigation with wastewater produced a far better crop yield and beneficial soil properties than the groundwater would have (Loy et al. 2018). However, this is not the situation in all locations: for example, in Jordan or Lebanon, the outcome could be quite different. While reuse is important, the long-term impact on the ecosystem in which the soil is exposed to reused irrigation water must also be considered. The trade-off between pumping and abstraction must also be analyzed to determine whether wastewater treatment facilities might be constructed close enough to production units to allow full utilization of that reuse. Wastewater reuse is a potential alternate source for irrigation that needs to be considered as a factor in the analysis.

Another hotspot is in the Lubbock area, located in the panhandle region of Texas. It has thriving agriculture at the expense of the declining water table of the Ogallala aquifer due to over-pumping (Texas Parks and Wildlife 2022). Solutions include encouraging dryland agriculture, increasing reliance on treated wastewater, and investing in renewable energy to drive the transition. These require financial investment to allow infrastructure for the solutions. It involves heavy engagement with the agriculture sector and an understanding of the tradeoffs between the economics and the long-term sustainability of the sector. It also involves investment in the wastewater system, in terms of both treatment and conveyance that allow the farms to thrive on the use of treated wastewater. These are typically outside the scope of traditional IWRM regimes.

In soil science, field capacity and permanent wilting point are the two points that determine the quantity of water available for crop growth. These can be identified and quantified using pedology, a discipline within soil science focused on understanding and characterizing soil formation, evolution, and theoretical frameworks for modeling soil bodies, often in the context of the natural environment. This knowledge holds great importance in precision irrigation and can also lead the way to improving the future of irrigation (Assi et al. 2018; Mohtar and Assi, 2019). (Uhlenbrook et al. 2022) argue that agricultural water use should be embedded in a larger systems approach that creates a basis for policy and incentive schemes that optimize water use for food production.

In the discussion of water productivity, the value of water must include economic, social, and cultural attributes. Currently, agriculture consumes two-thirds of global freshwater; in the future this may be an unaffordable luxury. To maintain productivity, we must look at alternative water as our first-choice water sources. Today, when a farmer is asked about water productivity, the response will be in tons per hectare or tons of produce per hectare of land. This utterly fails to consider the value of the water used for that production. It also fails to assign value to energy, air quality, or impact on soil. We must look at the existing complexities in a new, value-based production system that considers nutritional output, water footprint, energy footprint, plant footprint, soil-health implications, air quality, water quality, etc. Efficiency is necessary, but not sufficient, where water productivity is concerned. Lebanon, for example, exports potato and other cheap produce without accounting for the loss of virtual water involved. The new approach to agriculture must properly value water, including green water, a huge resource whose use must be maximized given what is known today about soil-water interactions and how much green water and brackish wastewater can be effectively used for agriculture production.

Water Quality and Agriculture

Agriculture is both a cause and a victim of water pollution (IRENA 2015). Past food requirements have driven the expanded use of fertilizer and pesticide to achieve and sustain higher yields (OECD-FAO). Although agriculture accounts for 70% of global freshwater withdrawals, much of that water flows back into surface and/or ground water (the remaining 30% is lost through evapotranspiration). This allows for the discharge of pollutants and sediment, with a net loss of soil due to poor agricultural practices, salinization and waterlogging irrigated land. In total, the food sector contributes 40% and 54%, respectively, to the load of organic water pollutants in high-income and low-income countries (UNESCO-WWAP 2012). At the same time, wastewater and polluted surface and groundwater used for irrigation are contaminating crops and transmitting disease to consumers and farm workers.

Water Loss and Food

Losses along the food supply chain represent a waste of the resources such as water and energy used in their production. The main challenge facing the food system is not expanding agricultural production but rather ensuring that existing food stocks reach consumers. Roughly one-third of the edible portion of food produced for human consumption is lost or wasted globally, equivalent to approximately 1.3 billion tons per year (FAO 2011). Although estimates of loss embedded in water remain limited on a global and regional scale, country-level assessments demonstrate its significance.

South Africa loses nearly one third of food production annually through water waste. This amounts to roughly one-fifth of South Africa's total water withdrawals (nearly 600,000 Olympic-sized swimming pools) (Notten et al. 2014). Reducing losses in the field, storage, and along the remaining supply chain would go a long way toward offsetting the need for more production and reducing strains on water and energy resources (UNESCO-WWAP 2012).

Virtual Water and Food

Although most of the food produced is consumed domestically, trade in agricultural commodities continues to grow, making quantification of the virtual (or embedded) water content of agriculture products important. Virtual water refers to the total amount of water needed for food production. This changes with the region depending on agriculture practices. International trade in crops and crop-derived products accounts for the largest share (76%) of virtual water flows between countries. Trade in animal and industrial products each contribute about 12% to global virtual water flows (Mekonnen and Hoekstra 2011). Countries can reduce their use of national water resources by importing agricultural products. Japan, for example, saves 134 billion m3 per year, Mexico 83 billion m3, Italy 54 billion m3, the U.K. 53 billion m3 and Germany 50 billion m3 (Mekonnen and Hoekstra 2011). Especially in water-scarce countries, water savings is likely to have positive environmental, social, and economic implications. Hence, all other things being equal, one might expect that countries underwater stress adopt a trade strategy to alleviate their water scarcity problem. However, international trade in agricultural goods is driven largely by factors other than water, such as consumption patterns, market complexities, policy priorities and wealth endowment.

Meeting the growing demand for water and food requires careful management of the risks and opportunities closely related to the interaction between the different attributes of food and water security. Accessibility to water of sufficient quality affects several food security concerns. An adequate quantity and quality of water is necessary to both produce food and, further downstream, for preparation and consumption of food. The intensification of certain food production practices like a more aggressive use of soil-enriching nutrients or evolving diets (e.g., growing demand for protein-rich diets involving meat) has significant implications for water security. The risks posed by these are summarized in Table 5 below.

Water and Health

Water security is a key to public health. While in 2020, 74% of the world's population used safely managed drinking water, up from 62% in 2000, the lack of access to clean drinking water, safely managed sanitation, even soap and water for hand sanitation may be as high as 27% of the population. People who lack basic drinking water services must depend on unsafe surface or wastewater: at least 2 billion people around the world use drinking water sources contaminated with faecal matter. Continued progress on SDG Target 6.1 is threatened by the impacts and uncertainty of climate change, competing agricultural and ecological water needs, competing financial priorities and the challenges of existing and emerging threats to water quality (UNICEF-WHO 2020; UN-Water 2021). Despite advancements in science, technology, and water security measures, water-borne diseases kill 2,195 children every day: more than AIDS, malaria, and measles combined. This accounts for 1 in 9 child deaths worldwide and makes waterborne diseases the second leading cause of death among children under

Table 5 Summary of risks and impacts in the water - food system

	Risks	Impacts
Water-related risks to food security	Increased variability in water availability, particularly due to climate change Regional concentration fo food production and consumption	Changes in supply of food products, leading to higher price volatility, further compoun ded by regional concentration of food production activities
	Impact of water quality on food production and consumption	Utilisation of poor-quality water along different stages of the food suppl chain can have negative impacts, including soil degradation and accumulation of contaminants within the food chain
Food-related risks to water security	Impact of agricultural activities on water resources	Uses of external inputs for agriculture and food production can lead to water pollution affecting downstream activities and aquatic life
	Poorly regulated agricultural foreign direct investments (e.g., international land leasing)	Increased agricultural land leasing, when poorly regulated, could lead to expanded use of local water resources, with negative local socio-economic impacts
	Water resource over-utilisation due to food security ambitions	Pursuit of food security ambitions can strain water resources, often leading to substantial depletion in freshwater reserves

Source: IRENA 2015

the age of five, even in the 21st century (CDC 2021). Diarrheal diseases, the most common type of water-borne disease, are particularly serious for children and vulnerable people in low-income countries (WHO 2022).

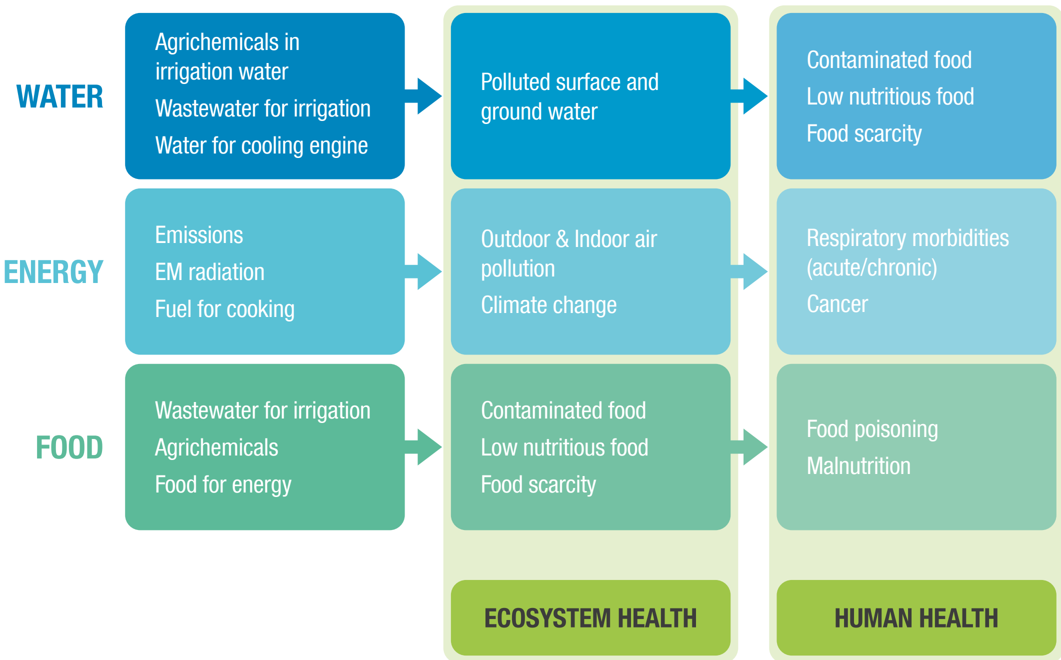
Absent, insufficient, or poorly regulated water and sanitation services increase vulnerability to preventable health risks (WHO 2022). From an environmental perspective, water-related diseases can be waterborne (caused by ingestion of contaminated water); water-washed (caused by poor personal hygiene), water-based (caused by parasites living in the water) or transmitted by water-associated insect vectors that breed in water (White et al. 2002). Water-borne diseases also occur through leakage of contaminated run-off water or within the distribution of pipe systems (WHO 2014). Climate related hazards such as floods and droughts can further increase the pathogen load making water unsafe to drink. Floods damage water infrastructure and sanitation facilities, reduce water quality, and can mix drinking water with industrial and agricultural waste (Talbot et al. 2018) while droughts lead to shortages of water and poor water quality (CDC 2021; EEA 2018; Sadoff et al. 2015). Water scarcity, quality, and access to clean water can also contribute to mental health issues like stress, alienation, intra-community disputes, despair, hopelessness, depression, and anxiety (Kumar et al. 2020; Stanwell-Smith 2009).

Health and the Water-Energy-Food System

The interactions between water, energy, and food systems with the health system have not been widely studied Many studies of the interlinkages of water, energy, and food systems fail to discuss human health as a factor (Nuwayhid and Mohtar 2022; Calder et al. 2021; Slorach et al. 2020). Figure 8 reflects an attempt to understand the interlinkages of the ecosystem and human health with water, energy, and food.

Polluted water has health outcomes, such as diarrhoea, blue baby syndrome, or chemical poisoning. At the interface of health and energy are gas emissions, electromagnetic radiation, and cooking fuels that cause indoor and outdoor air pollution, climate change, and consequently, to health outcomes such as acute and chronic respiratory morbidities and cancers. As for the food-health interface, the use of wastewater in irrigation, agrichemicals, and food for energy lead to contaminated food, foods with low nutritional value, and food scarcity as outputs and to food poisoning and malnutrition as health outcomes. The outputs associated with the interfaces of water-health, energy-health, and food health reflect the health of the ecosystem (ecosystem health), while the different health outcomes associated with these outputs reflect the health of affected populations (human health) (Nuwayhid and Mohtar 2022).

◇ Figure 8 Diagrammatic scheme of how health is part of the WEF System



Source: Nuwayhid and Mohtar, 2022

Water and Industry

The private sector, though increasingly aware of the problem of freshwater scarcity, faces the challenge of formulating effective responses. Even companies operating in water abundant regions are vulnerable to water scarcity because the supply chains of most companies stretch around the globe. The focus needs to be shifted from whether industries have sufficient water abstraction permits or whether wastewater disposal standards are met to the more pressing question regarding does the company contribute to the overexploitation and pollution of water resources, not only through its own facilities but also through its supply chain. In food and beverage industries the connection with water is explicit, but in some industries the connection with water is not always clear, it is indirect and mostly through the supply chain.

Thus, the Water Footprint (WF) offers a perspective on how a product, producer, or consumer relates to the use of freshwater systems. The WF is a volumetric measure of water consumption and pollution that provides spatiotemporally explicit information on how water is appropriated for various human purposes or industrial uses. WF is a measure of freshwater appropriation underlying a given product or consumption pattern.

Three components are distinguished (Table 6): blue, green, and grey (Mekonnen and Hoekstra 2011).

- Blue WF is a measure of the volume of water abstracted from the ground or surface water system minus the volume of water returned to the system.
- Green WF refers to the volume of rainwater consumed in a production process.
- Gray WF is the volume of freshwater required to assimilate a load of pollutants based on natural background concentrations and existing ambient water quality standards, an indicator of freshwater pollution.

Economic activities are generally categorized into three sectors. The primary sector of the economy is that sector which extracts or harvests products from the Earth. It has the largest WF and includes activities like agriculture, forestry, fishing, aquaculture, mining, and quarrying. It has been estimated that approximately 92% of the blue WF of humanity is in agriculture alone. The secondary sector covers the manufacturing of goods, including processing materials produced by the primary sector, construction, and public utilities (electricity, gas, and water). Sometimes, the public utility industries are also mentioned under the tertiary sector because they not only produce something (electricity, gas, purified water) but also supply it to customers (as a service). Water utilities also partially fall under the primary sector because part of the activity is the abstraction of water from the environment (rivers, lakes, and groundwater). The work of water utilities comprises water collection, purification, distribution and supply, wastewater collection, wastewater treatment, materials recovery, and wastewater disposal. It is rather common to categorize the whole water utility sector under the secondary sector. The tertiary sector is the service industry and includes both businesses and final consumers. This sector includes activities like sales (retail and wholesale), transportation and distribution, entertainment, restaurants, clerical services, media, tourism, insurance, banking, health care, defence, and law. Though sometimes categorized as a quaternary sector, one can list activities related to government, culture, libraries, scientific research, education, and information technology. The secondary and tertiary sectors have much smaller WFs than the primary sector.

Table 6 Water footprints of different industries

	Raw material production	Suppliers	Direct operations	Product use/end life
Apparel	blue, green, gray	gray		
High-tech / Electronics	gray	gray		
Beverage	blue, green, gray	blue	blue, gray	
Food	blue, green, gray		blue, gray	
Biotech/ Pharma			gray	
Forest products	green		blue, gray	
Metal/Mining	blue, gray		blue, gray	
Electric/ Power/Energy	blue, gray		blue, gray	

Legend: blue water, green water, and gray water
Source: Pawar et al., 2013

Secondary and Tertiary Industry Sectors

Food and beverage products: The food and beverage sector carries the largest WF of the manufacturing sector because it is the largest client of the agricultural sector, which is responsible for the largest share in global water consumption.

Textile and apparel: The supply chain WF of the textile and apparel sector depends on the type of fibre used and the source region of the fibre.

Paper the WF of any wood product is the sum of the WFs in the forestry and the industrial stage. Paper industries are known for their large water demand and for producing polluted effluents, which, if not properly treated, can cause significant ecological damage in the streams into which the effluents are disposed.

Computers The semiconductor manufacturing process requires high-purity water, which is generally produced on-site from municipal water.

Motor vehicles Several car companies have performed WF studies. One interesting study involved the blue WF of three car models of Volkswagen over full life cycle. It was estimated that the water consumption along the life cycles of the three cars studied amounts to 52 m3 (Polo 1.2 TDI), 62 m3 (Golf 1.6 TDI), and 83 m3 (Passat 2.0 TDI). In all three cases, 95% of the total water consumption lies in the production stage of the car (as opposed to the use and end-of-life stages (Berger et al. 2012)

Water supply One would expect that the WF of the “water supply” sector to be the most significant of all sectors, but this is not the case. On a global level, the WF of the municipal water supply has been estimated to be 3.6% of the total WF of humanity.

Construction The direct WF of the construction industry is small compared with the indirect WF related to the mining and manufacturing of materials used in construction. Transport In the case of the WF of a final product, the contribution of transport is generally relatively small: not much freshwater is consumed or polluted during transport. It is worth considering the indirect WF of transport related to materials (trucks, trains, boats, airplanes) and energy used, but materials will generally contribute very little because the WF of a transport vehicle can be distributed over all goods transported over the lifetime of the vehicle. The WF of energy may be more relevant, but even that can be small compared with the other components of the WF of goods, particularly in the case of agricultural goods. The key determinant in the WF of transport is probably the energy source (King and Webber 2008; Gerbens-Leenes et al. 2012).

Wholesale, retail trade, and services There has been little investigation of the WF of these sectors because their direct WF is generally small compared with their indirect WF, i.e., the WF of the goods bought for use or sale. Particularly in the wholesale and retail trade sectors, all that matters is the WF of the goods purchased to sell. Wholesale and retail companies can play an important role in WF reduction, not because of the significance of their operational WF but rather because they form a point where many products from a great number of producers come together to be distributed over large numbers of consumers. Wholesale companies and retailers can influence the WF of the products on their store shelf by using sustainability criteria in their purchasing choices. In the service sector, the major determinant of the total WF is the WF of consumables (paper, computers, printers, machineries, vehicles, materials, energy). The WF of the construction materials of office buildings may play a minor role. One component will often dominate: the food served in the company restaurant, even though this is obviously not part of the primary business of a company.

Water and Climate Change

Global freshwater is under enormous anthropogenic strain; climate change is one of the key elements causing this strain. Freshwater distribution and availability are expected to vary, water-related disasters like floods and droughts are increasing and worsening. At the same time, demand for water from rivers will likely rise (Tir and Stinnett 2012), impacting supply (Mitchell et al. 2012). The Intergovernmental Panel on Climate Change (IPCC) reported in 2014 that climate change had already begun. In 2022, IPCC noted that “currently, roughly half of worlds ~8 billion people are estimated to experience severe water scarcity for at least some part of the year due to climatic and non-climatic factors (medium confidence). (IPCC, 2022b). IPCC in 2022 also noted the “reducing the acceleration of sea level rise beyond 2050 will only be achieved with fast and profound mitigation of climate change…. Realizing global aspirations for climate resilient development depends on the extent to which coastal cities and settlements institutionalise key enabling conditions and chart place-based adaptation pathways to close the coastal adaptation gap” (IPCC 2015; IPCC 2022). Climate change will affect people, ecosystems, and economies primarily through water. While the relationship between rising temperatures and variations in rainfall have been extensively modeled, their impacts on river flows and subsurface recharging have not. Specific issues brought on by melting snow and glaciers, and their affects on water quality, need to be better recognized (Sadoff and Muller 2009). Some of the impacts of climate change on Water Security include: reduced ground water recharge, river flow reduction that impacts water supply and soil moisture availability, and increased crop water requirements resulting in more competition among sectors for water resources. Mohtar explains that understanding the interlinkages between climate change and water, energy, and food securities is critical to developing effective strategies to adapt to the projected changes and ensure sufficient access to these resources and that an integrated, systems approach to adaptation is needed to address them and can be achieved through creating regional cooperation and shared community success stories and practices. (Mohtar 2017)

Water and Education

Harlan et al (2007) demonstrated a strong link between income, education, water supply choice, and household water use. The results of the study clearly show that poverty and education influence household water supply technologies, which in turn affects the quantity of water used by households: better educated, wealthier richer households rely more on private connections and the differences between these households those that must collect their water are striking. The ‘collecting’ household uses about 14.5 litres per day per capita compared to 88 litres per capita per day for those with a private connection. This impacts, most importantly, the use of water for hygienic purposes (bathing, washing dishes, and washing clothes, etc.). Similar evidence was seen in a study conducted in Philippines, by Persson (2002). Income and education levels are important determinants of a household’s water supply/choice situation.

It is increasingly recognized that a primary determinant for addressing the issues of global poverty is the provision of safe water; access to safe water enhances the potential for educational opportunities and participation in local community economic development. The training and professional development courses on an integrated, systemic approach can empower stakeholders to become better decision makers. When introduced to these ideas, young researchers reflect their unique perspectives as they devise unique solutions to analytical challenges. For example, in a graduate level course on water, energy, and food systems offered at Texas A&M by Prof. R H Mohtar, students were asked to identify a hotspot of their choice and to develop the analytics that demonstrate the synergies and trade-offs in various, hypothetical scenarios. Interestingly, students developed good recommendations and solutions that were later followed up by the stakeholders involved in their respective projects (Mohtar 2015).

Water and Peace

The world's 263 international river basins cover 45.3% of Earth's land surface, host about 40% of the world's population, and account for approximately 60% of global river flow. The number of basins is growing with the "internationalization" of basins through political changes and improved mapping technology. Territory in 145 nations lie within international basins and 33 countries are located almost entirely within such basins. As many as 17 countries share the Danube River Basin. Contrary to perceived notion, evidence shows that this interdependence does not lead to war. Researchers at Oregon State University compiled a dataset of every reported interaction driven by water in the last half century, both conflictive and cooperative, between two or more nations. They found that the rate of cooperation overwhelms the incidence of acute conflict. In the last 50 years, only 37 disputes involved violence. Thirty of those occurred between Israel and one of its neighbours. Outside of the Middle East, researchers found only 5 violent events while 157 treaties were negotiated and signed. The total number of water related events between nations favours cooperation: the 1,228 cooperative events dwarf the 507 conflict-related events (OSU 2022). Simply put, water is a greater pathway to peace than conflict in the world's international river basins. International cooperation around water has a long and successful history and some of the world's most vociferous enemies have negotiated water agreements.

The institutions they have created are resilient, even when relations are strained. The Mekong Committee, for example, established by Cambodia, Laos, Thailand, and Vietnam in 1957, exchanged data and information on the river basin throughout the Vietnam War. Israel and Jordan held secret "picnic table" talks to manage the Jordan River starting in 1953, even though they were officially at war from 1948 until the 1994 treaty. The Indus River Commission survived two major wars between India and Pakistan. All 10 Nile Basin riparian countries are currently involved in senior government level negotiations to develop the basin cooperatively, despite the verbal battles conducted in the media. Southern African nations signed several river basin agreements while the region was embroiled in a series of wars in the 1970s and 1980s, including the "people's war" in South Africa and civil wars in Mozambique and Angola. These complex negotiations provided rare moments of peaceful cooperation. Now that most of the wars and the apartheid era have ended, water management forms a foundation for cooperation in the region and produced one of the first protocols signed within the Southern African Development Community (SADC).

Water management and peace are correlated in several ways. Water wars warnings force military and other security groups to take over negotiations and push out development partners such as aid agencies and international financial institutions. Water management offers an avenue for peaceful dialogue between nations, even when combatants are fighting over other issues. Water management builds bridges between nations, some with little negotiating experience, such as countries of the former Soviet Union. Water cooperation forges people-to-people or expert-to-expert connections, as demonstrated by the transboundary water and sanitation project conducted in Israel, Jordan, and Palestine, Friends of the Earth Middle East. A water-peace making strategy can create shared regional identities and institutionalize cooperation on issues larger than water, as exemplified by the formation of SADC in post-apartheid southern Africa.

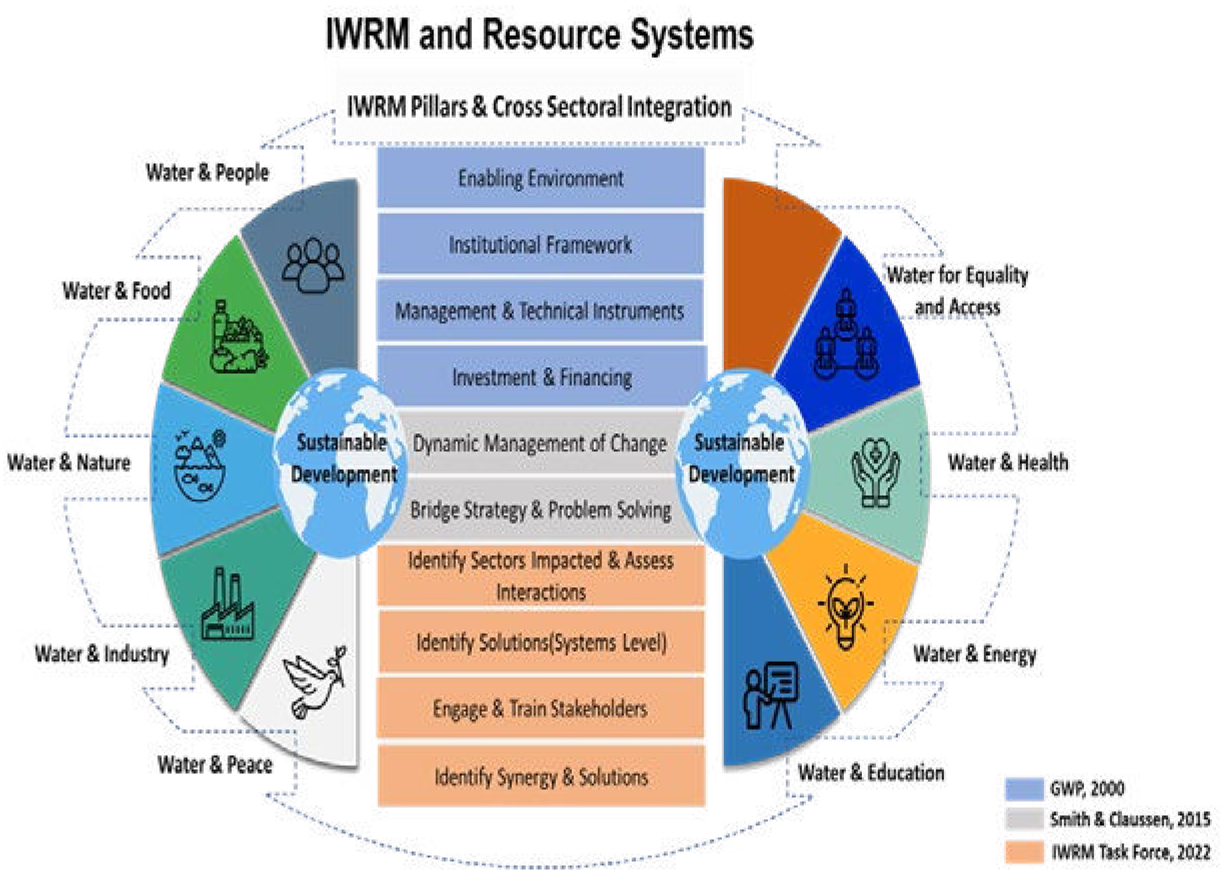
A SYSTEMS VISION FOR IWRM

Demands for reform that leads to more effective, efficient, and sustainable water resource management have grown since the World Summit on Sustainable Development in Johannesburg in 2002. The effects of climate change are intensifying, mostly through consequences on land and water. As a result, there is a rising need to coordinate stakeholders and sectors in order to manage water resources coherently and adapt to long-term change, increased unpredictability, and extremes. The historical shortcomings that allowed for poorly coordinated, fragmented water management across sectors are decreasing. Integrated water resource management is thus critical for climate change adaptation and building climate resilience (IPCC 2018) and to ensure that the major water users and water-dependent sectors can collaborate on solutions to tightening water supplies in response to rising demand. Indeed, the GCEW's call for collective action.is more timely in that it includes global water as a global good connecting global communities through the sustainable development goals

The concept of the water-energy-food system emerged from the World Economic Forum and Bonn Conference in 2011. The concept focuses on a systems approach to real action, motivating active ownership and engagement of the key water-dependent sectors and moving beyond IWRM as a water-centric undertaking (WEF 2011, Hoff 2011). This system of systems provides IWRM with the task of working in a truly systems-based approach by developing a common agenda with the energy, food, education, and health sectors, especially with respect to inter-dependencies on ecosystems and demonstrating its success through results. Together with climate change adaptation, the water-energy-food-education-health security nexus and IWRM have the same objective, and the same urgent need, to speed action that leads to solutions.

The IWRM Taskforce of 2022 in consideration of key messages from the 9th World Water Forum, proposed expanding the original IWRM pillars developed in 2000 by GWP (enabling environment, institutional role, management instructions) (Lenton and Muller 2012) and to which Smith and Clausen proposed two additional pillars: dynamic management of change and bridge-strategy problem solving (Table 1). They proposed expanding to 10 pillars by adding four new pillars: identify sectors impacted and assess interactions, identify solutions at systems level, engage and train stakeholders, identify synergy and solutions. This addition is accomplished by considering Cross-Sectoral Integration (Figure 9) with water-as a catalyst for sustainable development: "IWRM and Resource Systems." From both the original and the extension of IWRM, as we move into cross-sectoral integration, each pillar needs to be highlighted. In essence this is a call for a systems view of water management.

◇ Figure 9 Extended IWRM Framework & Pillars



IMPLEMENTATION STRATEGY FOR THE SYSTEMS VISION

The following steps are proposed for implementing the new IWRM vision.

1. Define water management hotspots for the region under consideration. These hotspots are thematic or regional vulnerabilities that need to be looked at.
2. Identify stakeholders and sectors impacting and being impacted by water challenge related to the identified hotspot. These sectors in most cases will include actors outside the water stakeholders.
3. Identify and Quantify interlinkages between water and the other sectors and hotspots identified earlier.
4. Model the system and develop implementation scenarios to simulate and analyse the effects on all stakeholders and sectors involved.
5. Identify trade-offs associated with each scenario being studied.
6. Assess trade-offs and identify solutions considering the entire system.
7. Identify synergies among various stakeholders and scenarios.
8. Engage stakeholders, disseminate system thinking protocol and bring awareness to system level solutions for the water challenge through inclusive dialogue and discussions.

The implementing levers for the proposed new vision for water management include:

1. **Technological solutions:** These are solutions either for water sector (i.e. desalination) or in the energy sector (i.e. reducing the water footprint in the energy production or utilization) or in agriculture technologies (i.e. dryland dryfarming technologies or high efficiency indoor production systems). In any specific case, these technological solutions are levers that we need to use to bridge the water gap.
2. **Policies and incentives:** These include policies and incentives that could promote certain solutions that are more sustainable in the long run. For instance, in the state of Texas, government should institute policies and incentives to promote initiatives such as dryland farming, which though it may not be economically feasible or may cause compromises in agriculture production, will in the long run, be more appropriate and sustainable for the state.
3. **Education and awareness for changing behaviours:** These include behavioural and anthropological changes that could happen through education to increase awareness and to change behaviour towards utilization of these resources (for instance, reducing waste in water, energy, food, and other resources) to promote ecosystem health and human health.

A COMPREHENSIVE SYSTEMS APPROACH TO DELIVER WATER TO SOCIETIES – SAN ANTONIO, TEXAS CASE STUDY

The 2017 State Water Plan of the Texas Water Development Board declares that Texas will have a nearly 40% water gap by 2070. Thus, the question of how to bridge the anticipated water gap is pressing, given the projected population growth and stresses imposed by climate change while accounting for variable water availability and the water-demanding sectors across the multiple regions of the state. Texas has some of the fastest-growing major population centers in the USA, one of which is San Antonio. Texas is home to major centers of energy production that compete for water with its agricultural production centers. A systems approach has allowed the development of a framework to quantify the interlinkages of the competing water, energy, and food sectors that is governed by science and data tools. These tools assist by identifying existing potential hotspots, accounting for expected tradeoffs in resource allocation strategies, and informing policy through dialogue that identifies and clarifies existing opportunities for cooperation (Dargin et al 2019).

The San Antonio water-energy-food system is an exemplary “hotspot,” a vulnerable region that faces stresses in one or more of its resource systems due to resource allocation policies at odds with the interconnected nature of its food, energy, and water resources. Texas has a thriving energy sector, particularly in the Eagle Ford Shale region where water is extracted for energy production (Mohtar et al 2019). The region includes some of the fastest-growing cities in the United States: Austin, San Antonio, Houston, and Dallas, and Texas also has a thriving food and agriculture sector that demands water. (Mohtar 2019; RRC 2022). All this makes Texas, and particularly the San Antonio region, a typical example of water that is allocated to multiple sectors (water, energy, food) without policy coherence, thereby creating competition, not synergy, between sectors.

The Texas A&M University Water-Energy-Food Nexus Initiative (WEFNI) was created to help address this incoherence. WEFNI included scientists and educators committed to finding solutions grounded in state-of-the-art science to address the nexus grand challenges. Multidisciplinary teams shared skills, knowledge, and scientific talents during a three-year project (2015-2018). The goal of WEFNI was to achieve better understanding of the interconnections among the sectors, to produce the needed analytics and a platform to facilitate inclusive stakeholder dialogues about resource management, and then to use that understanding to sustainably address the issues presented to achieve equitable allocation and improved management of the resources. WEFNI activities included the San Antonio Case Studies – WEF Nexus Initiative (SACS-WEFNI), and these case studies included several townhalls, workshops, and webinars. Two special issues were published. The first reported the outcomes of an NSF sponsored workshop held in January 2017, FEW Nexus Workshop on Integrated Science, Engineering, and Policy: a Multi Stakeholder Dialogue Symposium (Mohtar 2017). The second special issue was published in Science of the Total Environment (STOTEN) and focused on the theme that “while the principles and experiences of FEW system dynamics are common across hotspots, the solutions and responses to system challenges are bound by local knowledge, conditions, and rates of change” (Mohtar 2019).

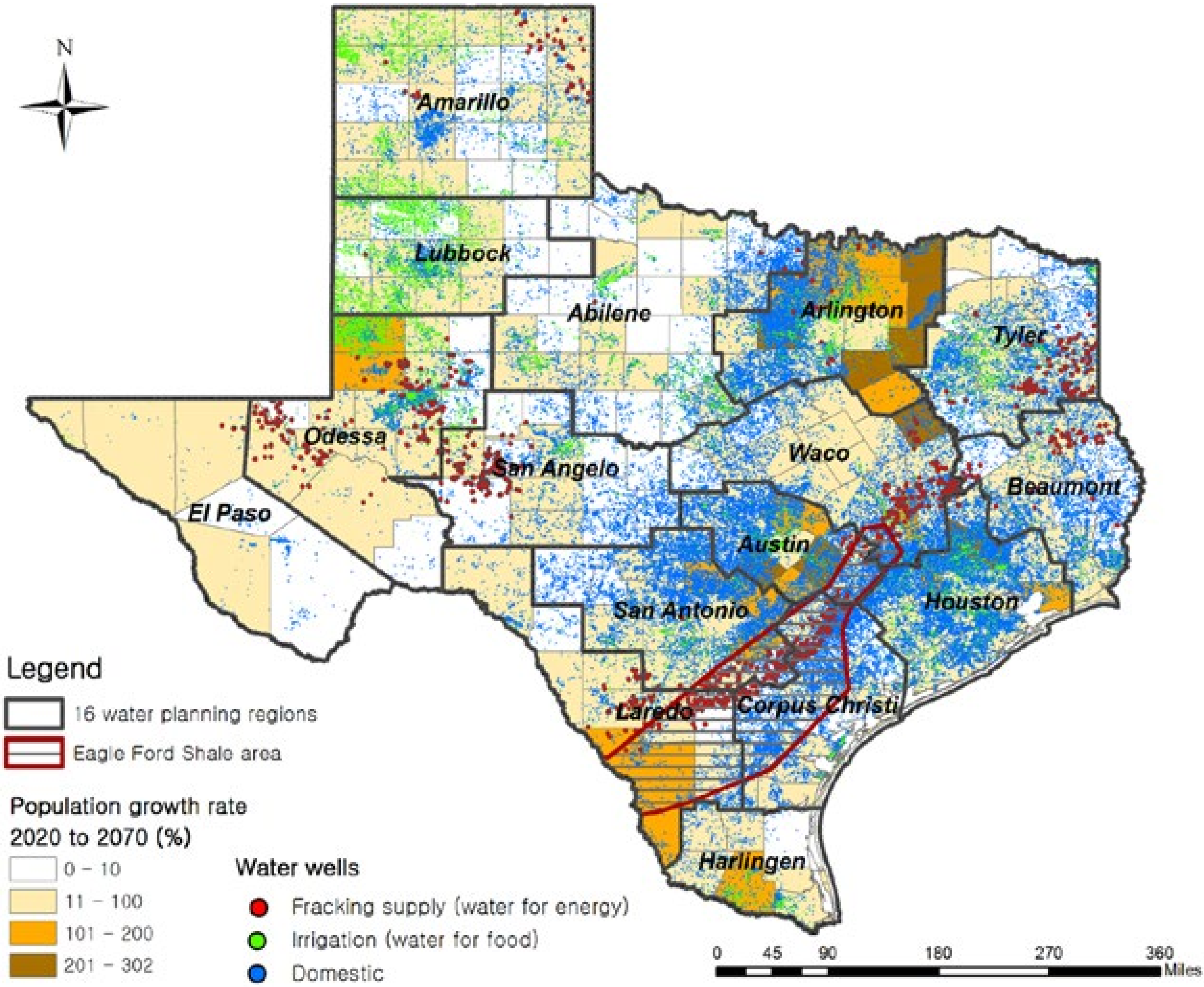
The activities of the Texas A&M WEFNI community have continued, notably through NSF award 1739977, Decision Support for Water Stressed Nexus Decisions (DS-WSND), which used San Antonio, TX and the Salton Sea Basin, CA as case studies for sustainable resources management. The project aimed to equip multi-sectoral stakeholders with models and decision support tools capable of evaluating the trade-offs and synergies associated with decisions made across food, energy, and water (FEW) systems in the two regions. An interdisciplinary team of hydrologists, agricultural economists, energy engineers, water engineers, agricultural experts and outreach specialists worked over five years, engaging with stakeholders from both regions throughout. The project outcomes include the development of innovative integrated FEW models and key recommendations for better coordinated management of the interconnected resources systems in water scarce regions. (INFEWS DS-WSND 2022).

Daher et al (2019) discuss the experience of the SACS WEFNI project, in which an interdisciplinary group addressed the resource challenges faced in the complex resource hotspot region of San Antonio Texas, home to a rapidly growing population and located in the Eagle Ford Shale region. The region increased oil and natural gas production and its major agricultural activity. Ensuring sustainable urbanization of San Antonio made it critical to identify possible interventions to reduce existing and projected resource stresses. (Mohtar and Daher 2018).

Figure 10 illustrates Texas and the San Antonio hotspot. The blue dots represent water wells for municipalities, hence their concentration in cities. The green dots represent water for agriculture, and the red dots denote extraction wells for hydraulic fracturing. The map indicates the competition for water among all sectors: there will be conflicts in water allocation to meet municipal demands for water, energy, industry, and agriculture. It illustrates how traditional water management approaches fail. It is a complex problem and will involve transforming the way we manage and govern water.

In the San Antonio region, much of the land use is urban. Among the solutions proposed there was the use of low impact development (LID) technologies – such as the use of porous concrete or increasing the recharge area due to over pumping to meet the municipal demand. LID structures allow for increased aquifer recharge, thus additional water supply, for a city that requires an investment and trade-offs assessed using a systems approach. This has financial costs but also involves stakeholders outside the water sector working with the city planners, the mayor’s office, and other policymakers who govern the management of open spaces in San Antonio.

◇ Figure 10 San Antonio hotspot



Source: Daher et al. 2019

SUMMARY AND CONCLUSIONS

Addressing the global water challenge of the future, requires coordination and engagement of major sectors of the economy, including water, energy, food, health, and education, among others. A system level paradigm to delivering water to society is needed to engage these stakeholders. This report reviews various implementation of water management projects and lessons learned across various nations and applications. It then presents a new vision for water management based on system and multidisciplinary approaches for water and its interdependencies on food, energy, health, and education. The report highlights an implementation strategy to the new vision and share some recommendations for the future. Solutions of the water challenge need not be water specific. Solutions must mobilize multiple stakeholders, from public, private, civil society, and local community. Solutions must use innovative policy to catalyze solutions and create new public-private partnerships. Solutions must be multi-sectoral. Not less, solutions must be holistic, Incorporating water and energy and food production and consumption. Engaging all stakeholders in co-creating solutions and examples implementation from San Antonio, Texas case study was presented and summarized.

Lessons learned in south Texas relate to the increased groundwater consumption and alleviation of this use of groundwater with technologies that reduce the water used in hydraulic fracturing, agriculture, and domestic water use, placing greater value on other natural resources of these vital economies of the state. Doing so involved engaging the energy and the agricultural sectors and municipalities to allow a reduction of the water footprint. This exemplifies that solutions to the water challenges must also involve the non-water sectors. This means looking at the political-economic-supply chain dialogue that moves us from conflict across water consumers into synergies among them. Solutions must be synergistic among sectors and must be communicated through inter-sectoral dialogue. The systems approach presented does not stop at the interlinkages or the hotspot and trade-off analysis. It is used as a catalyst to create a platform for informed dialogue to help reach these potential solutions.

In conclusion, the water gap requires holistic, yet localized, solutions. It involves muti-stakeholder approaches to adoption of these solutions and must account for the spatial and temporal distribution of the resources. It will also involve accounting for the interconnections between competing resource systems. Proper communication of tradeoffs between resource systems associated with the multiple growth trends among water demands for each sector is critical. Finally, governance challenges need to be addressed for implementation, for example, who will pay for the infrastructure? Society requires that there be adoption by multiple stakeholders (Aldaco-Manner et al 2019).

GLOSSARY OF TERMS USED

Aquatic ecosystem integrity The ability of an ecological system to support and maintain a community of organisms that has species composition, diversity, and functional organization comparable to those of natural habitats within a region

Cross-sector collaboration is a term used to describe a process where various community organizations come together to collectively focus their expertise and resources on a complex issue of importance to a community they serve.

Holistic characterized by comprehension of the parts of something as intimately interconnected and explicable only by reference to the whole.

hotspot: a vulnerable sector or region of a defined scale, that faces stresses in one or more of its resource systems due to resource allocations that are at odds with the interconnected nature of their food, energy, water, and health resource systems (Mohtar and Daher, 2016).

Integrated systems-approach emphasizes the importance of inter-sectoral coordination to achieving goals, provides a comprehensive water management platform compatible with IWRM practices and accounts for the close interlinkages between sectors while addressing the challenges of sustainably fulfilling these simultaneous, often competing, demands. The systems-approach offers a strategy for planning, policy development, and technological decisions through analysing possible trade-offs and investigating potential synergies in their production and usage while also considering natural resource assets and climate issues

Integrated Water Resources Management (IWRM) a process which promotes the coordinated development and management of water, land, and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital ecosystems.

Riparian zones or areas are lands that occur along the edges of rivers, streams, lakes, and other water bodies. Examples include streambanks, riverbanks, and flood plains. They're different from the surrounding uplands because their soils and vegetation are shaped by the presence of water

Sustainable Development Goals (SDGs) are a collection of 17 interlinked global goals designed to be a «shared blueprint for peace and prosperity for people and the planet, now and into the future». The SDGs were set up in 2015 by the United Nations General Assembly and are intended to be achieved by 2030

Systems analysis is «the process of studying a procedure or business to identify its goal and purposes and create systems and procedures that will efficiently achieve them».

Systems thinking is a way of making sense of the complexity of the world by looking at it in terms of wholes and relationships rather than by splitting it down into its parts. Systems thinking draws on and contributes to systems theory and the system sciences.

Systems theory is the interdisciplinary study of systems, i.e. cohesive groups of interrelated, interdependent components that can be natural or human-made. Every system has causal boundaries, is influenced by its context, defined by its structure, function and role, and expressed through its relations with other systems. A system is «more than the sum of its parts» by expressing synergy or emergent behavior.

Stakeholder - The international standard providing guidance on social responsibility (ISO 26000), defines a stakeholder as an «individual or group that has an interest in any decision or activity of an organization.

Transversal project management is a management approach suitable for complex and large projects. Transverse project management goes beyond the traditional top-down approach to encompass different hierarchies and functions.

Water deficit: Cumulative difference between potential evapotranspiration and precipitation during a certain period in which the precipitation is the smaller of the two.

Water security: the capacity of a population to safeguard sustainable access to adequate quantities of and acceptable quality water for sustaining livelihoods, human well-being, and socio-economic development, for ensuring protection against water-borne pollution and water related disasters, and for preserving ecosystems in a climate of peace and political stability

Water Use Efficiency (WUE) is defined as the amount of carbon assimilated as biomass or grain produced per unit of water used by the crop.

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