Iraq Salinity Assessment

Managing Salinity in Iraq's Agriculture

Current State, Causes, and Impacts

An overview of the scope and scale of soil and water salinity in Central and Southern Iraq

Report 1: Situation Analysis

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Cooperazione Italiana allo Sviluppo
Ministero degli Affari Esteri

Acknowledgments

This report is a collaborative effort of the entire research team of the Iraq Salinity project. The following researchers have contributed to this report, directly or through technical papers and studies prepared for the project, that have been synthesized here (in alphabetical order): Dr. Abdul Jabar Al-Meini, Ministry of Water Resources, Iraq; Dr. Abdul Jabbar Khalaf Fanash Ministry of Water Resources, Iraq; Dr. Abdulkareem Hasan Odafa, Ministry of High Education, Iraq; Dr. Abdulkareem Hamad Hassan, Ministry of Agriculture, Iraq; Dr. Abdul Khalek Saleh Naema, Ministry of Agriculture, Iraq; Dr. Ahmad Adnan Ahmad, Ministry of Agriculture, Iraq; Dr. Ahmed S. Mhaimeed, Ministry of High Education, Iraq; Dr. Alexander Platinov, IWMI, Uzbekistan, Dr. Ali Abbas Al-Hasani, Ministry of Science and Technology, Iraq; Dr. Ali Hasan Faraj, Ministry of Agriculture, Iraq; Mr. Ali Muhammed Jawad, Ministry of Water Resources, Iraq; Dr. Asad Sarwar Qureshi, IWMI, Pakistan; Dr. Ayad Hameed Abbas; Ministry of Water Resources, Iraq; Dr. Boubaker Dhehibi, ICARDA, Jordan; Prof. Dr. Ed Barrett-Lennard, University of Western Australia, Australia; Dr. Evan W. Christen, CSIRO, Australia; Dr. Feras Ziadat, ICARDA, Jordan; Dr. Hasan Hameed Al-Musawi, Ministry of Water Resources, Iraq; Dr. Hayley Norman, CSIRO, Australia, Dr. Husamuldeen Ahmed Tawfeeq, Ministry of Science and Technology, Iraq; Mr. Husham Salman Hussien, Ministry of Science and Technology, Iraq; Dr. Ibrahim B. Abdul-Razzaq, Ministry of Science and Technology, Iraq; Dr. Iman Sahib Salman Ministry of Agriculture, Iraq; Mr. Jafar K. Alwan, Ministry of Water Resources, Iraq; Dr. Kasim Ahmed Saliem, Ministry of Agriculture, Iraq; Dr. Khudhair Jaddoa, Consultant, Iraq; Dr. Moutaz Al-Dabbas, Ministry of Higher Education, Iraq; Dr. Raad Omer Salih, Ministry of Agriculture, Iraq; Mr. Ray Evans, Sinclair Knight Merz, Australia; Dr. Rich¬ard W.O. Soppe, CSIRO, Australia; Dr. Roberto Telleria, ICARDA, Jordan; Dr. Saad Hatem Mohamed, Ministry of Agriculture, Iraq; Mr. Shawket Saib Jameel, Ministry of Agriculture, Iraq; Dr. Vinay Nangia, ICARDA, Jordan; Mr. Waleed Mohammed Al-Shafie, Ministry of Agriculture, Iraq; Dr. Weicheng Wu, ICARDA, Jordan

Editorial support: Paul Neate, Elsy Melkonian (ICARDA), Michael Devlin (ICARDA).

Iraq Salinity Assessment

The Iraq Salinity Assessment is the result of a three-year research project on soil salinity in Central and Southern Iraq - by the Government of Iraq, Ministries of Agriculture, Water Resources, Higher Education, Environment, and Science and Technology, and an international research team led by ICARDA in partnership with the University of Western Australia, the Commonwealth Scientific and Industrial Research organization (CSIRO) of Australia, the International Water Management Institute (IWMI), Sri Lanka, and International Center for Biosaline Agriculture (ICBA), Dubai, United Arab Emirates. This research is funded by the Australian Centre for International Agricultural Research (ACIAR), AusAID and the Italian Government.

Key Words

soil salinity in Iraq, salinity in agriculture, land and water management, Irrigation systems rehabilitation, dryland agriculture, improving agricultural productivity, dryland farming systems, development policies; arid zones, Iraq, Agricultural Research in the Dry Areas, ICARDA, Australian Centre for International Agricultural Research, ACIAR, Government of Iraq.

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ISBN 92-9127-280-9

ICARDA -- International Center for Agricultural Research in the Dry Areas
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Contents

Executive Summary

About This Report

This report is the first in a series of publications that comprise the Iraq Salinity Assessment. This report documents the current state, causes, impacts of salinity in central and southern Iraq. Other reports in the Assessment propose solutions and investment options to manage and remediate salinity in Iraq.

The Iraq Salinity Assessment synthesizes the results or the Iraq Salinity Project, a research partnership between five Iraqi ministries and national agencies and an international team of researchers, led by ICARDA, specialized in land and water management, crop improvement and plant breeding, and socioeconomics.

This research builds on previous work and technical studies done in Iraq and on the expertise of Iraqi agencies working to promote agricultural development over the past decades. It provides analysis of historical data and new data compiled in the Iraq Salinity Project and provides an insight into the extent and severity of soil and water salinity in Iraq.

The Assessment benefits from Australia's experience in dealing with similar salinity problems in its agricultural sector. The salinity situation and agro-hydrological problems faced by Iraq are similar to those faced in Australia's Murray-Darling river basin. Australia has tackled its salinity problem in a systematic way since the 1980s, and today salinity is being controlled and reversed in many areas.

This report is a synthesis and analysis of a body of research - field-level and technical studies in North and Central Iraq, a new body of data and information collected and compiled by the research team and a series of technical and background papers. All information related to this research can be consulted at www.iraq-icarda.org

Use of soil-water-plant modeling to determine optimal irrigation water allocations to control water tables and soil salinity.

Iraq Salinity Assessment - Three Reports:

- Stage 1: Overview and scope of the problem (this report)
- Stage 2: A detailed analysis of the problems and potential solutions and development of a framework for a national, integrated approach to salinity management in Iraq.
- Stage 3: Investment options to support a long term strategy of soil and water salinity management in Iraq.

Iraq Salinity Research - Multi-disciplinary, Multi-scale:

- A multi-scale focus, from the farm to irrigation project to the whole of the Mesopotamian plain.
- A 'bright spots' approach, working with farmers to understand their practical approaches to fighting salinity at field level and studying ways to scale-up these innovations for use by many other farmers.
- Use of soil–water–plant modeling to determine optimal irrigation water allocations to control water tables and soil salinity.
- Assessment of optimal solutions for refurbishing irrigation and drainage infrastructure.
- Testing of new crop varieties of salt-resistant crops to be used in Iraqi farming. This includes forage crops that can bring increased income to communities that are living in areas with degraded soils.
- Investigation of the socio-economic impacts of soil salinity on farmers and national agricultural production.
- Mapping of soil salinity and river water salinity in the Tigris and Euphrates river basins.

Executive Summary

Key Findings – The Salinity Situation in Iraq

This report provides an overview and situation analysis of the state of soil and river salinity in Central and Southern Iraq. New perspectives and findings on the current status of salinity problems are presented here.

The objective of the Iraq Salinity Assessment is to provide evidence on which long-term investments can be made to improve the management of salinity in Iraq's agricultural sector. It proposes strategies and practices that will improve the livelihoods of rural communities and smallholder farmers, who are put at risk due to salinity on their lands.

These findings can inform the thinking, approaches and investment of senior decision makers in Iraq's government, its agriculture and rural development agencies; and of international development partners who are active in agricultural and environmental projects in Iraq. Other countries in the world's dry areas with salinity problems will also find these results useful for developing strategies to manage their salinity problems.

Overview of Findings

The picture emerging from this research is that action is needed in four areas:

- Iraq's irrigation and drainage systems need to be upgraded.
- Strategies are needed for farm-level water management, improved salinity control and irrigation management.
- Management of drainage water and other saline inflows to the river systems
- Water-use policies and institutions need to be strengthened.

Previous attempts to address and mitigate the effects of salinity in Iraq have focused primarily on field drainage, an expensive and technical proposition. For maximum effectiveness, the use of field drainage for future work must be done as part of a comprehensive framework that analyzes the costs and benefits of this and other approaches and or the upstream/downstream impacts of interventions.

Addressing Land Salinity

Salinity in Central and Southern Iraq is so pervasive that its impact on farming systems is a major constraint to agricultural productivity. A strategic focus is needed on investment in salinity management at the farm scale.

The challenge for policy makers is to encourage investment in human and financial resources where skilling and investment levels are unlikely to be able to address the scope of the problem. Likewise, it will be important to target investments and interventions, as focusing in equal measure on all problem areas is unlikely to give a positive long-term outcome.

For planners and development partners, the best option, then, is to focus the limited resources available on areas where the greatest impact and rapid results can be achieved.

- Moderately saline irrigated land will benefit strongly from investment in irrigation and drainage infrastructure and from improvements in the salt tolerance of the currently-grown crop species.
- In the country's more severely saline irrigated areas, it can be expected that the current mixed production of vegetables, cereals, and high-value fodder can best be replaced by growing salt-tolerant forages, and that these farming systems will in the future be dominated by livestock production. Investment in developing severely saline lands in this way should target making a transition to livestock production. This requires the creation of extension packages that address ways to maximize animal performance using salt-tolerant forages and fodders. And on research on the introduction and development of forage types with higher nutritive value that complement existing livestock feeding systems.

Strategies for Improving Livelihoods in Severely Saline Areas – Forage and Livestock Production

In the most severely affected areas, effective solutions to soil salinity require changes in land-use practices and production activities over entire districts. To improve farm-water productivity under saline agriculture, districts will need to set rehabilitation priorities that address soil and water-salinity problems. Authorities will need to create mechanisms for direct farmer participation in technology development, evaluation, extension, and monitoring.

Approaches that improve livelihoods and generate income and employment for farm families need to be identified and highlighted to farmers and rural communities. These include planning for livestock production associated with irrigated areas and saline lands. Livestock production has the potential to bring a major source of income for the poor. So rehabilitation approaches that integrate irrigated cropping and livestock production are a key strategy for improving the livelihoods of disadvantaged people in areas where cropping systems are declining due to salinity.

In the Iraqi landscapes that are severely saline, investments should be targeted at identifying drought-tolerant halophytic (salt-tolerant) shrubs that will prevent these lands from becoming desertified, and ensuring that they can provide feed for livestock over the long term.

Australia’s experience indicates that severely saline areas may partially rehabilitate over time and salt-sensitive plant species will eventually return if grazing is well managed. Highly saline land is still capable of producing high yields of forage crops.

With this scenario it is expected that, in highly saline areas, agriculture will become increasingly dominated by the production of forages for livestock, and farmers will need to develop new skills in forage conservation and livestock management.

Currently, farmers in these areas vary in their experience in obtaining production from saline landscapes. National and local authorities will need to ensure that practices for livestock and forage production are communicated to farmers in the affected areas.

Addressing River Salinity

It is important to reduce the salinity levels in the Tigris and Euphrates rivers, especially in their lower reaches. This is critical not only for agriculture but also for the communities that rely on these rivers for their drinking water and other needs. Most of the increase in the salinity of these rivers occurs within Iraq; the research team’s analysis shows that the salinity of water entering Iraq appears to have been stable since the 1980s.

This situation provides excellent opportunities for the Government of Iraq to invest in measures that will halt and even reverse the salinity trends in these rivers. These actions need to be undertaken soon and within a comprehensive framework that prioritizes specific measures that deliver the greatest benefit for least cost.

Key Areas for Investment

The Government of Iraq needs to invest in five key areas: continued research, policy development and management frameworks, infrastructure, education/training and extension. The other components of the Iraq Salinity Assessment elaborate on requirements with a view to determining key investment decisions for the future effective management of salinity in Iraq.

Future Requirements to Manage Salinity in Iraq

1. Focus strategically on best-best areas. Iraq needs to take a strategic approach to the rehabilitation and reclamation of saline irrigated areas, based on the recognition that some areas will strongly benefit from investment, benefits will be limited in some areas, and in other areas it may not be possible to restore irrigated agriculture. Farming systems may have to change according to the long term potential of land to produce specific types of crops. Taking this approach will help direct funding and human resources to the places where they will deliver the greatest impact.

2. Salinity management framework. An integrated approach is vital to resolving Iraq’s salinity problems. This should start with the development of a salinity management framework for the Mesopotamian plain.

3. Reduce surface water salinity. Surface-water salinity must be controlled by tackling the major sources of saline water inflows to rivers within Iraq.

4. Rehabilitate irrigation and drainage concurrently. The work should be conducted within a salinity management framework, and based on analyses of upstream/downstream impacts, costs and benefits. Funding should be targeted to maximize the return on investment and speed of return on investment.

5. Continued testing of sale tolerant crops (food and forage). Testing of salt-tolerant crops is needed (for mildly to moderately saline areas) and forages (for moderately to highly saline areas). The nutritive value of forages and their fit within existing, new, and evolving feeding systems should be considered when introducing new species.

6. Take an integrated approach. An integrated and multidisciplinary approach to the salinity problem is required. Tackling the problem from one approach, one scale, or one area alone will not result in a sustainable solution.

7. Close coordination between ministries. Ministry of Water Resources, the Ministry of Agriculture, and other ministries need to collaborate closely to address the salinity problems within an integrated catchment approach. A multidisciplinary approach is essential.

8. A continuous improvement approach. Managing the salinity problem in Iraq requires a cyclical process (plan–act–review–plan) at all levels. Actions must be driven by the need to achieve rapid improvements on the ground and should be evaluated continuously for improvements.

Discussion

Iraq's extensive irrigation and drainage infrastructure has fallen into disrepair. As a result, a large area of land is lost every year due to salinization and waterlogging. Halting and eventually reversing soil salinity problems will require large-scale, concerted efforts. Investment in rehabilitation of the irrigation and drainage infrastructure is urgently required. However, these works, especially drainage works, should consider downstream effects on water quality.

The salinity of the Tigris and Euphrates rivers within Iraq is increasing. It is vital that the salinity in the rivers is addressed both for agriculture and for the communities that rely on these rivers for their drinking water and other needs. The research team's preliminary analysis indicates that the salinity of water entering Iraq has been relatively stable since the 1980s and that salinity in the lower reaches of the Euphrates – and most probably the Tigris – is derived predominantly from irrigation drainage and saline groundwater inflows to the rivers within Iraq. Thus, investment in salt management measures in Iraq should be able to halt and even reverse the salinity trends in these rivers. Actions to control soil and river-water salinity need to be taken soon and as part of a comprehensive framework that prioritizes measures that will deliver the greatest benefit for least cost. It is important that an approach to managing salinity in the rivers is done in coordination with investments in drainage infrastructure for irrigated areas.

The rehabilitation of irrigation and drainage infrastructure will be a long-term exercise and for some areas rehabilitation may not be cost effective. Thus, farmers must be provided with effective ways to adapt to soil salinity, such as changes to land-use practices and production systems. Farmers should participate in the development, evaluation, extension, and monitoring of these approaches, and in identifying livelihood-enhancing and employment-generating opportunities for farm families. This approach should be based on a clear understanding of the current situation and planning for changes in the mix of farm enterprises associated with irrigated areas and saline lands.

Future Requirements to Manage Salinity in Iraq

Overview: Iraq's current salinity state

- There is a lack of strategic frameworks to manage and adapt to salinity in the Mesopotamian plain.
- Current efforts aimed at managing land salinity are not based on strategic plan with clear targets
- Currently there is little emphasis on controlling salinity in the rivers and surface waters within Iraq.
- There is a lack of targeted interventions to efficiently manage land salinity and control salinity in the surface waters.
- There is a lack of coordination between Ministries in tackling agricultural, water resource management, and salinization problems
- Policies related to agriculture and water management need to be evaluated for their effectiveness in controlling salinity and promoting sustainable agriculture
- While science in Iraq takes a multidisciplinary approach, implementation of integrated solutions does not.

The simplest way to deal with increasing salinity in cropping systems is to grow salt-tolerant genotypes of the crop species farmers are currently growing. This minimizes the need for the large-scale dissemination of new farming skills, management systems, and markets. It is therefore very important to define land capability from the perspective of existing crops and new salt-tolerant genotypes of existing crops and to identify areas where new halophytic forages are the only option. Rapid classification of land capability, with parallel testing of new plants, will allow government agencies to develop management recommendations for farmers. Where halophytic forages are the only option, farmers will have to be trained in their use in livestock feeding.

The trend across world agriculture is for vegetable and grain crops to be replaced by forage crops as soil salinity increases. The evolution of systems from mostly crop to mixed crop and forage. Production may be positive for farmers. Many farmers in the irrigated zone of Iraq already keep some livestock. Livestock can be a significant source of income for those badly affected by soil salinity as forages are more salt tolerant crops, hence the development of integrated crop–livestock systems will have major benefits for poor people and offer a positive message for communities that are suffering from the decline of traditional cropping systems. This will require adaptation to farming practices and agricultural policy in Iraq.

The Government of Iraq should invest in key areas, such as continued research, management frameworks, policy development, infrastructure, and education/training. This project will develop aspects of these investment requirements with a view to informing key investment decisions for future effective management of salinity in Iraq.

Salinity Impacts in the Mesopotamian Plain

1. The Mesopotamian plain has poor drainage and large stores of salt; salinity has been a problem there since Babylonian times, nearly 4000 years ago. However soil salinity is now widespread and possibly more severe than any of previous assessments indicated, with virtually all areas affected by soil salinity. Currently an unquantified, amount of agricultural land is lost to salinity every year.

2. Water productivity in many areas is very low as a result of degradation of irrigation and drainage infrastructure. For example, overall irrigation efficiency in the Dujailah irrigation project is as low as 31–38%. This low efficiency is leading to soil salinization.

3. The water in the Tigris and Euphrates rivers in Iraq is becoming increasingly saline (e.g., up to 7 dS/m at Basra, too salty to support most crops) due to slaine surface and groundwater inflows. This increase in river-water salinity has serious consequences for the water supplies of communities and agriculture.

4. Salinity and waterlogging is currently impacting upon agricultural production, society and the economy, culture, and the environment:

5. In salt-affected areas farmers are cropping only about 30% of their land and are achieving only about 50% of expected yields. With current salinity levels we estimate that about US$300 million per year is lost due to salinity effects. So there is a great opportunity to increase production if water and salinity management can be improved.

6. Many farmers make up a large majority of the poor in Iraq.

7. In 2009, the country imported some US$2.1 billion-worth of crops that could be grown in Iraq, including US$342 million- worth of fruit and vegetables that could be grown under irrigation.

8. The ancient practice of date farming and the lives communities living in the marsh areas are severely affected.

9. The land, marshes, rivers, and estuary ecosystems have been severely affected.

1 Overview of Salinity in Soil and Water

Iraqi agriculture is predominantly irrigation based (~70% by value). Hence, any factor that affects the productivity of irrigated lands has a large impact on Iraqi agricultural production. This is why the management of salinity in Iraq is so critical.

Soil and water salinity are critical issues in Iraq, affecting the quality of water for irrigated agriculture and domestic and industrial use across the country. Soil salinity mainly affects irrigated land; application of irrigation water combined with poor drainage has led to high water tables and hence soil salinization. Soil salinity in Iraq is thus very much an irrigation-based issue.

In Iraq, salinity and irrigation are intimately bound together: irrigation causes waterlogging and salinization and these in turn reduce the productivity of irrigated agriculture.

1.1 The importance of irrigation to Iraqi agriculture

Irrigation is critical to Iraqi agriculture. Most of Iraq receives less than 250 mm of rainfall per year. Many of Iraq's most important crops are grown under irrigation, and 73% of the value of agricultural production comes from irrigated crops (Table 1). Animal products also benefit from irrigation, as some of the fodder and grain fed to livestock are produced under irrigation.

Table 1. The top 20 agricultural products by value produced in Iraq. Those shaded are produced entirely under irrigation.

Rank	Product	Value (US$ million)	Production (t)
1	Tomatoes	374.44	1013180
2	Dates	234.84	566829
3*	Wheat	195.47	2748840
4†	Cattle meat	133.98	49598
5†	Sheep meat	127.92	46981
6	Grapes	121.55	212649
7	Okra	96.7	151219
8	Cucumbers and gherkins	85.87	432500
9	Eggplants	82.83	387435
10†	Chicken meat	69.75	48970
11†	Cow milk, whole, fresh	56.77	191500
12	Leguminous vegetables	48.32	140542
13	Lettuce and chicory	41.98	89795
14	Rice, paddy	41.42	155829
15	String beans	39.38	41300
16†	Goat meat	36.6	15275
17	Watermelons	34.65	30419
18†	Wool, greasy	32.91	17200
19	Other melons	32.58	176996
20	Chilies and peppers	32.54	69120
Total value		**1920.5**	
% associated with irrigation		**73%‡**	

*67% of wheat production is from irrigated areas (Bishay, 2003).

† These products may also have inputs from irrigated agriculture.

‡ Including value of wheat from irrigated areas.

Source: adapted FAOSTAT (http://faostat.fao.org/

1.2 Irrigated Cropping

Wheat and barley are by far the most widely grown crops in Iraq, occupying most of the area planted in the winter season. Maize, millet, cotton, rice, sorghum, sesame, and sunflower are produced in smaller quantities in the summer season. Widely grown vegetable crops include tomatoes, beans, eggplant, pepper, cabbage, lettuce, okra, cucumber and onion. Orchard crops, such as dates and oranges, and grapes are also grown under irrigation.

Almost all fodder crops are grown under irrigation and fed to animals using a cut-and-carry system. The most widely grown forage crops are alfalfa, maize, sorghum and vetches (FAOSTAT: http:// http://faostat.fao.org). Most alfalfa is preserved as hay. Surpluses of alfalfa are transported and sold throughout the country for use when forage is scarce.
Cropping intensity varies both temporally and spatially. In winter, about 80–90% of land is used along the irrigation canals and on the present levees of the Euphrates and Tigris rivers. Further away from the main canals, the salinity of the soil increases and cropping intensity decreases, falling to almost zero in saline basins. In summer, the intensity of cultivation is usually of the order of 50%, although a small amount of multiple cropping, usually of vegetables, occurs where irrigation water is available over more than one season.

Almost all agricultural practices are mechanized and fertilizers are widely used. Harvesting is done mostly by combine harvesters. Iraqi farmers generally receive wheat and maize seed from the government but some farmers conserve seeds, especially barley, from their last harvest. Vegetable seeds are purchased from the local markets.

The Iraqi agricultural economy is essentially dependent on the irrigation water supplied by the Tigris and Euphrates River. However, small amounts of groundwater and drainage water are also used for the irrigation of crops. Most farmers use traditional flood irrigation techniques, planting on the slopes of furrows. Most farmers are not familiar with modern irrigation techniques. Spray and drip irrigation systems are still in the first stages of adoption. The Iraqi Ministry of Agriculture Strategic Plan (2009–2015) intends to apply these techniques to 750,000 ha.

Yields of crops in Iraq are generally extremely low by world standards due to the use of traditional production and irrigation management practices, the lack of seeds of improved varieties, and saline soils and water supplies.

1.3 Irrigation in the Landscape

Land use in Iraq can be broken down into five agricultural landscape categories: Cultivated (rain fed) (18%); cultivated (irrigated) 9(%); range or scrub land (27%); desert (42%); and forest (4%) (Figure 1).

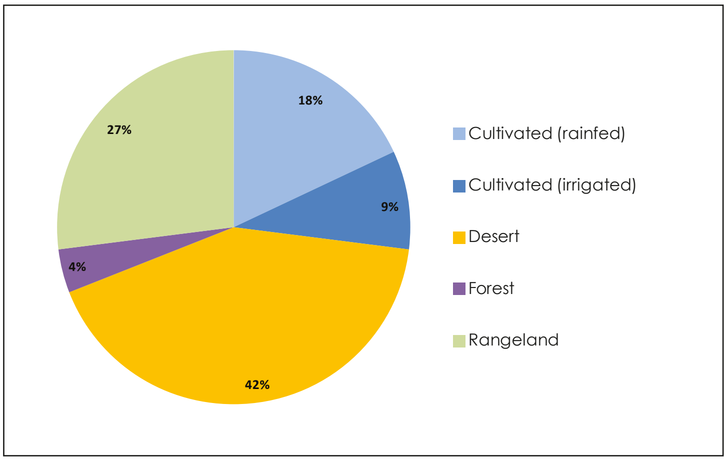

Figure 1. Land use in Iraq.
Source: Al-Tikriti et al. (1981).

The 9% of the land that is associated with irrigated agriculture represents about 2.5 million ha. In 1990, the irrigated area was estimated to be 3.5 million ha, but as of 1993 only approximately 2 million ha were irrigated.
The irrigated area is spread out in central and southern Iraq, in the area adjacent to and between the Tigris and Euphrates rivers, known as the Mesopotamian plain (Figure 2).

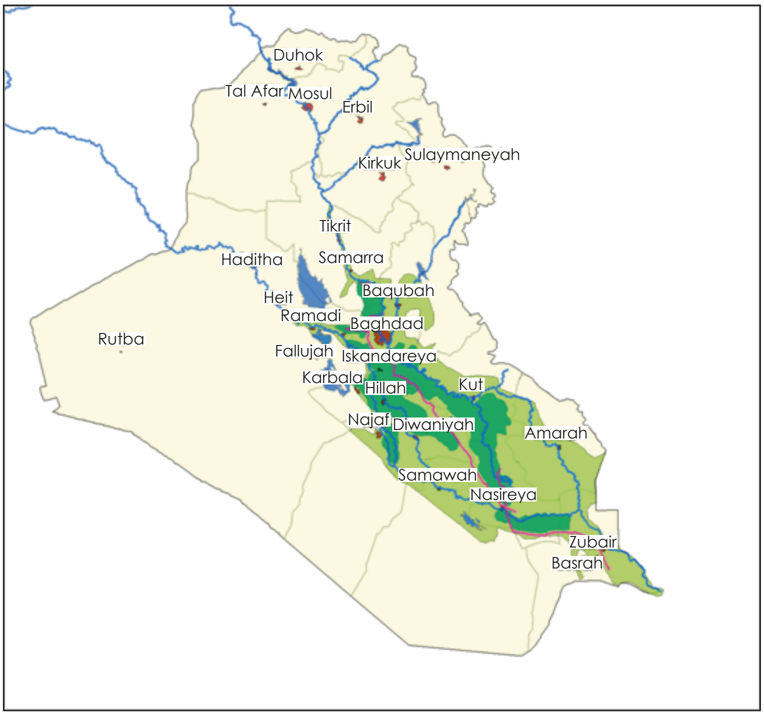

Figure 2. A map of Iraq showing the Mesopotamian plain, where most irrigated agriculture is conducted (dark green areas are main irrigated areas in the plain).

The Mesopotamian plain is a very large floodplain bordered by high mountains in the west, desert in the east, and the Persian Gulf in the south. The floodplain consists of sediments predominantly derived from the flow and flooding of the Tigris and Euphrates rivers.

The rivers deposit a large volume of sediments in large, irregular floods that spread across the plain. The plain itself is very arid, with less than 200 mm annual rainfall. Little of the river water entering the floodplain leaves by surface flow. Major aquifer systems drain into the plain from the north, west, and east, and groundwater drains slowly from the plain to the Persian Gulf to the south. The aquifers of the floodplain are also connected to the surface water in the rivers and exchange flows depending on the relative hydraulic gradients. The low rainfall and the very shallow topographic gradient to the coast mean that there has been little opportunity for flushing of salts from this landscape. There is saline groundwater flowing into the plain from the mountains and the sediments of the underlying geological basin also contain major evaporitic layers (gypsum and other salts) which contribute to the high salinity levels of the very shallow groundwater under much of the plain. This salinity is manifest as widely distributed gypsiferous and saline soils.

Figure 3 shows the groundwater level contours for the Mesopotamian plain, emphasizing the semi-closed nature of the plain and, in particular, the very flat hydraulic gradient along the length of the plain from the northwest to the southeast.

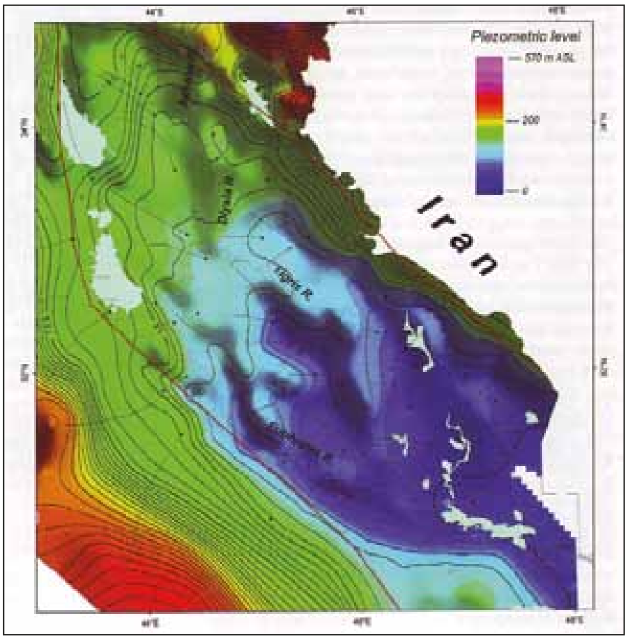

Figure 3. Groundwater levels and flow directions of the Mesopotamian plain of Iraq.
The map shows the groundwater level contours for the Mesopotamian plain, emphasizing its semi-closed nature and, in particular, the very flat hydraulic gradient along the length of the plain from the northwest to the southeast.
Source: Jassim and Goff (2006).

The majority of Iraq's irrigated agriculture is on the Mesopotamian plain. This area is a very flat alluvial plain that is poorly drained and contains much salt in the soil and groundwater.

1.4 Irrigation and Salinity

The majority of Iraq's irrigated agriculture is on the Mesopotamian plain. This area is a very flat alluvial plain that is poorly drained and contains much salt in the soil and groundwater.

The Mesopotamian plain contained a vast amount of salt in its soils and groundwater even before humans started to apply artificial irrigation. The application of irrigation water and the leakage of water from the associated network of water storage, distribution, and drainage channels caused the groundwater to rise close to the soil surface and even inundate some areas. This mobilizes the stored salt and when the water table comes close to the soil surface, soil salinization and waterlogging result, with detrimental effects on agricultural production. Raised water-table levels also increase hydraulic gradients between the groundwater and surface-water resources, leading to increased movement of salty groundwater to drains, streams, and rivers, adversely affecting downstream users of that water. This effect is increased when water levels in rivers are low.

Saline soils and saline irrigation water reduce the ability of plants to take up water and thus reduce plant growth and crop yields. Over time soil salinization may increase to the point where more salt tolerant plants have to be grown or the land will fall out of irrigated production. This affects crop yields and crop choices and ultimately some farmers may only be able to use land for production of halophytic forages. All of these will impact on food security and farmer livelihoods.

Adequate leaching and drainage are necessary to remove salt left in the root zone after the crop has taken up irrigation water. Unfortunately, the natural drainage capacity of the soil and the groundwater system in irrigated areas is usually insufficient to achieve this. As a result, the water table rises. In these situations, engineered drains are necessary to prevent waterlogging and salinization of the crop root zone (Tanji, 1996). In Iraq this problem can be addressed by both improving irrigation practice and using drains to remove water from the soil profile and allow leaching of salts from the crop root zone.

2 Soil Salinity in the Mesopotamian Plain

As soil salinity increases, plant growth is affected. Soil salinity can be controlled by a combination of improved drainage and better irrigation practices. The best combination of these approaches to use depends upon local circumstances and the downstream impacts of any drainage. In some areas, salinity may be so high and problematic that reclamation is not financially feasible.

Table 2 summarizes the terms used in this report to describe different levels of soil salinity and the response of crops to these.

Table 2. Terms for soil salinity classification and crop responses to soil salinity

Term (salinity class)	Salinity range (EC_e, dS/m)	Crop response
Non saline (S0)	0–2	Salinity effects on yield negligible
Slightly saline (S1)	2–4	Yield of very sensitive crops reduced
Moderately saline (S2)	4–8	Yield of many crops reduced
Highly saline (S3)	8–16	Only tolerant crops yield satisfactorily
Severely saline (S4)	16–32	Halophytes and a few very tolerant crops yield satisfactorily
Extremely saline (S5)	>32	Often bare. Only very salt-tolerant halophytes grow

Source: after Withers and Vipond (1988) and Bennett and Barrett-Lennard (2008)

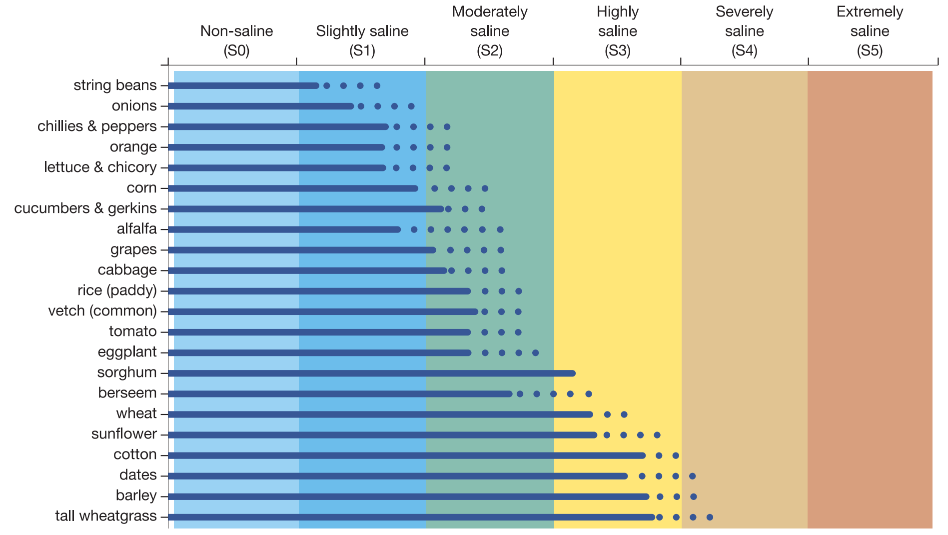

Figure 4. Ability of typical Iraqi crops to grow in soil of different categories (see Table 2). Solid lines indicate yields of 75-100% maximum yield; dotted lines indicate yields of 50-75% maximum yield. Adapted from the data of Steppuhn et al. (2005).

2.1 Historical Soil Salinity Surveys

An extensive soil survey conducted in Iraq from 1955 to 1958 (Buringh, 1960) described the extent of soil salinity in the Mesopotamian plain:

“Almost all soils are saline, most of them even strongly saline and large areas are out of production. The process of salinization still continues and it will even increase when floods are controlled.”

The survey estimated that even if all salts could be leached from the upper few meters of the soil, 20% of the Mesopotamian plain’s soils would be highly productive, 40% would be moderately productive, and 40% would remain marginal land, because the productivity of soils after salinity is reduced is determined by the physical properties.

An inventory of soil salinity in select projects first published in 1963 (Dieleman, 1977) showed that three projects north of Baghdad had a soil salinity greater than 8 dS/m over 35–50% of the area, and greater than 16 dS/m over 15–25% of the area, while projects south of Baghdad had soil salinity greater than 8 dS/m over more than 80% of the project area, and greater than 16 dS/m over 60% of the project area (Figure 4).

Survey indicates that the first reclamation efforts in Iraq were conducted in 1927–1929, and a second reclamation effort was conducted in 1944. Broader reclamation efforts started in 1956 with the introduction of several rehabilitation projects and installation of drainage systems. The main drain flowing into the Shat-Al-Basrah was finished in 1992.

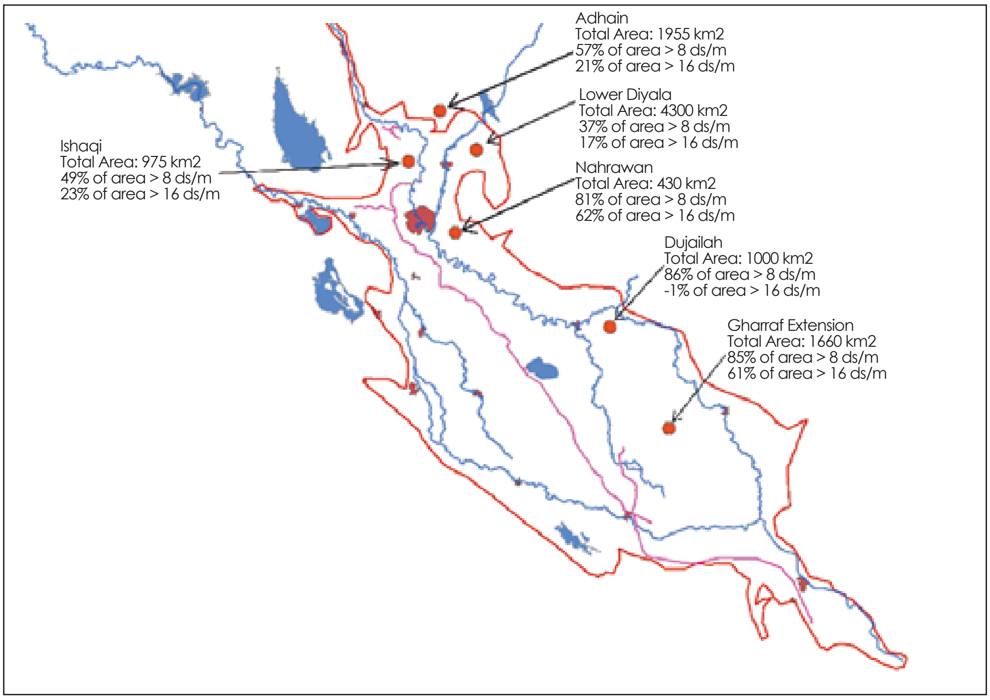

Figure 5. Location of projects with indication of saline areas in the Mesopotamian plain.
A map developed by FAO (1980) shows that soil salinity was increasing by 2 to 5 dS/m per year across almost the whole plain, and large parts had soil salinity in excess of 15 dS/m.
Source: Data from Dieleman (1977).

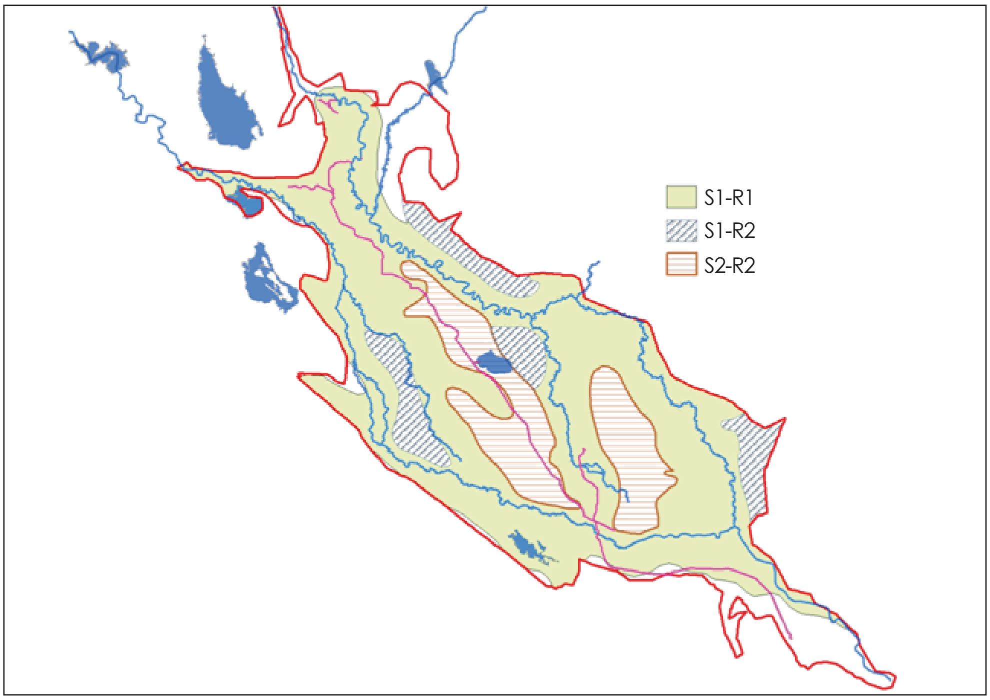

Figure 6. Degradation rate and current state of soil for the Mesopotamian plain in 1980.
S1: soil salinity of 4–15 dS/m; S2: soil salinity greater than 15 dS/m; R1: soil salinity increasing by 2-3 dS/m per year; R2: soil salinity increasing by 3–5 dS/m per year and sodicity by 2–3 exchangeable sodium percentage units/year.
Source: FAO (1980).

Despite the introduction of drainage systems to try to control soil salinization, in 2002 it was estimated that 4% of irrigated areas were severely saline (>16 dS/m), 50% were moderately saline (> 4 dS/m), and 20% were slightly saline (>2 dS/m). So, a total of 74% of irrigated land suffered from some degree of elevated salinity (UNEP 2003). Historical surveys show that soil salinity has been extensive across the Mesopotamian plain for a long time.

2.2 Regional-Scale Soil Salinity Survey, 2011–12

The present project has undertaken a soil salinity survey relying for a large part on remote sensing data. This is because an extensive soil salinity survey is time consuming and currently difficult due to accessibility issues in parts of the Mesopotamian plain. Remote sensing methods also have the advantage that large areas can be surveyed with a standard methodology. However, remote sensing methods cannot directly measure soil salinity in the root zone. Hence, root-zone salinity needs to be estimated based on secondary indicators.

Crop growth and crop vigor are indicators of soil salinity. Crop vigor and intensity can be deduced from the normalized difference vegetation index (NDVI) obtained from satellite images. Assuming that soil physical properties do not vary much over time but that soil salinity can change quickly over time, mapping crop vigor and crop intensity over time can be used to identify areas that, at some time during the survey, were able to grow high intensity crops.

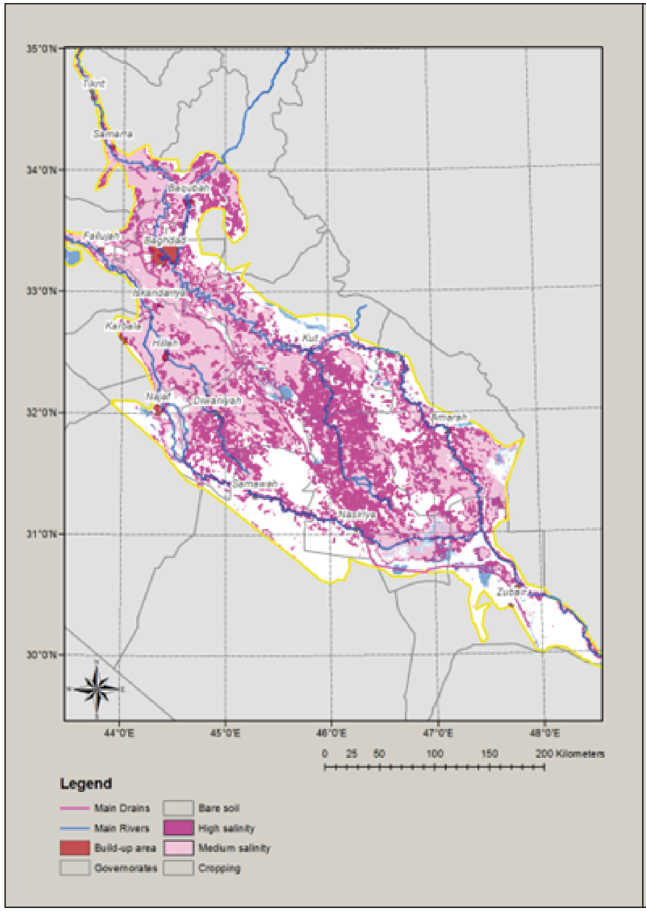

Figure 7. Areas of possibly saline land based only on NDVI data.

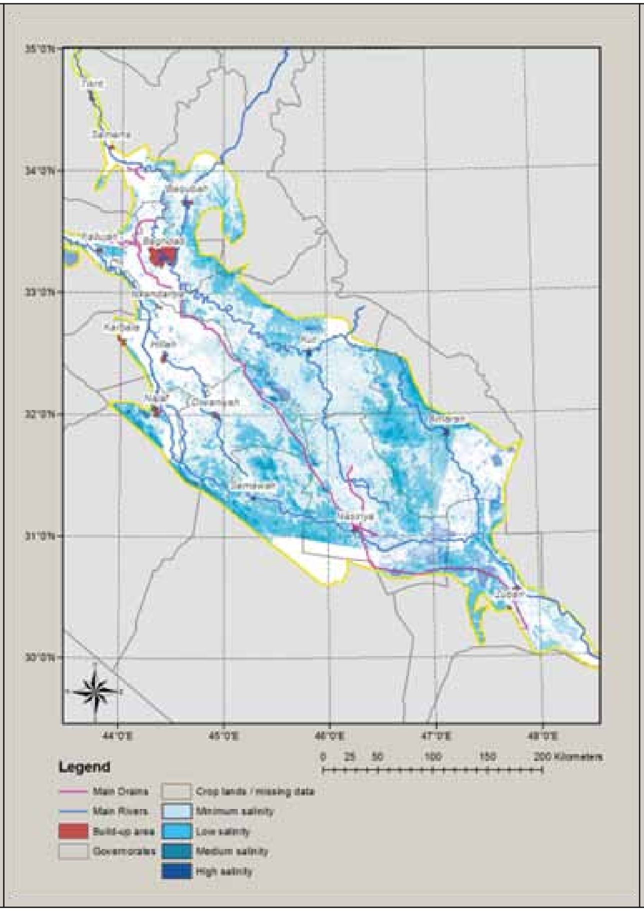

Figure 8. Areas of possibly saline land based only on bare soil reflectance data.

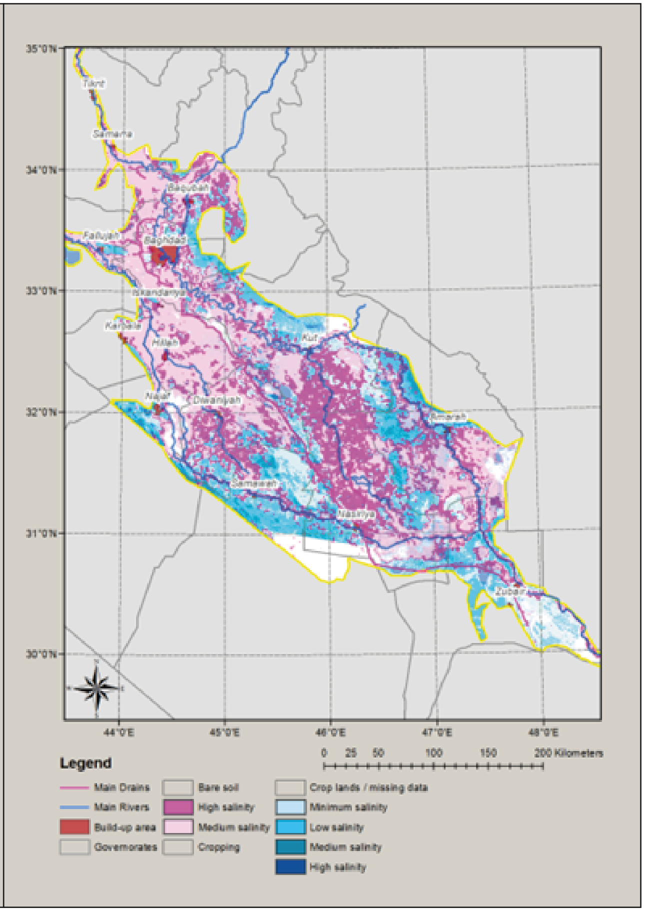

Figure 9. Combined analysis of possibly saline land using NDVI and bare soil reflectance data.

Salinity generally appears to increase towards the south of the Mesopotamian plain. Field validation of these indicative surveys is continuing. The additional data will enable an indication of soil salinity values, instead of relative spatial patterns in the plain.

This broad-scale assessment shows that almost all of the Mesopotamian plain is affected by salinity. This is in agreement with UNEP (2003), which reported that 74% of irrigated land in Iraq suffered from some degree of elevated salinity.

2.3 Field-Scale Studies, 2011–12

To complement the regional-scale surveys, the project carried out field-scale studies in the Mussaiab (83,500 ha) and Dujailah (99,000 ha) irrigation project areas. All soils in the Mussaiab and Dujailah project areas originate from Holocene alluvial deposits.

The Mussaiab Irrigation Project area is severely affected by salinity and the Dujailah Irrigation Project area is the largest and oldest settlement project in Iraq, started in 1946. Much reclamation work (installation of surface and subsurface drains) was undertaken in Dujaila, but the reclamation of soils ceased in 1983. The Dujaila Irrigation Project is divided into three areas: “Non-reclaimed” (no drainage), “Semi-reclaimed” (surface drains), and “Reclaimed” (both surface and subsurface drains).

Soil samples from three locations at Mussaiab all showed slight (2–4 dS/m) to moderate (4–8 dS/m) levels of salinity between the soil surface and 90 cm, while samples taken in three locations in Dujaila ranged between highly saline (8–16 dS/m) and extremely saline (greater than 32 dS/m) (Figure 10). At Dujaila, “semi-reclaimed” soils were the most saline. The change in soil salinity with depth is mostly determined by the agricultural use of the land. In fallow or abandoned land soil salinity increases exponentially near the surface (Jabbar and Muhaimeed, 2001).

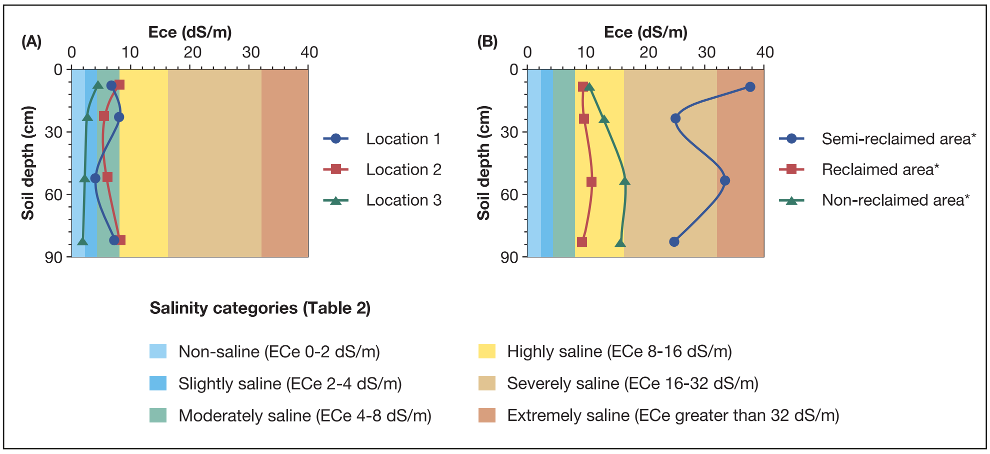

Figure 10. Soil salinity profiles between the soil surface and 90 cm depth at: (A) Mussaiab and (B) Dujailah, May 2011.

The soils in Mussaiab project are silty clay loams with high levels of soil salinity. Their pH is only slightly alkaline (pH 7.51–7.96), due to the salts in solution being calcium based. The soils in Dujailah are clay to silty clay loam and pH ranges from 7.68 to 7.85. Soil salinity persists even in areas that are termed “reclaimed” or “semi-reclaimed”.

Salinity of topsoil (0–30 cm) samples, where salts accumulate most strongly due to evaporation, taken at random from fields across the Mussaiab Irrigation Project between July and October 2011 ranged from 0.7 to 74.8 dS/m (Figure 11). In terms of salinity classes this is from non-saline to extremely saline. However, overall only 20% of sites were non-saline, and 27% of soils were highly saline, with the bulk of sites in the slightly and moderately saline categories.

This broad-scale assessment shows that almost all of the Mesopotamian plain is affected by salinity. This is in agreement with UNEP (2003), which reported that 74% of irrigated land in Iraq suffered from some degree of elevated salinity.

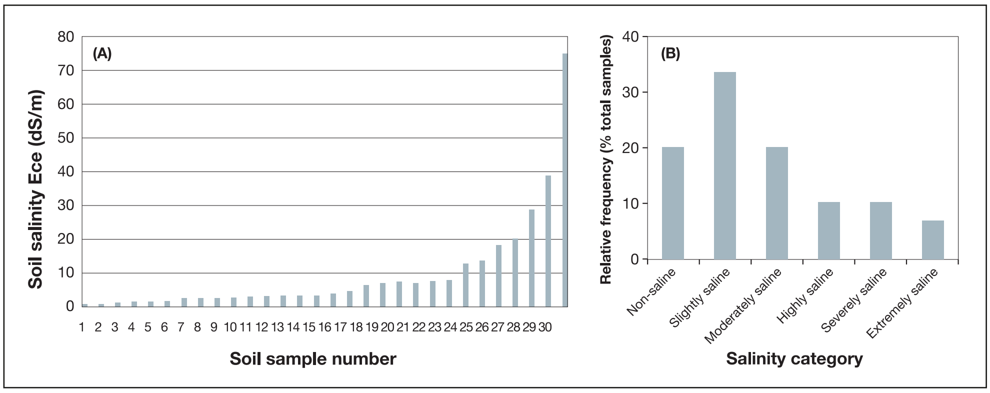

Figure 11. Variation in salinity of soil samples taken across the Mussaiab Irrigation Project area, July–October 2011: (A) Range of values; (B) Frequency distribution of topsoil samples across different soil categories.

The range of salinities shown in Figure 11 and from historic data across the Mesopotamian plain suggests that local conditions and management practices strongly affect soil salinity. For example, land that is left fallow tends to accumulate large amounts of salt due to the shallow water table and the silty clay texture of the soil. However, on the positive side, the soil can be relatively easily reclaimed because it is well-structured with a salt mix containing high levels of calcium relative to sodium (Buringh, 1960; Delver, 1962; Al-Nakshabandi et al., 1971; Kasim Saliem 1982). If the salts were sodium based as in many parts of the world, the soils would be dispersive (structurally unstable) and soil leaching would be far more difficult.

Shallow water tables contribute to soil salinization by preventing adequate leaching from occurring and allowing capillary up-flow of saline water to the surface. As the saline water evaporates the salts are left in the topsoil. Shallow water tables are widespread across the Mesopotamian plain (Figure 3). Our monitoring at Dujailah and Mussaiab shows that the water table is generally shallow (1–2 m) and responds to irrigation (Figure 12).

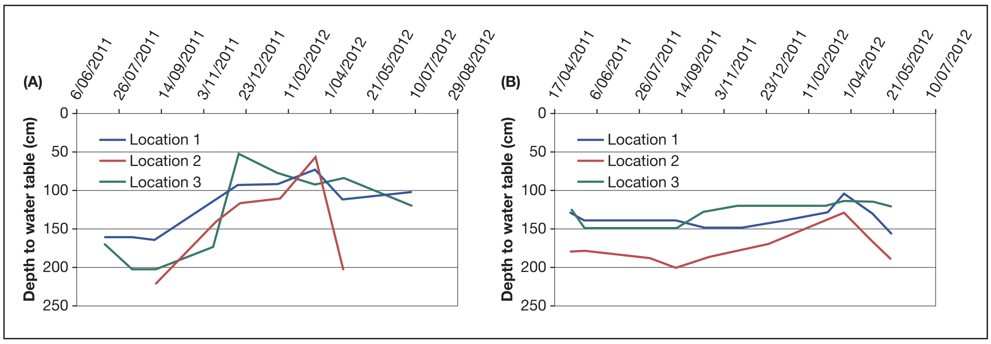

Figure 12. Changes in the water table in the Mussaiab (A) and Dujailah (B) irrigation project areas in response to irrigation, November 2011 to Aril 2012.

The three locations monitored in Dujailah had average groundwater salinities (ECw) of 8.9, 9.4, and 36.6 dS/m, respectively, while the three locations in the Mussaiab area has average ECw of 5.0, 7.6, 4.0 dS/m, respectively. At these salinities, groundwater has the potential to contribute a large amount of salt to the topsoil by capillary up-flow and evapoconcentration.

The conditions described above are typical of much of the Mesopotamian plain. Water tables will have to be managed if the soil is to be reclaimed and maintained at a low salinity. This can be achieved by improved irrigation practices that reduce the amount of water that goes to the water table together with the installation or refurbishment of surface and subsurface drainage systems.

Shallow water tables also lead to waterlogging. Waterlogging reduces the amount of oxygen in the soil, which reduces plant growth and the ability of plants to tolerate salt. Waterlogging can be assessed by measuring the depth to the water table. For example, the water table at the three sites in Mussaiab (Figure 12A) was within 1 m of the soil surface during the irrigation season and thus will affect plant roots and crop growth.

3 Surface Water Salinity in the Mesopotamian Plain

The field data show that soil salinity is widespread and this is due to shallow water tables and highly saline groundwater. However, leaching of salts can be readily achieved if water tables are controlled.

Knowledge of the salinity of surface water is critical to understanding likely future salinization of irrigated areas in south-central Iraq. The following discussion focuses on evidence of declines in surface-water flow (where this might lead to increase in salinity) and direct evidence of historical trends in surface-water salinity as measured at the numerous gauging points throughout the plain. Surface-water salinity is also assessed in terms of the spatial distribution of salinity along the river system, as a guide to understanding salinization processes and to provide guidance for where effort might be invested to reduce salinity in the system.

3.1 Changes to the Hydrology of Iraq

The Tigris–Euphrates river system lies across four countries and has been subject to increasing levels of development. Construction of dams started in 1973 and is continuing. Cumulative storage capacity in Turkey, Syria, and Iraq totals 2.5 times the mean annual flow.

A number of studies of the changes in the river system have been undertaken by international groups and are reported in the general literature. Two studies have been used here to characterize the change in flow and its correlation with development levels.

The first study is that undertaken by the US Army Corps of Engineers (USACE). The data presented here are from various presentations sourced from the internet, and no report compiling results has been seen. The data presented below highlight differences in flow before and after 1974.

The average flow of the Euphrates at the border between Syria and Iraq was about 28 billion m3 between 1932 and 1974 and about 22 billion m3 between 1975 and 2003 (Figure 13). The Euphrates has historically made up 37% of the flow volume in the Tigris–Euphrates river system (about 30 billion m3 in a total of 80billion m3).

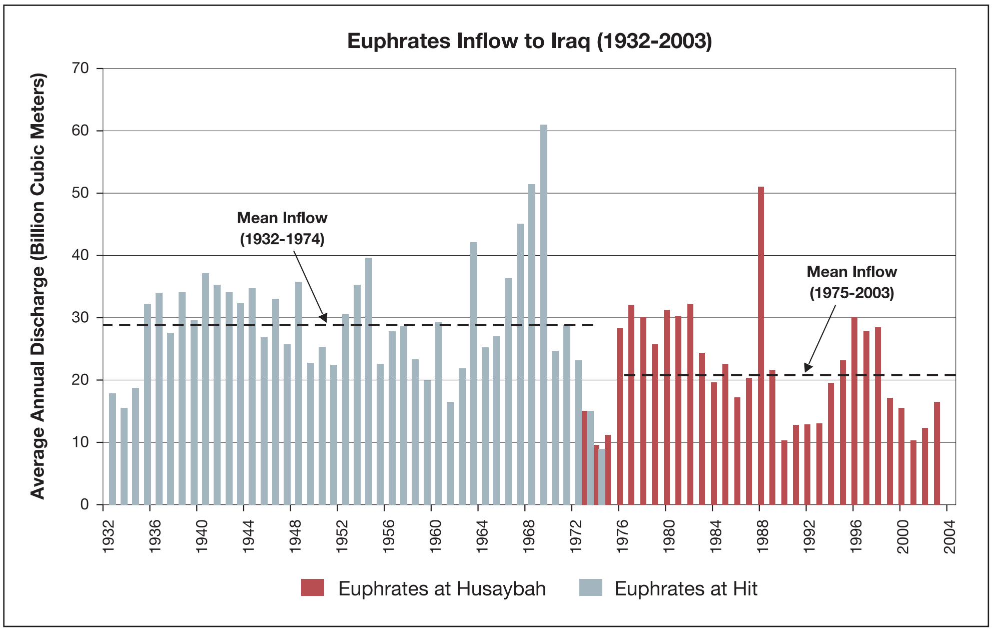

Figure 13. Average annual flow rates for the Euphrates at the Syrian/Iraqi border, 1932–2003 (billion cubic meters).

In a study of the effects of engineering projects on the function of the lower river marshes, Jones et al. (2008) modeled changes in flow volume at the downstream end of the Tigris–Euphrates system (that is, at about Basra, rather than at the border as assessed in the USACE study quoted above) between 1965 and 1998 (Figure 14).

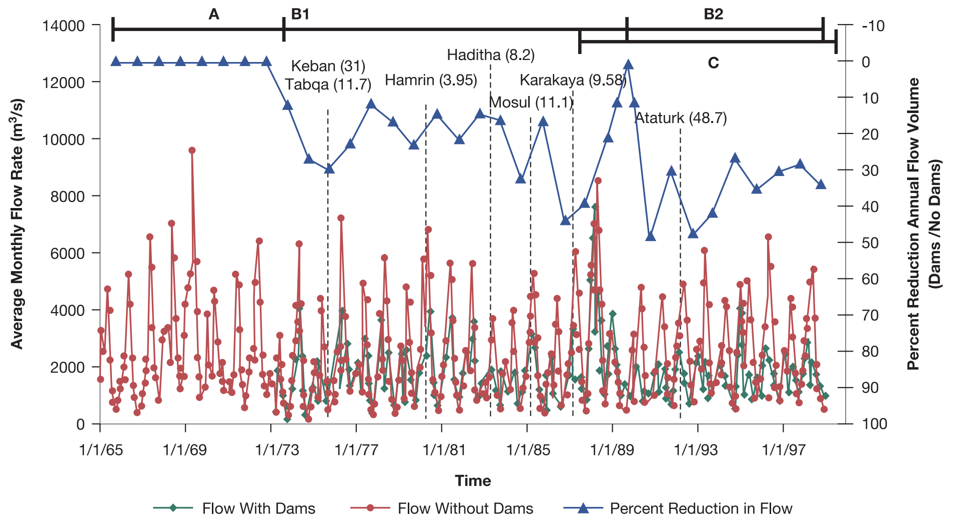

Figure 14. Simulated monthly flow rates of the Tigris–Euphrates system from 1965 to 1998 (black curve) are compared with flow rates that would have existed if no dams had been constructed (pink curve), showing the decline in annual flow volume since 1973 (blue curve).
Source: Jones et al. (2008).

Flows of the Tigris–Euphrates system have fallen since 1973 as a result of construction of dams in Turkey, Syria, and Iraq. Modeling suggests that flows are currently ~70% of pre-1973 volumes.

Three major time periods are represented on the figure. Time period A (1965–1973) covers the time before any major dams had been constructed. Time period B1 (1973–1989) covers the period during which the Keban (Turkey), Tabqa (Syria), Hamrin, Haditha, Mosul (Iraq), and Karakaya (Turkey) dams were constructed. Time B2 (1989–1998) covers the period during which the Ataturk dam (Turkey) was completed. The pink (flow without dams) and black (flow with dams) curves overlap in period A, the time period during which there were no major dams on the rivers, but progressively diverge in periods B1 and B2 as more dams were constructed.

The flow depletion percentage includes diversions for irrigation. The analysis predicted a maximum reduction in flow of about 45% and then would stabilize at about a reduction of 30% of pre-1973 flow volumes by 2000. The reductions in flow were greatest following the building of each dam as the reservoir formed filled, with flows returning to higher levels once the reservoirs are filled. Given that salinity of river water is expected to increase as flow decreases, these results suggest that the salinity of the water of the Tigris–Euphrates system will have been increasing since 1973.

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3.2 Changes in Salinity

3.2.1 Longitudinal Profiles of River Salinity

There is limited data to speak of the salinity status of the Tigris-Euphrates system before 1973. Rahi and Todd (2009) reported that the salinity of the Euphrates at the Syrian border doubled from 1973 to an unspecified date after 1980 (Figure 15), and more than trebled at Nassariyah, towards the end of the system[1]. The authors postulated several processes that might have caused this, with the most likely assumed to be increased return flows from irrigation as a proportion of total flow in the river. This could be brought about by either a reduction in river flow resulting in less dilution of a constant irrigation return, or by an increase in salinity in the drainage water. The authors also postulated that groundwater intrusion could also be an important factor. The correct explanation is probably a combination of all of these.

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[1] 1000 ppm is approximately equal to 1.43 dS/m

The process of salinization has continued since the 1980s, particularly downstream from Al Kufa, as indicated by Figure 16, with salinity at Al Nassariah rising from over 3000 ppm total dissolved salts (TDS) in the 1980s to over 5000 ppm in 2002 (Rahi and Halihan, 2009).

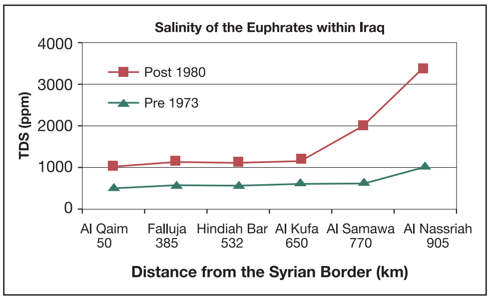

Figure 15. Change of water salinity in the Euphrates within Iraq between 1973 and post-1980. (640ppm ~ 1 dS/m)
Source: Rahi and Todd (2009).

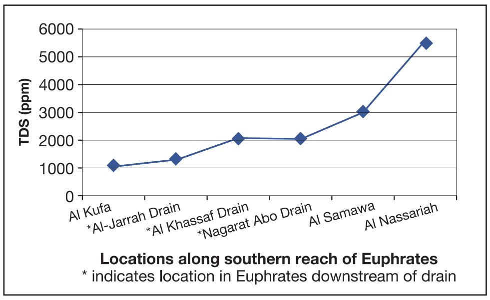

Figure 16. TDS in Euphrates River in 2002.
Source: Rahi and Halihan (2009).

Data collected by the current project between April 2007 and October 2009 show the same trend of salinity increasing towards the lower reaches of the Euphrates (Figure 17), as depicted by Rahi and Halihan (2009). However, even though the trend is almost identical proportionately, the absolute salinity we found is lower than that published by Rahi and Halihan (2009).

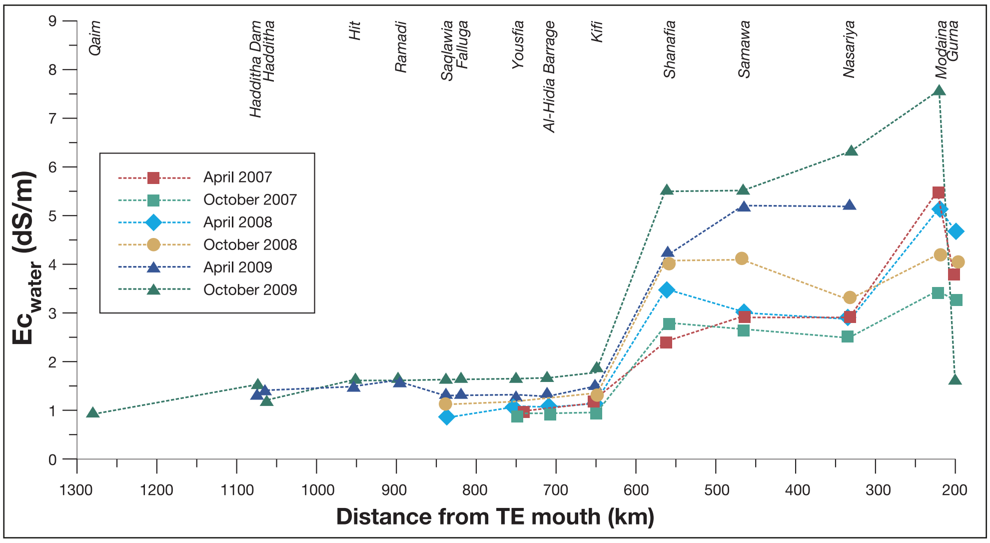

Figure 17. Salinity of water in the Euphrates from Qaim (near the Syrian border) to Modaina Guma (near where it joins the Gulf), April 2007–October 2009.
Source: Ministry of Agriculture and Ministry of Water Resources data.

Salinity increases dramatically between the Kfil and Shanafia gauging stations. The data also show the marked influence of wet years (and higher river flows): April 2007 was wet, whereas October 2009 was dry. This is especially apparent downstream of Kfil. This indicates the importance of dilution flows in controlling river salinity in the lower reaches of the river.

A similar trend is seen for the Tigris River between 1979 and 2010, with salinity increasing from the Turkish border to the river's confluence with the Euphrates (Figure 18). The point on the river where the trend changes is near Baghdad, (marked as Mouthana and Shuhada bridges on Figure 18), is at about the point where the Diyala River joins.

It is assumed that similar processes to those identified for the Euphrates are operating also on the Tigris, which is a combination of lack of dilution, increased return flows from drains, and ingress of more saline groundwater due to abstraction for irrigation.

Salinity increases towards the mouth of the Tigris and Euphrates rivers and there are key points along the length of the rivers where water salinity increases. Understanding and tackling these salinity increases can have major benefits to downstream water users.

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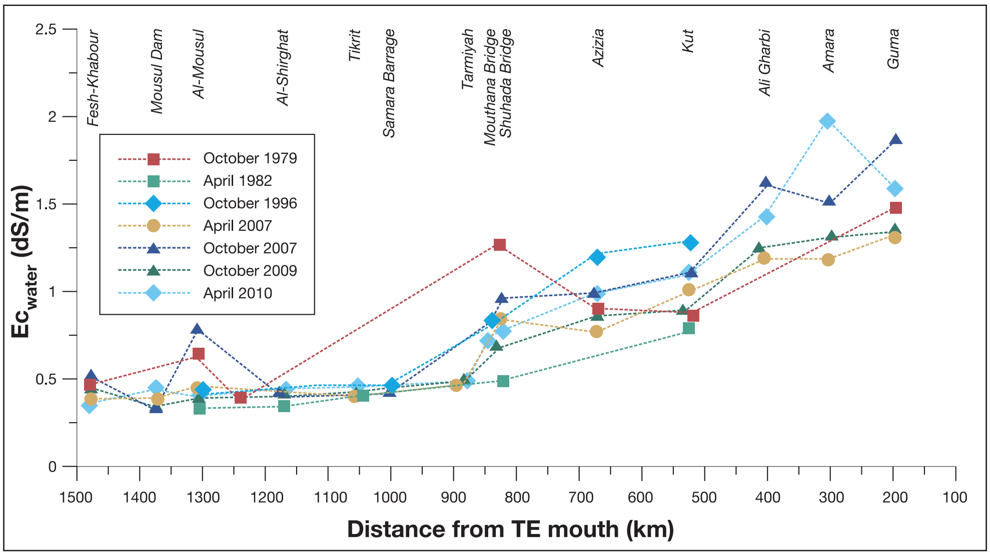

Figure 18. Salinity of water in the Tigris from the Turkish border to its confluence with the Euphrates, 1979–2010.
Source: Ministry of Agriculture and Ministry of Water Resources data.

3.2.2 Time Series Trends in River Salinity

Time series data of salinity of water in the Tigris show some variation in salinity, which is assumed to be related to flow volume: higher flows equate to lower salinity (Figures 19, 20, and 21). The dynamic variability increases substantially as one progresses downstream from Mosul to Gurna Tigris, indicating a complex combination of controlling processes. Interestingly, the data for Al Mosul, which is situated above any irrigation development in Iraq, does not show any long-term increase in salinity.

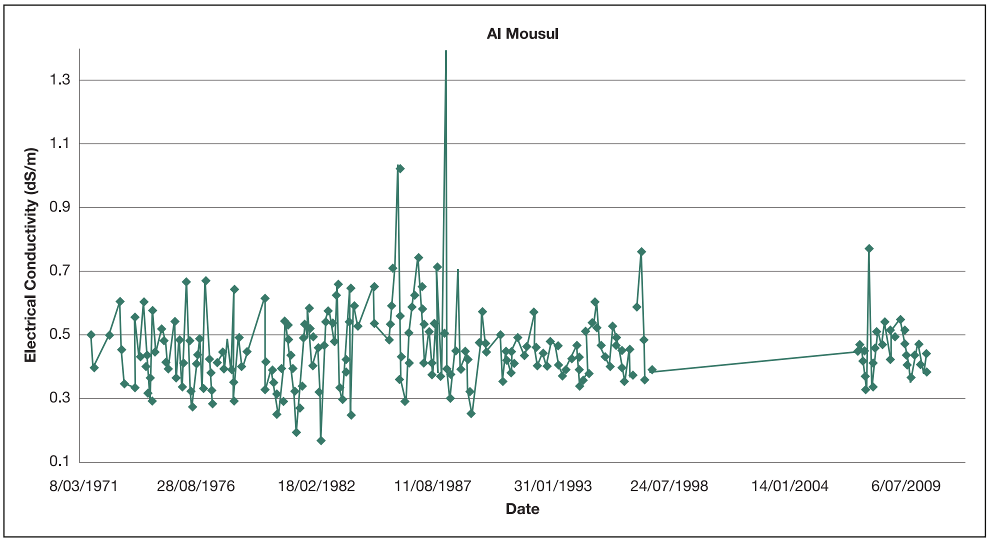

Figure 19. Salinity of water in the Tigris at Al Mosul, 1971–2009.
Source: Ministry of Agriculture and Ministry of Water Resources data.

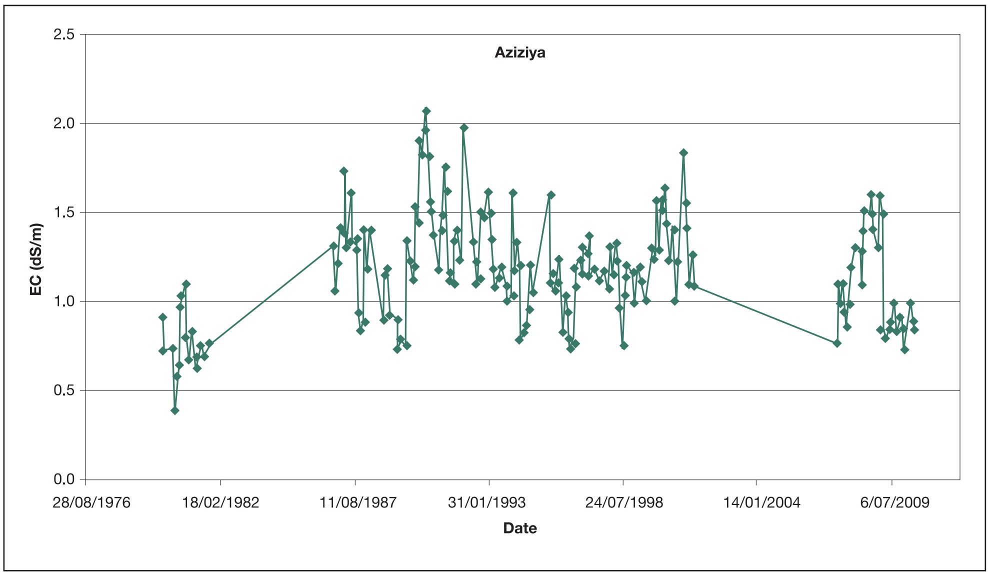

Figure 20. Salinity of water in the Tigris at Aziziya, 1980–2009.
Source: Ministry of Agriculture and Ministry of Water Resources data.

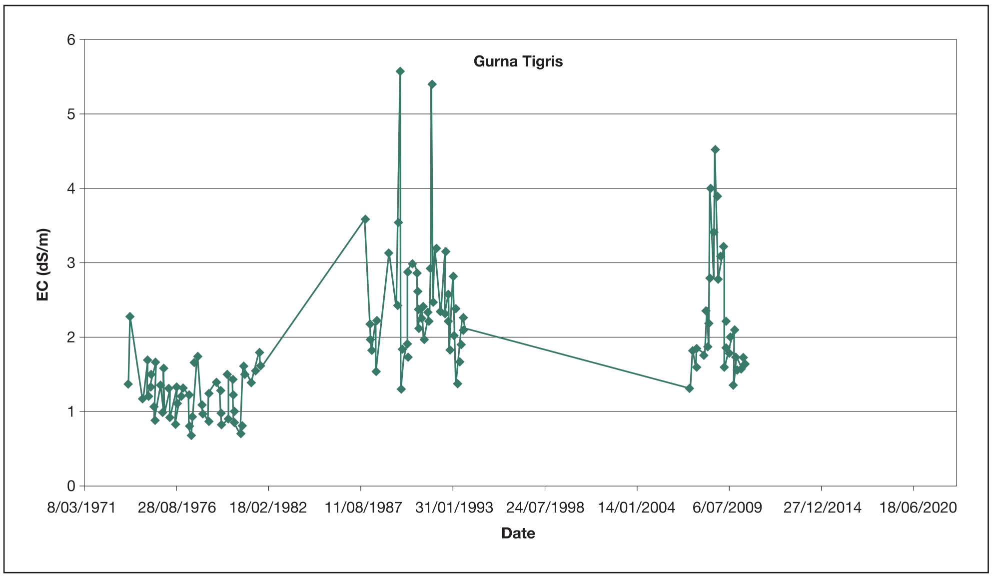

Figure 21. Salinity of water in the Tigris at Gurna, 1973–2009.
Source: Ministry of Agriculture and Ministry of Water Resources data.

Time series data for the Euphrates River have been more difficult to obtain[2]. Figure 22 shows data for TDS and flow volume at Haditha Dam, relatively close to the Syrian border and upstream of most irrigation development in Iraq. The data show a large dynamic range in salinity that correlates well with flow volume, as would be expected, but no trend in increasing salinity over time on average.

Salinity in the Euphrates below the Ramadi dam is also influenced by the transfer of water from the Tigris via Lake Tharthar, a large off-stream reservoir. The operation of Lake Tharthar is complex and difficult to establish, but appears to have a major impact on salinity concentrations.

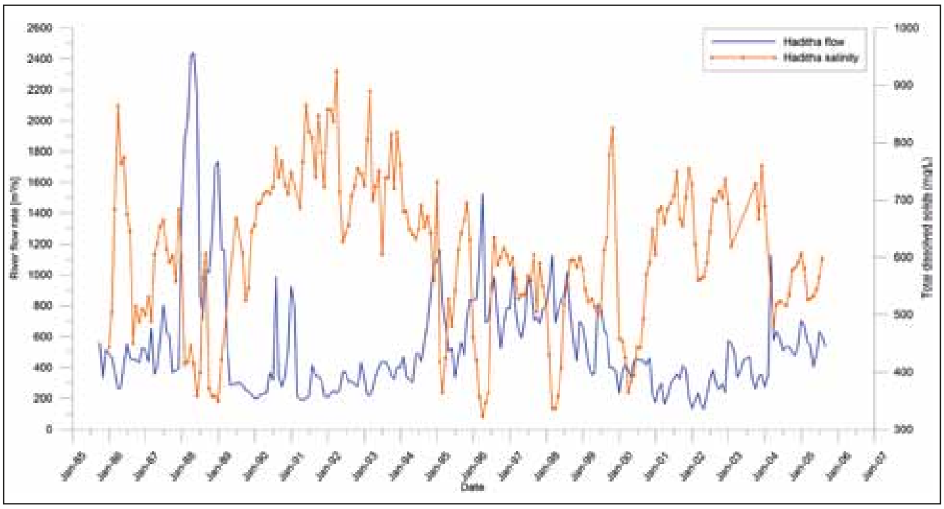

Figure 22. Salinity and flow rate of the Euphrates below Haditha Dam, 1982–2009.
Source: Ministry of Agriculture and Ministry of Water Resources.

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[2] Data for the Euphrates have been recently obtained and are being processed for inclusion in a later report.

4 Irrigation and Drainage Infrastructure

Based on the data available, the salinity of water in the Tigris and Euphrates does not appear to be increasing where the rivers enter Iraq. However, salinity in the river system will be influenced by changes in flow volume during the Euphrates much higher than in the Tigris in the lower parts of the river system.

4.1 Introduction

We reviewed the current state of irrigation and drainage infrastructure at the Great Mussaiab Irrigation Project (Babil Governorate) and Dujailah Irrigation Project (Wasit Governorate) to assess the factors influencing irrigation delivery, irrigation management, and disposal of drainage effluent. This was undertaken with a view to highlighting the key deficiencies in the system that contributes to soil salinization and low land and water productivity.

The Great Mussaiab and Dujailah Projects are typical of the pilot land-reclamation irrigation projects that were constructed during the second half of the 20th century. They exemplify the many irrigation and drainage projects that were implemented earlier and now suffer from deterioration.

The Mussaiab Irrigation Project was constructed between 1952 and 1956, and redeveloped between 1965 and 1980. The Project covers 86,195 ha with a net irrigated area of 66,750 ha. The area is supplied with water from the Euphrates through a 49.5 km canal with designed discharge of 40 m3/s. The irrigation network consists of 13 branch canals (total length of 95.1 km) from the main canal, and 82 distributary canals. All canals of the project are unlined and the whole irrigation project is designed to work by gravity alone. The drainage network consists of open field drains, which flow into collector drains, which in turn flow into branch and secondary drains connected to the main drains of the project, which flow to three pumping stations.

The Dujailah Irrigation Project was built in 1954, with some improvements implemented in the late 1970s to early 1980s. The Project covers 99,000 ha, and is supplied with water from the Tigris through a 57 km canal with a designed discharge of 40 m3/s. The Dujailah project differs from the Mussaiab project in that attempts were made at Dujailah in the 1980s to reclaim land from waterlogging and salinity by constructing drainage infrastructure. The Project is now divided into three areas:

- "Unreclaimed" areas, with no drainage.
- "Semi-reclaimed" areas. This area, covering 14,000ha, has unlined irrigation canals and a network of surface drains but no field drains.
- "Reclaimed" areas. Covering 19,000 ha, these have both surface and subsurface drains, with a full network of branch, collector, and field drains, concrete-lined main and branch irrigation canals, and subsurface asbestos pipes feeding the farms.

The condition of the infrastructure at the two irrigation projects was assessed at two levels. A high-level assessment comprised evaluation of head regulators, cross regulators on the main and branch canals, and the status of main, branch, and distributor canals, and assessment of the status of the drainage system, including main, branch, and secondary drains as well as pumping stations. A more in-depth assessment evaluated the feeder canals and farm intakes in addition to evaluating the field and collector drains. Irrigation and drainage water were sampled at various locations within the projects. The following sections present a very brief summary of some of the data collected.

4.2 Evaluation of Irrigation and Drainage Infrastructure at Mussaiab and Dujailah

The irrigation system at both projects works by rotation and is controlled through the regulators. These regulators control the water levels and volumes flowing through the canals. These regulators require urgent maintenance. We estimate that the functionality of regulatory structures at Dujailah is only 30–80% (Table 4) and at Mussaiab is only 40–70% (Table 5).

Table 4. Evaluation of cross and head regulators at Dujailah Irrigation Project, 2011.

Regulator type	Location	No.	Estimated functionality	Remarks
Main head	Tigris river	1	70%	Maintenance required
Cross	Dujailah main canal	5	50–60%	Maintenance and rehabilitation required
Head	Unreclaimed areas	6	60–80%	Maintenance and rehabilitation required
Head	Semi-reclaimed areas	5	30–70%	Maintenance and rehabilitation required
Head	Reclaimed areas	5	50–70%	Maintenance and rehabilitation required

Source: Project survey 2011.

Table 5. Evaluation of cross and head regulators at Mussaiab Irrigation Project.

Structure type	Function	Estimated functionality	Remarks
Mussaiab canal head regulator	Control water flow to main canal	70%	Under annual maintenance: works well
Main canal cross regulators (3)	Control water levels within the main canal	65%	Under annual maintenance: works well
Branch canal head regulators	Control water flow to the branch canals	65%	Under annual maintenance: works well
Distributor canal head regulators	Control water flow to the distributaries	40%	Poorly maintained Water level low
Branch canal cross regulators	Control water levels in the branch canals	50%	Modified because of the low water levels upstream

Source: Project survey 2011.

There are many problems with the regulators. For example, many of them were designed to operate with an electromechanical computerized system, but the computerized regulators have been destroyed and the computers and other components of the electrical control system have been removed, along with many other parts of the system (Figure 23). As a result, the regulators are currently being controlled using a simple electric system. Also, regulator gates for feeder canals and farm intakes are mostly broken or lost, and the concrete lining in many parts of the lined canals is damaged or has collapsed and the expansion joints are leaking, causing seepage and water losses.

Figure 23. Remains of a control system for a main regulator at the Dujailah Irrigation Project.

The unlined canals in Mussaiab and Dujailah require continuous maintenance because of weed growth in the canal and sedimentation. As a result of continuous cleaning using hydraulic excavators, the canals have become much wider and deeper than their designed dimensions. As a result the water in the canals is shallower than intended. Weirs, farm intakes and tail escapes no longer function as planned or have been demolished by farmers in their efforts to obtain water as shown in Table 6; Figure 24 for Mussaiab Irrigation Project.

Table 6. Status of weirs, farm intakes, tail escapes, and bridges at Mussaiab, 2011.

Structure type	Function	Estimated functionality	Remarks
Weirs	Provide irrigation water to the farm intakes upstream	0%	Useless because of low water levels resulting from bad maintenance
Farm intakes	Divert water to the farm units	0%	Demolished by farmers because of low water levels in canals. Replaced by low-level pipes
Tail escapes	Return irrigation water to the drains	0%	Demolished because of the deepening of canal and the low water levels
Bridges	Crossings for vehicles and people	50%	Need maintenance

Source: Project survey, 2011.

Figure 24. A main canal in the Mussaiab Irrigation Project showing loss of canal shape and poor condition of regulator.

Figure 25. Irrigation pump installed by a farmer on an irrigation canal to combat low water levels in the canal.

Since the water levels in the canals are below design level, the water levels at the farm intakes and weirs have fallen, which has forced farmers to install pumps on the canals to be able to obtain water (Figure 25).

Few of the canals in Dujailah are operating to design specifications as shown in Table 7.

Table 7. Evaluation of Dujailah Irrigation Project main canal Branches source project survey 2011.

Location	No. of canals	Canal type	Total length (km)	Conveyance efficiency	Remarks
Unreclaimed area	6	Unlined	72.5	60–80%	Not performing to design specifications
Semi-reclaimed area	5	Unlined	83	50–70%	Not performing to design specifications
Reclaimed area	5	Lined	40.8	80%	Not performing to design specifications
Whole of irrigation project	54	Unlined		50–70%	Less than 400 l/s discharge without head regulators

Source: Project survey, 2011.

The poor state of the irrigation infrastructure and the use of level basin flood irrigation reduce irrigation efficiency. We estimate the total irrigation efficiency of the Mussaiab Irrigation Project at 30%, based on our estimated average conveyance efficiency of 63% multiplied by our estimated average field application efficiency of 48%. This compares with design values of 80% conveyance efficiency and 70% field application efficiency, which gives an overall design irrigation efficiency of 56%. Low irrigation efficiency and high water losses were also found in Dujailah.

The current low efficiency indicates that there is likely to be high water losses to the groundwater which together with the poor condition of the field drainage systems within the irrigation project areas leads to high water tables and increased salinity problems.

The current poor state of infrastructure makes it very difficult for farmers to access water and grows crops. This situation also leads to inefficient use of irrigation water and increased salinity and waterlogging due to high water tables.

Given the low irrigation efficiencies, the drainage network is vital for controlling salinity, as illustrated by the fact that in Dujailah the average salinity of the irrigation water was 1.2 dS/m, and the average salinity of the drainage water was 9.8 dS/m. The drainage system at both irrigation projects uses pumps, which we estimate are operating at efficiencies of 70–80% at Mussaiab and 50–60% at Dujailah. We estimate the average efficiency of the main drains, branch drains, and collector drains at 50–70%, and that of the field drains at about 20%. Main, branch, and collector drains are often over run with weeds (Figure 26). Field drains were mostly blocked because no cleaning had been carried out by farmers. In the semi-reclaimed area, the average efficiency of main drains, branch drains, and collector drains was estimated at 50–60%.

In the semi-reclaimed area, the average efficiency of main drains, branch drains, and collector drains was estimated at 50–60%.

The Dujailah Irrigation Project has three pumping stations. These were operating at 50–60% of design capacity: some pumps were broken; others required maintenance. Over the 5 years prior to our 2011 survey, only 42% of the designed irrigable area had been cropped in Dujailah and only 57% of the irrigable areas have been cropped in Mussaiab. This low cropping intensity is at least partly associated with a decline in drainage infrastructure.

Figure 26. Surface drain in Mussaiab overgrown with weeds.

4.3 Evaluation of Technical and Administrative Performance of Irrigation and Drainage Systems at Mussaiab and Dujailah

In addition to the infrastructure problems, there are other technical and administrative problems relating to irrigation project management and the farmers' practices that contribute to the deterioration of these irrigation projects.

One of the key problems is farmers drawing larger amounts of water than their allocated share by installing unapproved irrigation intakes and water pumps on the irrigation canals (Figures 27 and 28). This results in water scarcity in many parts of the irrigation projects, especially in areas furthest from the head reaches of canals. Other problems include intentional or unintentional damage to the head regulators of distributor canals, irrigating areas outside the planned agricultural areas, and building unauthorized fishes farms.

Figure 27. Unapproved pumping of water from a main canal.

Figure 28. Illegal water-off take from a main canal.

Irrigation project management is inadequately resourced. For example there is a shortage of vehicles for operation/maintenance and removal of illegal structures. The Ministry of Water Resources (MoWR) faces an acute shortage of equipment, finance, and technical staff to carry out maintenance and rehabilitation of irrigation regulators and gates. There is also lack of awareness amongst farmers regarding the importance of efficient use of irrigation water; as a result, they mostly use flood irrigation methods lead to waterlogging and soil salinization. Moreover, farmers lack the technical ability and financial resources to conduct their share of maintenance works. Water users' associations could contribute to maintenance of infrastructure and system management to maintain fair allocation of water, but none have been established.

4.4 Infrastructure Summary

Irrigation infrastructure is in poor condition at both Mussaiab and Dujailah, resulting in low irrigation efficiencies (30% at Mussaiab, 31–38% at Dujailah) and high water losses. Moreover, the absence of a field drainage system within the Mussaiab Irrigation Project means that the water table levels have risen, resulting in salinity problems. Between 2007 and 2011, only 57% of the designed irrigable area at Mussaiab was cropped, probably as a result of the poor irrigation infrastructure and also at least partly because of salinity problems. At Dujailah, only 42% of the designed irrigable area was cropped over the same period, probably as a result of the poor irrigation infrastructure and also at least partly because of the decline in drainage infrastructure.

Responsibilities for management, operation, and maintenance of the irrigation and drainage projects are shared between MoWR and the farmers. However, the Ministry lacks the capacity to enforce implementation of farmer's responsibilities. Consequently, field and collector drains in particular suffer from lack of maintenance.

Key deficiencies in the system include shortage of water, structural shortcomings, planning gaps, and lack of institutional capacity. Irrigation channels are now wider and deeper than when planned, regulatory structures are damaged and out of use, or missing altogether, drainage is inadequate in some areas and many existing drains are blocked. No plans are in place to combat overarching issues such as climate change, land degradation, illegal structures, and enforcement of farmer's responsibilities. The institutions lack the capacity to enforce regulations and penalize offenders. There is a severe scarcity of resources in terms of skilled manpower, equipment, and funds to carry out maintenance and management. Capacity building and farmer's education does not exist at the institutional level.

The irrigation networks are old and in poor condition. Farmers do not comply with the rotational system, irrigate land that should not be irrigated, and establish illegal fish ponds. All these factors lead to serious water allocation problems, causing water scarcity in many parts of the irrigation projects. Meanwhile, areas that do have water suffer from low irrigation efficiencies, resulting waterlogging and soil-salinity problems.

5 Impacts of Salinity in Iraq

The poor state of the irrigation and drainage infrastructure, operations and maintenance, and farmers' irrigation practices all contribute to increasing soil salinization and reducing the productivity of land and water in the project areas.

5.1 Impacts on Agriculture

5.1.1 Regional Analysis of Salinity by Remote Sensing

Rice productivity (t/ha) has declined slightly from the end of the 1960s to 2010s, while maize productivity appears to be constant between the late 1970s to the 2010s. Wheat productivity has increased since the end of the 1970s, while barley yield appears to be declining (Figure 29).

Wheat and barley are the most widely-grown crops in Iraq, and approximately 67% of wheat and barley comes from irrigated production in the Mesopotamian plain. Rice and maize are grown only under irrigation. The large fall in rice and maize yields between 2000 and 2002 (Figure 29) appear to be related with low water availability. The increase of wheat yields appears related to improved agronomic practices, such as use of fertilizer and mechanization.

Both wheat and barley yields and areas fluctuate considerably from year to year. In 2005, the wheat area was nearly double that in any other year from 2000 to 2009 because of good rainfall in that year and poor rainfall in the other years. Area and yield of barley fluctuate less, perhaps because barley requires less water than wheat and is more tolerant of soil salinity. For these reasons, Iraq started to substitute barley for wheat in the 1970s, particularly in southern regions troubled by soil salinity. However, although between 2000 and 2008 the total area under barley grew slightly, by 2009 wheat production was 2–3 times higher in terms of total yield.

Yields of these four cereals in Iraq are only about a quarter of what could be expected from irrigated agriculture on non-saline soils with modern germplasm and management systems and full availability of inputs.

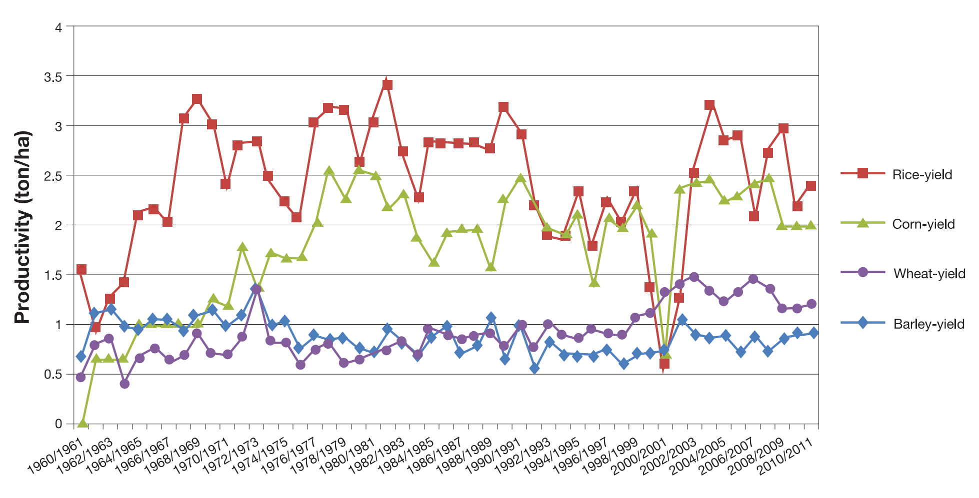

Figure 29. Yields of wheat, barley, rice, and maize in Iraq, 1960/61–2010/11.
Source: FAO statistics.

As the remote sensing analysis for soil salinity indicated (Figures 6A and B), agricultural intensity is generally higher in the northern part of the Mesopotamian plain than in the southern part. Intensity of agriculture in the southern part of the plains in closely related to the health of the southern wetlands.

Annual average NDVI for the Mesopotamian plain varies widely from year to year, and appears to be related to the availability of water (Figure 30). For example, low water availability in 2000 resulted in a dramatic reduction in rice cultivation around Najaf compared with 1999, a year with greater water availability (Figure 31).

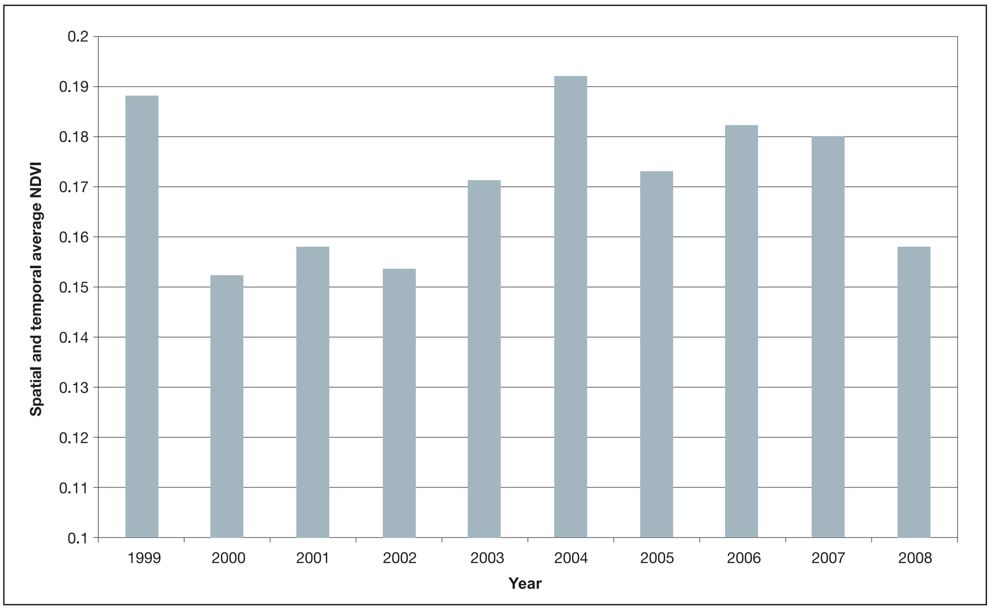

Figure 30. Average NDVI for the Mesopotamian plain, 1999–2008. Source: Project analysis, 2011

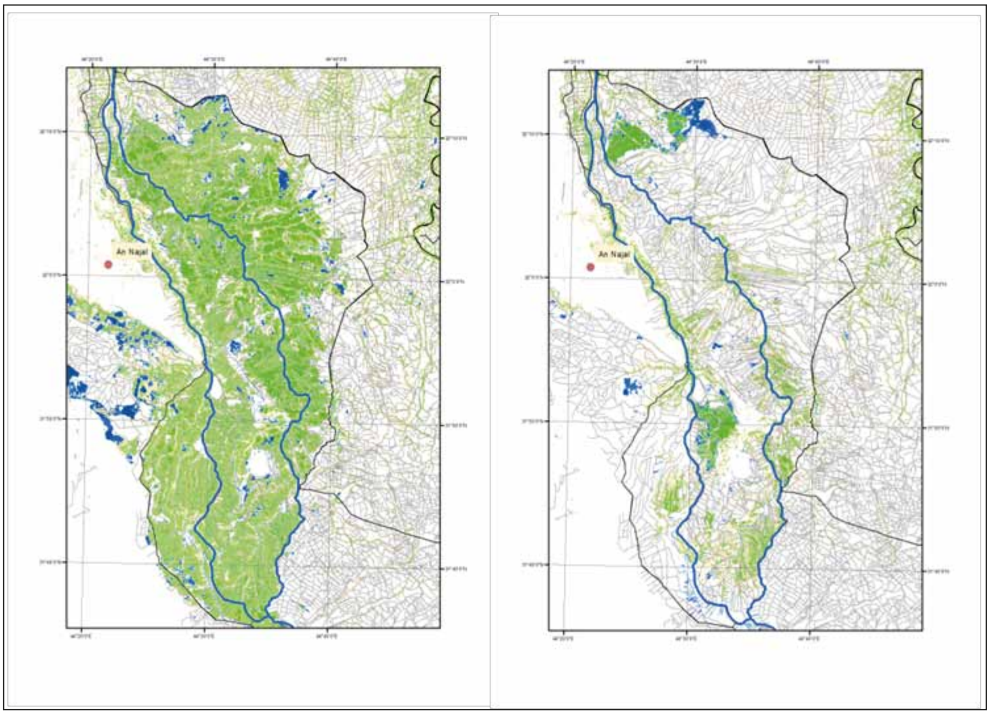

Figure 31. Area planted to rice near Najaf, Iraq, November 1999, in a year of high water availability (left) and September 2000, in a year of low water availability (right).
Source: Project analysis, 2011.

A spatial analysis for summer and winter cropping in irrigation projects shows that during the summer the cultivated area is far less than during the winter. Irrigation water supply remains fairly constant throughout the year, while atmospheric water demand is higher during the summer months. As a result, less land is cropped during the summer (Figure 34), thus maintaining the same volumetric water consumption at the district level as in the winter.

A 10-year time series of NDVI was calculated for the Abu Ghreib Irrigation Project in the northern part of the Mesopotamian plain and for the East and West Gharraf Irrigation Projects in the southern part of the Mesopotamian plain, Figure 32. It is clear that the cultivated area is higher for Abu Ghreib, but there is a declining trend in cultivated area after 2003–2004, while West Gharraf and East Gharraf have much lower cultivated areas than Abu Ghreib, but show an increase in cultivated area after 2003 for both the winter and the summer crop. This increase appeared as a step, but not as a trend. The changes in production do not appear to be related to soil or water salinity, hence must be affected by other external factors.

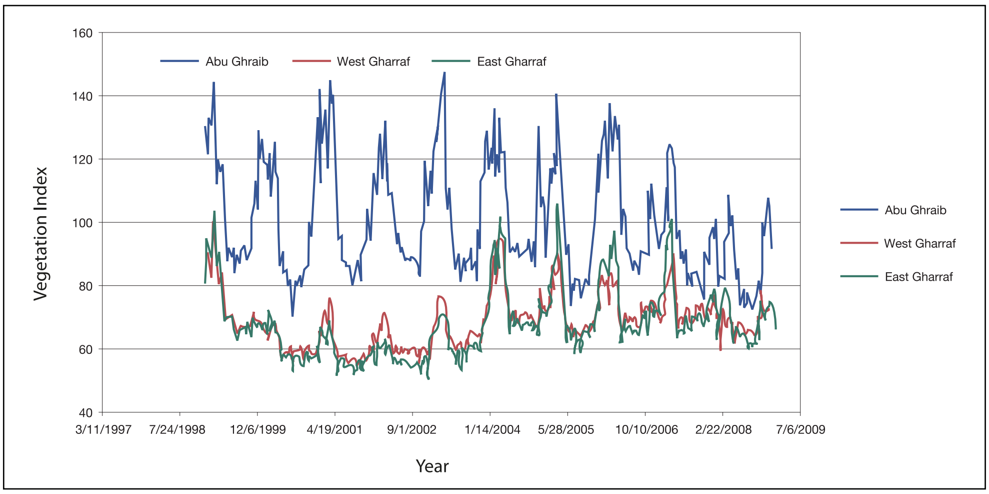

Figure 32. Ten-day-interval vegetation index values for irrigation projects Abu Ghreib (northern Mesopotamian plain) and West Gharaf and East Gharraf (southern Mesopotamian plain), 1999–2008. Source: Project analysis, 2011.

Agricultural productivity in Iraq is low overall and irrigated production at the southern end of the Mesopotamian plain is lower than at the northern end. This is presumably due to both water availability and water salinity.

Spatial and temporal trends in production and the links with water supply, water salinity, and soil salinity thus need to be investigated in more detail.

Agricultural productivity in Iraq is low overall and irrigated production at the southern end of the Mesopotamian plain is lower than at the northern end. This is presumably due to both water availability and water salinity.

5.1.2 Impact of Salinity on Crops and Farming Systems in Iraq

In the three irrigation project areas – Dujailah, Mussaiab, and Abu Al-Khaseeb – socio-economic surveys were undertaken in 2011. Farmers were questioned using semi-structured interviews, and additional data were gathered from various district and governorate government offices.

All three areas suffered from salinity to some extent. Some 54% of farmers in Mussaiab believed that they were affected by salinity, whereas 99% of farmers in Abu Al-Khaseeb and 95% in Dujailah reported that they were affected by salinity (see Table 8). Farmers growing vegetables and other high value crops who were affected by salinity reported yields of only 25–50% of those not affected by salinity. Between 65% and 90% of farmers identified a problem of inadequate water supplies, including reduction of the area they could crop and consequent decreases in their incomes.

Land holdings in the irrigation projects are in the range of 6–70 ha. However, most farmers report that they cultivate an average of only about 30% of their land because of lack of water and high soil salinity. The rest of their land is subject to salt accumulation and salt crusts. The cultivated land ranges in salinity from 11 to 22 dS/m (highly to severely saline), which severely restricts the growth of commonly grown crops and so limits the choice of crops that can be grown. Uncultivated lands are often extremely saline (32–70 dS/m), on which only highly salt tolerant plants (halophytes) can grow.

Yields of wheat, barley, maize, cotton, and sunflower on saline soils in Iraq are commonly 40–65% below those attainable under improved management on non-saline soils (Table 8). The reduction has been attributed to soil salinity, the use of traditional farming methods as a result of inadequate extension services, and the limited availability of fresh irrigation water.

Table 8. Mean yields (t/ha) of wheat, barley, maize, cotton, and sunflower in areas affected by salinity and attainable yields on non-saline soil.

Crops	Yield on saline land* (t/ha)	Attainable yields on non-saline soils† (t/ha)	Approximate yield reduction (%)
Wheat	1.2 –3.0	4–5	55
Barley	1.0 –2.8	3–4	50
Maize	1.0 –2.8	4-6	65
Cotton	2.0 –2.4	4–5	50
Sunflower	1.0–2.0	2–3	40

*Project survey data 2012.

† Ministry of Agriculture estimates of attainable yields on non-saline land under good management.

Farmers in Mussaiab, Dujailah and Abu Al-Khaseeb who are affected by salinity adopt various strategies to maintain their income. All areas are characterized by mixed crop–livestock systems. The proportion of income derived from crop and livestock production varies markedly between the three irrigation projects (Table 9). In Mussaiab, where 54% farmers stated that they were affected by salinity, 67% of income was derived from growing crops, about 30% from livestock, and very little from off-farm activities. In Dujailah, where salinity affects most farmers, cropping accounts for only 52% of on-farm income and livestock production accounts for over 46%. In Abu Al-Khaseeb farmers have responded to salinity problems by relying on off-farm income for 59% of their income.

Table 9. Percentage of total income derived from crops, livestock production, and other on-farm sources and from off-farm activities in Mussaiab, Dujailah, and Abu Al-Khaseeb irrigation projects, Iraq.

Irrigation Projects	Proportion of farmers affected by severe salinity* (%)	On-farm sources of income (% of total income)			Off-farm income (% of total income)
		Crops	Livestock production	Others	
Mussaiab	54	67.0	29.5	1.2	5.5
Dujailah	95	52.2	46.3	1.2	0.3
Abu Al-Khaseeb	99	28.0	12.0	1.0	59.0
Total		51.0	29.0	1.0	19.0

* Farmer self assessment in the survey

Source: project survey of 530 farmers.

Farmers adopted various strategies to minimize costs and risks, such as using only family labor. The farmers report poor support services from extension agents and government, so are reliant on their own knowledge to try to adapt to increasingly saline conditions. One strategy that farmers use is to apply large amounts of fertilizer to try to offset yield reductions (Table 10). We would ordinarily expect such large amounts of fertilizer to be used when target yields are much higher than those actually being achieved, e.g. the fertilizer applied to wheat would be sufficient for an 8 t/ha crop, rather than the 1–3 t/ha being achieved. This investment in high rates of fertilizer application is a highly inefficient approach to overcoming salinity problems and may exacerbate the salinity situation by adding salts to the root zone. It is an example of poor understanding of effective approaches to mitigate salinity effects. The implication is that training and extension services are inadequate to tackle the issue of salinity.

Table 10. Amounts of urea, diammonium phosphate (DAP), nitrogen (N), and phosphorus (P) fertilizers applied to wheat, barley, and maize in Mussaiab and Dujailah project areas, Iraq.

		applied with either	
Crop	**Urea (kg/ha per season)**	**DAP (kg/ha per season)**	**or NP (18:18) (kg/ha per season)**
Wheat	500 divided into 3 applications	240	600
Barley	400 divided into 2 applications	none	400
Maize	500 divided into 3 applications	400	none

Other adaptations reported were to raise livestock for home consumption and sale, and groups of farmers coming together to build plastic houses and raise vegetables.

Although Iraqi farmers may be badly affected by salinity and water shortage they are adapting as best they can, thus indicating a willingness to remain in and invest in agriculture.

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5.1.3 Lessons from the World Literature on Plant Responses to Salinity

We have conducted an extensive review of the world literature on the effects of salinity on the growth of crop plants; see Norman et al (2012). Our review identifies four major impacts of salinity on agricultural production, which are discussed below.

1. Increasing salinity decreases the yield of all crops (Figure 33). However plants differ widely in their tolerance of salinity, as measured by the salt concentration (ECe) at which their yield decreases by 50%. The most salt-sensitive plant shown in Figure 33 had a 50% decrease in yield at an ECe of 2.2 dS/m, while the most salt-tolerant plant had a 50% decrease in yield at an ECe of 28.5 dS/m.

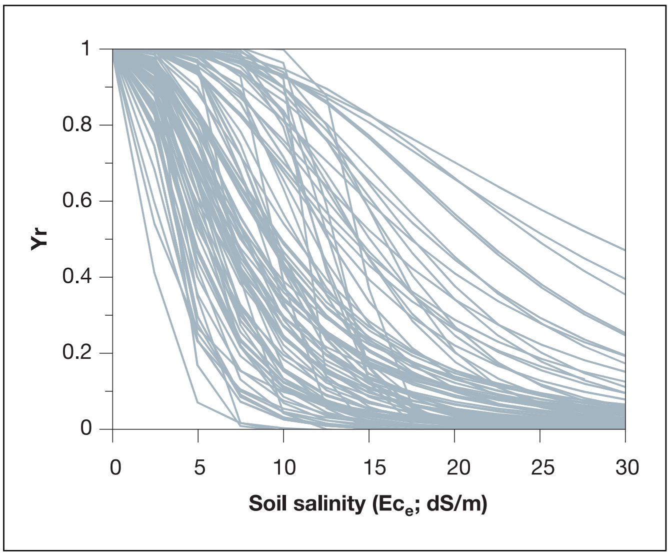

Figure 33. Impact of soil salinity on the relative yield (Yr) of 108 agriculturally significant plants.
Source: After Steppuhn et al. (2005).

2. In general, increasing salinity causes agricultural systems to transition from potentially highly profitable cropping such as horticulture, vegetables, grains, forages, and fibers to lower-value salt-tolerant crops such as barley and halophytes such as salt-tolerant grasses and chenopod shrubs. Additionally, as salinity increases, the feeding value of the available forage often decreases and issues of nutrient imbalances in the diet of animals increase.

3. Many agricultural systems rely on the use of leguminous crops and pastures to fix nitrogen biologically, thereby decreasing reliance on nitrogenous fertilizers, and as a disease break, as grasses may carry over cereal diseases. However, legumes and their associated rhizobia tend to be salt-sensitive. Increasing salinity therefore results in the loss of legumes (and therefore biological nitrogen fixation) from agricultural systems; farming systems that remain in highly salinized landscapes can therefore be expected to be more nitrogen deficient.

4. Many saline soils are also waterlogged. The interaction between salinity and waterlogging causes even more acute effects on plant growth than those described above. Waterlogging causes soils to become oxygen deficient. This is important because roots of crop plants use oxygen to burn sugars to produce energy, and energy is required by plants to exclude salt from their tissues. Waterlogging therefore causes increases in salt concentrations in plant leaves, which decreases plant growth and survival (Barrett-Lennard, 2003).
Salinity and waterlogging can also lead to mineral toxicities, including boron, sulfur, selenium and molybdenum toxicity, and induced mineral deficiencies, including calcium and copper deficiency (Diaz and Gratten, 2009, Norman et al., 2012). These require further investigation as one issue of concern is the potential for reduced performance of animals that graze on forages containing high concentrations of such minerals. There are also opportunities to improve animal health and meat quality; an example would be the provision of vitamin E.

Soil salinity causes cropping systems to move away from high-value crops to lower-value crops. Saline soils also suffer from a number of additional issues, such as waterlogging and mineral toxicity and deficiency.

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5.1.4 Livestock Systems in Iraq

There are an estimated 9.3 million small ruminants (~80% sheep and 20% goats) and 1.88 million cattle and buffalo in Iraq, and livestock production accounts for approximately 24% of the value of agricultural production (FAOSTAT: http://faostat.fao.org/). Cattle and sheep meats are the fourth and fifth most valuable agricultural products (Table 1). Livestock have been part of the ecosystem of the region for millennia and livestock husbandry is an important part of the cultural heritage of the region.

Al-Rawi et al. (1996) estimate that about 90% of small ruminants are managed under traditional systems, including sedentary (45%), transhumant (18%) and nomadic (27%) systems. Approximately 7% are managed in household systems, producing milk for consumption by the household, and the remainders are kept in semi-intensive systems in which animals are fed mixed rations (Al-Rawi et al., 1996).

In the sedentary system, livestock tend to remain in the same area throughout the production cycle. The animals are fed crop residues and purpose-grown irrigated forages (predominantly alfalfa and berseem clover, and may be given various supplements. In addition they may be walked to nearby non-arable roadsides and hills to graze remnant vegetation and weeds. The livestock are often (but not always) owned by farmers who also have irrigated. Flocks in the transhumant system are larger than those in the sedentary system and move between rangeland and irrigated zones. Livestock spend nine months of the year in (or adjacent to) the irrigated areas. If there has been good rainfall they will spend February to April in the rain-fed rangelands. If however there is a drought, the animals remain in the irrigated areas and are subject to confined feeding or the shepherd purchases crop stubbles.

Table 11 summarizes animal lifecycle, feed resources, and nutritional gaps for both the sedentary and the transhumant system in the irrigated zone. For both systems the critical feed gap is in late autumn and winter when ewes are lambing and lactating and nutritional demands are high.

Table 11. Small ruminant animal lifecycle, feed resources, and nutritional gaps in sedentary and transhumant flocks in the irrigated zone, Iraq.

Month	Season	Ewes				Irrigated zone systems	
		Join.	Preg	Lamb.	Lact.	Sedentary	Transhumant
Feb	winter				■	Green forage. Barley cut for feed. Alfalfa	Animals moved to the southern rangelands unless the season is poor then green crops may be purchased. Communal grazing in south
Mar	spring				■		
Apr	spring				■		
May	spring					Early stubbles, remaining green forage	
Jun	summer	■	■			Cereal stubbles (ideal for flushing) but protein deficient. No supplements offered. Some green pick from roadsides	
Jul	summer	■	■				
Aug	summer	■	■				
Sep	autumn		■				
Oct	autumn		■			Hand feeding may start	
Nov	autumn		■	■	■	**Critical feed gap**; full supplementation with wheat bran, barley grain, dates, and straw	
Dec	winter		■	■	■		
Jan	winter			■	■		

Join. is time of joining (mating), Preg. Is when most animals are pregnant, Lamb. Is time of lambing and Lact. is when animals are lactating.

In the traditional nomadic system, the flocks are taken to the desert in autumn or winter, as soon as green grass is available. At other times, when feed or water has been exhausted, the animals are kept on the fringes of towns on wasteland or moved to the mountains. The flocks are managed by the owner, a collective of owners, or paid shepherds (Alkass and Juma, 2005).

New arrangements for linking livestock to feed sources will be essential to cope with increasingly widespread salinity problems. Fodder conservation and seed production methodologies will need to be developed for novel salt-tolerant plants. Fodder trading between regions may increase if logistically feasible

5.1.5 Moving Away from Vegetable and Crop Production Towards More Livestock Production in Highly Saline Areas

Across much of central and southern Iraq, the land is either moderately or highly saline. However, the distribution of salinity is not uniform; certain regions on the Tigris and Euphrates are becoming dominated by highly saline land (Figure 34). We would expect livestock production to become increasingly important in these areas. Highly-saline land is capable of producing high yields of fodder. At Dujailah, for example, with soil ECe values of 12–18 dS/m, with irrigation over the summer we obtained fresh matter yields of up to 15 t/ha of guar, a salt-tolerant forage, 5–10 t/ha of pearl millet, and 8–11 t/ha of sorghum. We expect to demonstrate similar potential with salt-tolerant wheat and barley cultivars. In highly saline areas (such as those indicated in Figure 34), agriculture will become increasingly dominated by the production of forages for the use of livestock; these systems will also be profitable and productive.

Both the sedentary and transhumant livestock systems strongly rely on the seasonal utilization of cereal grains and residues and other forages for feed. Where there is a patchwork of moderately and highly saline land, it would be easy to transfer animals between "cropped" and predominantly "forage-growing" areas. However, new arrangements for livestock management may need to be developed where substantial areas (such as those indicated in Figure 34) grow only forages. These new forages will have lower nutritive value than existing feeds, so livestock producers will need technical assistance in developing feeding systems that meet livestock requirements (Norman et al., 2012). Mineral imbalances and toxicities need to be investigated as salt-tolerant forages tend to accumulate salt and other potentially toxic minerals.

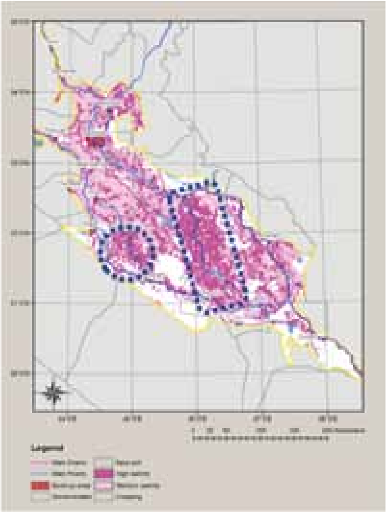

Figure 34. Regions (indicated with dotted lines) where high salinity may lead to the transition of farming systems from cropping to forage production (and therefore livestock production).

In the nomadic system, 27% of animals do not currently rely on forage from irrigated zones, but are fed grain supplements. If cereal crop production is restricted, the increased cost of feeding grain may lead to productivity decline in nomadic systems.

New arrangements for linking livestock to feed sources will be essential to cope with increasingly widespread salinity problems. Fodder conservation and seed production methodologies will need to be developed for novel salt-tolerant plants. Fodder trading between regions may increase if logistically feasible

5.2 Economic Impacts of Salinity on Agriculture

5.2.1 National Effects

Iraqi agriculture has been declining in terms of production and productivity, but is still the second largest contributor to Iraqi gross domestic product (GDP) after oil revenues. It has the potential to play a key role in reducing poverty and unemployment in Iraq if significant and concerted efforts are made towards its rehabilitation.

From 1993 to 2007 the agricultural sector contributed 8–9% of GDP, despite the poor state of irrigation and drainage infrastructure and widespread salinity.

Iraq depends heavily upon imported food to satisfy local demand. The estimated import dependency ratio (IDR) for cereals in 2007 was 56% overall, 62% for wheat, and 87% for rice. Severe droughts in 2008 reduced Iraqi wheat production by 55% and increased dependence on imports to 74% for wheat and 69% for cereals overall.

Imports of foods that could be produced with irrigation in Iraq totaled nearly US$2.2 billion in 2000 and US$2.7 billion in 2009 (Table 12). This does not include all crops or added value products such as poultry and beef meat or dairy products. If Iraqi irrigated agriculture could be revived some of these imports could be replaced by local production, especially fruit and vegetables – high-value, perishable items that have relatively low water requirements. Imports of such products totaled US$342 million in 2009.

Table 12. Value of imported agricultural products that could have been produced under irrigation in Iraq, 2000 and 2009

	Imported value (US$ million)	
Product	**2000**	**2009**
Cereals	1,177	1,541
Rice	305	415
Sugar	116	375
Vegetable oils	229	359
Fruit and vegetables	334	342
Pulses	23	58
Total	2,184	2,715

We estimate that controlling salinity could increase agricultural production by in the order of US$314 million annually, or approximately 24% (Table 13). This is based on production data from 2010 (FAOSTAT: http://faostat.fao.org/), the assumptions that current agricultural production is based on soils with a salinity of 6 dS/m (moderately saline) and that with proper rehabilitation and management of irrigation and drainage schemes and water supply soil salinity could be reduced to 3 dS/m (slightly saline), and the salinity response functions shown in Figure 36.

Table 13. Possible effects of reducing soil salinity on production of some irrigated crops in Iraq.

Product	2010 production		Relative yield with salinity			Production increase	
	Tonnes	US$ millions	Current*	Future†	Change	Tonnes	US$ millions
Tomatoes	1,013,180	374	63%	93%	30%	303,954	112
Dates	566,829	235	94%	99%	5%	28,341	12
Wheat	2,748,840	195	95%	99%	4%	109,954	8
Grapes	212,649	122	54%	87%	33%	70,174	40
Cucumbers and gherkins	432,500	86	50%	91%	41%	177,325	35
Eggplants	387,435	83	66%	91%	25%	96,859	21
Leguminous vegetables‡	140,542	48	55%	88%	33%	46,379	16
Lettuce and chicory	89,795	42	36%	78%	42%	37,714	18
Rice, paddy	155,829	41	39%	95%	56%	87,264	23
String beans	41,300	39	18%	57%	39%	16,107	15
Chilies and peppers	69,120	33	35%	78%	43%	29,722	14
TOTAL	1,299						314

*Based on assumed soil salinities of 6 dS/m (moderately saline).
† Based on assumed soil salinity of 3 dS/m (slightly saline).
‡ Based on the salinity tolerance of broad bean

It is clear that soil salinity and the poor state of irrigation infrastructure are preventing a large proportion of the irrigated areas from being cropped. If reducing soil salinity could double the area cropped in the irrigation project areas from the current 30%, this could increase agricultural production from just these crops to about US$3.2 billion annually.

This analysis is for the limited range of crops for which data were available and is a conservative estimate of the agricultural revenue foregone by Iraq due to soil salinity and disrepair of the irrigation and drainage systems.

5.2.2 Rural Poor

Soil salinity also has major impacts at an individual level. One-third of the Iraqi population resides in rural areas and depends upon agriculture for their livelihoods. This segment of the population suffers disproportionately from poverty and food insecurity: 69% of all Iraqis living in poverty and with food insecurity reside in rural areas (WFP, 2008).

Initial analysis of our surveys of the Mussaiab, Dujailah, and Abu Al-Khaseeb irrigation project areas has shown that the farmers are poor and have little education: around 30% are illiterate and only 15–30% have completed secondary school. Sixty to 90% of the cropland in the irrigation project areas is devoted to wheat and barley, with little vegetable production, showing that the farmers have to undertake lower-value cropping due to the saline conditions.

Even these preliminary results show how salinity is impacting upon farmers' economic potential. Salinity and low water availability keeps them in poverty. Investment in agriculture is the most direct and sustainable path to addressing pervasive problems such as poverty and unemployment and leads to marked improvements in essential spheres of life such as health and education.

As noted in 5.2.1 National effects, agricultural production could be doubled if soil salinity were reduced, which would have an enormous impact on these rural poor to improve their livelihoods. Future activities to mitigate or cope with the effects of salinity have to focus on development, evaluation, and extension of technically and economically efficient farm-level technologies and appropriate regional-scale water and soil-salinity management strategies, policies, and institutions. However, there are gaps in our knowledge of the economic loss due to salinity and how economic factors influence land use change. In particular, there is little existing information on the relative profitability at the farm level of proposed alternative land-use options. The extent of salinity at the regional and district levels is not well documented nor are the farm-, district-, and regional-level impacts of salinity. In addition, there is been no credible assessment of the cost of salinity to Iraqi agriculture, the livelihood patterns of farm families, and the policy environment affecting water- and soil-salinity management.

5.3 Social Impacts of Salinity

As mentioned previously, irrigated agriculture dominates Iraqi agriculture in terms of the value of agricultural production. Agriculture is traditionally the major employer in Iraq but this is changing: the percentage of the labor force employed in agriculture fell from 11.4% in 1996 to 5.2% in 2011 (FAOSTAT: http://faostat.fao.org/). This indicates the difficulty in obtaining a livelihood from agriculture in Iraq.

Most of the people engaged in agriculture live in the irrigated regions of Iraq and as such any environmental effects due to soil and water salinity not only affect their incomes but also affect the very environment in which they live. The degradation of this environment can lead to loss of the ecosystem functions that contribute to quality of life. Problems include human health issues caused by poor-quality drinking water and dust.

The Government of Iraq must create jobs for more than three million people by 2014 to decrease unemployment. The agricultural sector needs to be restored in order to create jobs for unemployed people.

According to the Ministry of Planning and Development (2005), Iraqi living standards were lower in 2004 than the 1970s and 1980s, particularly in terms of water and electricity supply, sanitation, jobs, income, and assets. One-third of Iraqis were found to be living in poverty, and 5% in extreme poverty. The Iraqi household socioeconomic survey in 2007 found that around 23% of the population (almost seven million people) were living below the poverty line and that the rural population was twice as likely to be poor as those in urban areas (COSIT, 2007).

5.4 Environmental Impacts of Salinity

The poor state of irrigation infrastructure and water management has a number of environmental impacts other than salinization of agricultural land.
Many communities in southern Iraq now rely on reverse osmosis desalination units for their drinking water (COSIT, 2010). Some 160 such units have been installed in the Basra and Thi Qar governorates. The increasing salinity of the river water has also led to extensive changes in the flora and fauna of the lower reaches as freshwater marshes turn brackish (MoE, 2010).

The wetlands of the middle and lower basin of the Tigris and Euphrates in Iraq were, until recently, the most extensive wetland ecosystems in the Middle East. In their lower courses, the rivers created a vast network of wetlands – the Mesopotamian marshes – covering up to 20,000 km2. Massive drainage works in southern Iraq in the late 1980s and early 1990s, together with the effects of major upstream damming, caused the loss of 90% of the wetlands, and only minor and fragmented parcels remain today. The wetlands have been transformed into salt-encrusted bare land. The marshlands no longer function as a water filter and the remaining drainage canals carry polluted irrigation drainage and wastewater directly toward the Gulf, with potentially harmful impacts on local fish resources.

The impact on biodiversity has also been catastrophic. Prominent losses include possible extinction of the endemic smooth-coated otter, bandicoot rat, long-fingered bat, and various fish species. Several water birds are critically threatened. One-third of the remnant wetlands surviving in 2000 had disappeared by 2002. Unless urgent action is taken to reverse the trend and rehabilitate the marshlands, the entire wetland system is likely to be lost within three to five years (UNEP, 2003).

5.5 Cultural Impacts of Salinity

The destruction of the Mesopotamian marshes has led to entire communities in this area suffering severe social and economic upheaval, with some 40,000 people forced to flee to southwest Iran and hundreds of thousands internally displaced within Iraq.

During the 1980s and 1990s, 80% of the 17–18 million date palms lining the Shatt al-Arab estuary – once the largest area of date palms in the world and an economically important crop – were destroyed, in part due to increased water salinity in the estuary. The remaining, weakened palms are susceptible to pest infestations (UNEP, 2003).

6 Agricultural and Water Policy

A preliminary analysis of agricultural and water policy in Iraq is presented below. An in-depth assessment of the impacts of these policies on the current salinity situation in Iraq is required and will be done by this study.

Iraq has a complex history of agricultural policies, where the main drivers of policy interventions have been concerns about food security, constraints to agricultural growth, insufficient investment for building facilities and for maintaining agricultural infrastructure, under-investment in agricultural systems, and control of food chains and input markets. Overall, state control of procurement and delivery of both inputs and outputs has been a priority, as shown by the various instruments (subsidies, price controls, distribution monopolies, and others) used by the government.

Subsidization of production costs and commodity prices has been the most popular instrument in the last 50 years. Trade policies have been very limited, as the various governments have concentrated on self-sufficiency in food production. Without having obtained information about how agricultural policies have affected yields, governments have expressed concerns about the inefficient use of water resources in light of population growth. Thus, governments introduced many water and land-reclamation policies aimed at overcoming soil salinization, but no explicit evaluations of how such policies have affected salinization are to be found.

The 1991 and the 2003 wars in Iraq hampered the implementation of agricultural policies. Institutions were disrupted and poor security conditions have undermined the delivery of effective agricultural policies.

The Government of Iraq implemented a number of policies related to water and salinity control in the 1990s and up to 2003. Al-Hakim Abdul Hussein Nuri (2002; 2005a) identified the following issues associated to design and implementation of water policies in the country prior to 2003:

- Lack of large investments to build up new irrigation networks.
- Shortage of funding to maintain existing irrigation networks.
- Lack of incentives to implement widespread use of up-to-date irrigation technologies (e.g., sprinkler, drop, and under-surface irrigation).
- Weak rationalization in the use of groundwater, resulting in overexploitation of groundwater sources and increasing salinization. Traditional methods for well pumping in semi-desert, desert edges, and desert regions have not effectively been used.
- Poor enforcement of existing regulations on river water use, construction of dams for irrigation purposes, generation of electricity, etc.
- Weak in situ training of farmers on use of reservoirs to store surplus water in wet periods for use in periods of water scarcity.
- Weak institutions to enforce exiting water taxation policies. In 1995 the Iraqi government introduced a law (No. 12/1995) to annually tax water use based on land size and type of irrigation systems. The tax did not work properly, and few water revenues have been collected.
- Although good engagement with international cooperation for implementation of irrigation projects has been recorded, there is no evidence that enough projects have successfully been implemented in order to reduce land salinization in the country.

These policies have been jointly implemented by government bodies as well as by stakeholders, namely, the Ministry of Irrigation, responsible for implementing water policies and programs in the field; the Ministry of Agriculture, responsible for field irrigation; and farmer associations, responsible for maintenance of main and secondary water canals.

After the 2003 war, the administrative and political bodies of the new Coalition Provisional Authority governing Iraq experienced substantial changes in structure, duties, accountability, and obligations. Government authority was transferred to the Iraqi Interim Government in June 2004. Following elections in October 2005, the new constitutionally-based government took office in March 2006. Under the new government, the Ministry of Irrigation became the Ministry of Water Resources, which undertook several reviews of past water policies, to analyze the changes needed to control salinity and to improve irrigation schemes throughout the country (Al-Hakim Abdul Hussein Nuri, 2005a). The new government aimed at improving food production through increased productivity in order to be less dependent on international markets, with the objective of achieving self-sufficiency. The following water policy measures were implemented to support this objective (Al-Hakim Abdul Hussein Nuri, 2005b):

- Promoting water-users' associations to significantly reduce or eliminate traditional wasteful water practices, such flood irrigation, so as to reduced water losses, as well as to apply equity criteria in the use of water resources.
- Implementing water extension programs, aiming at better management in water transport and storage. A specific objective has been reducing illegal water flows to the Gulf countries.
- Investing in new pipe networks for improved irrigation and salinity control, aiming at rationalizing water consumption.
- Coordinating water policies with neighboring countries, particularly for the Euphrates and Tigris (Al-Hakim Abdul Hussein Nuri, 2006). The MoWR has been seeking strategic alliances with upstream countries – Iran, Turkey, and Syria – in designing a rational framework to make efficient use of shared water resources. Water policy has been regarded by the government as one element of a package of agricultural and nonagricultural policies that are of common interest to neighboring countries (Al-Hakim Abdul Hussein Nuri, 2006).
- Investing in improved irrigation systems, such sprinkler and drop irrigation, aiming at a more efficient use of water resources.
- Encouraging Iraqi nationals to study abroad on areas related to water management. The new government signed cooperation agreements with Australian, American, and Egyptian universities to grant preferences to Iraqi graduates to pursue advanced studies in agricultural disciplines. Graduates who benefit from these arrangements are required to come back to the country and work for various branches of the Ministry of Agriculture and the MoWR.

Although this broad range of policies has been implemented, the government has not conducted reviews to determine whether they have achieved their intended results.
At this point it would be valuable to investigate how agricultural, water, and research policies in Iraq have affected land and water salinity. Questions that need to be addressed are outlined below:

1. How have past policies in Iraq contributed to the widespread land and water salinity we currently find in Iraq? This needs to consider several areas:

    a) How do agriculture production policies affect viability of farming in Iraq and do they provide an incentive for farmers to invest?

    b) How much has the government invested in irrigation and drainage infrastructure and has there been any private sector investment in irrigation or drainage?

    c) What is known about water availability, distribution, and costs for use for irrigation? Who is responsible, who pays, and what are the objectives – equity or productivity?

    d) What types of land tenure are in effect and how do they affect government and individual investment in land?

    e) Who takes responsibility for land salinity, who is accountable? Is it the government, farmers' associations, or farmers themselves?

    f) Who takes responsibility for managing river salinity and how? What are the objectives?

    g) Who conducts agricultural research in Iraq, who pays for it, and how is it strategically planned to meet national objectives?

    h) Are policies to educate farmers and extension policies effective?

2. What are the current policies? How have they changed from the past?

3. Will current policies promote good management of land and water salinity?

4. How could policies to manage land and water salinity be improved?

Much of the above will come down to four key issues:

1. Who actually has responsibility for land and water salinity, i.e., which ministers and other bureaucrats are responsible for this issue? Are farmers also responsible? And how does this responsibility cut across jurisdictions, e.g., federal and governorate?

2. What land tenure do farmers have and how does it affect the incentive for private/farmer investment?

3. Does the total of agricultural, water and land policies provide incentive for farmers to invest in their lands to increase production?

4. Is government investment in irrigation and drainage infrastructure sustainable? What are the ownership, management, and maintenance issues?

7 The Future for Salinity Management – An Integrated Approach

Iraq has had a broad range of policies for agriculture and water management with varying objectives. It is now time to investigate whether these can help resolve the current salinity problems.

There is a growing awareness of the link between plot, command area, and regional/catchment salinity issues, and this has led to a re-evaluation of salinity management strategies. In particular, all costs of salinity mitigation actions are need to be fully accounted considered in when decisions related to investment in change are being made; that is, all costs and benefits are internalized into the decision. This is especially required where linkages between decisions about the use of engineered drainage to reduce and manage the impact of salinization on local irrigated farmland (perhaps at the command-area scale) can impact on, and the adverse effects of drainage disposal on the downstream water resources (at the catchment scale).

Salinity management in Iraq needs to incorporate actions at various scales:

- Basin scale (within Iraq): Salinity management frameworks, institutional arrangements, investment decisions.
- Irrigation project scale: Irrigation project management.
- Farm scale: Farm-scale intervention and adaptation.

Funds to invest in salinity mitigation activities at the national or catchment scale are usually limited, which calls for careful decisions about how they are best spent. Short-term plot-scale solutions generally have a tendency to incur costs elsewhere that can sometimes outweigh the initial investment.

A key step prior to in the investment process is to decide on the criteria to be used to evaluate investment so that all costs and benefits are considered, thus ensuring those investments with positive returns (or with the best national outcome) are recommended. It is immaterial whether the decision is market based or taken from the point of view of national interest; the outcome is still usually the same in that the most efficient and beneficial investments are the best. The key is to develop a set of values/objectives that guide the decision-making process. Where integrated salinity management has been implemented successfully (and there are few instances where this has occurred), decision making has taken account of economic, social, and environmental concerns at a scale that reflects all the major costs and benefits likely to accrue.

The approaches to investing in salinity management generally need to cover three interrelated component strategies: recovery, containment, and adaptation. These need to be implemented within an overall salinity-management framework in order to ensure that upstream and downstream effects are considered and the best financial investments are chosen. A key step in the process of salinity management in the irrigated areas of central and southern Iraq will be to develop the management framework so that it incorporates all the issues that are important to the Government of Iraq and the various key stakeholders involved.

7.1 An Example: The Murray–Darling Basin, Australia

The Murray–Darling Basin is the Australian food-bowl and is a major contributor to Australia's important and burgeoning food export markets. The basin is home to unique and environmentally significant natural features such as wetlands and forests, many of which are subject to international treaties. More than two million people directly depend on the natural resources of the basin for their livelihood, and their future prosperity is dependent upon its sustainable management. This is at risk from salinity. Under current trends, future basin-wide salinity impacts will be so large that it will not be feasible to contain or reduce them in all "at risk" areas. The high cost of salinity prevention and rehabilitation will prohibit protection or restoration of natural resource values in all parts of the basin.

The problem of salinity is addressed through the Basin Salinity Management Strategy (BSMS) (MDBMC, 2001) and its predecessor, the 1988 Salinity and Drainage Strategy (S&D Strategy).
The BSMS aims to:

- Maintaining the water quality of the shared water resources of the Murray and Darling Rivers.
- Controlling the rise in salt loads in all tributary rivers of the Murray-Darling Basin.
- Controlling land degradation and protecting important terrestrial ecosystems, productive farm land, cultural heritage and built infrastructure.
- Maximizing net benefits from salinity control across the basin.

In the middle 1980s, upstream state governments in the Basin recognized that future irrigation viability would rely on the installation of drainage systems to control the high water tables that existed across large areas of irrigated land, and it was assumed that the drainage water would be disposed of to the rivers. Meanwhile, the downstream state government was concerned by the increasing trend in the salinity of the river water, water they used for domestic drinking water. The two requirements were seemingly incompatible and led to tension between the parties. The S&D Strategy was an agreement that set out the framework for salinity management that allowed upstream governments to drain irrigation areas on the proviso that they co-invested in salinity mitigation elsewhere. Effectively, the strategy was a pollution-trading scheme that enabled mitigation options to be assessed against a common basis – a cap on salt in the river at a specified point at the downstream end of the system.

The BSMS incorporates key elements of using targets, managing risk, understanding accountability, and dealing with water quality and salinity issues in a whole-of-basin approach. This means that in different areas, careful choices need to be made between three approaches to salinity management: to attempt to reverse it; to limit its rate of spread and impacts; or to let it take its course. An overall "business as usual" approach is not acceptable.

The BSMS guides communities and governments in working together to control salinity in the Murray–Darling Basin and to protect key natural resource values within their catchments. It establishes targets for the river salinity of each major tributary valley and the Murray–Darling system itself that reflect the shared responsibility for action both between valley communities and between states.

A key feature of the 15-year strategy has been the adoption by the peak oversight group Basin operating authority of end-of-valley salinity targets for each tributary catchment and a basin target at Morgan in South Australia, at the end of the river system itself. The basin target is to maintain the salinity at Morgan at less than 0.8 dS/m for 95% of the time.

The strategy provides a stable and accountable framework that, over time, will generate confidence in how we are tracking our joint efforts to manage salinity.

Salinity of the Murray River has been significantly reduced, while at the same time rehabilitating degraded lands and allowing for new irrigation development. This was made possible by limiting the amount of salt entering the river through construction of salt-interception schemes, and due to the effectiveness of state salinity action plans and land and water management plans.

An important feature of the basin salinity target at Morgan is that it is supported by a system of salinity credits and debits. This generates a consistent currency – "EC units" or units of salinity at Morgan – through which trade-offs and basin-wide accountability can be accommodated.

While the essence of this strategy is to cap salt mobilization and export from across the basin landscape, thereby avoiding the need for further salt-interception schemes, it is clear that this is achievable only in the longer term. In the short term it is necessary to continue with salt-interception schemes to buy time for the benefits of actions to cap salt mobilization and export from the landscape to take effect.

A new joint program of salt-interception works was undertaken over the first seven years of the strategy. The aim was to maintain benefits to water users drawing on the shared rivers, and to provide an additional contribution to preserving water quality as measured at Morgan, beyond that deliverable by actions addressing the "legacy of history" within the tributary valleys. There will be provision to offset impacts of further, new irrigation development. There is also an incentive under this strategy to develop other, complementary mitigation works.

This approach of developing a management framework with target values of salinity at key points is highly applicable to managing the salinity in the Tigris and Euphrates rivers in Iraq. This type of approach allows for strategic planning and investment that aims to achieve specific goals and allows for the prioritization of investment to activities with most benefit to achieve those goals.

8 Conclusions

Effective salinity management in the irrigated areas of central and southern Iraq requires a management framework that incorporates all the issues that are important to the Government of Iraq and the various key stakeholders involved.

Irrigation water in Iraq is not being used to its full potential because of the poor state of the country's irrigation infrastructure and soil salinity. Tackling these problems is a priority if the country is to make best use of its water supplies.

Its irrigation systems will have to be modernized, but the country also needs farm-level water-management strategies, improved salinity control and irrigation management, and enabling water-use policies and institutions. Previous attempts to cope with or mitigate the effects of salinity have focused almost exclusively on field drainage, which is a highly expensive and technical proposition. The use of field drainage must be prioritized within a comprehensive framework that analyzes the costs and benefits of this and other approaches and the upstream/downstream impacts of interventions.

Addressing Land Salinity:

Investment in salinity management at the farm scale needs a strategic focus. Salinity in central and southern Iraq is so pervasive and severe that impacts on farming systems will be inevitable. To policy makers, the situation may appear overwhelming. Investment of human and financial resources will appear to be required everywhere, funding and human resources will probably never be available to address all the problems, and focusing equally in all areas where there are problems is unlikely to give the best long-term outcomes.

We suggest that there should be a strategic focusing of the limited resources available in Iraq to areas where they will achieve the greatest good as soon as possible. Moderately saline irrigated land will benefit strongly from investment in better drainage infrastructure and from improvements in the salt tolerance of the currently grown crop species. In the more highly saline irrigated areas, we expect that mixed production of vegetables, cereals, and high-value fodder will be replaced by growing salt-tolerant forages and that the farming systems will be dominated by livestock production. Investment for this kind of land needs to focus on issues related to the transition towards livestock production, e.g., on the development of extension packages focusing on ways to maximize animal performance using salt-tolerant forages and fodders, and research and development on the introduction and development of forage with higher nutritive value that complement existing feeding systems. Finally, there will be some landscapes that are severely saline: these should not receive investment for reclamation. This land is not likely to be ever recovered for irrigated farming, and investment should be targeted to identification of drought-tolerant halophytic shrubs that can prevent this land from becoming desertified and that can provide feed for livestock. Australian experience would indicate that these areas may in time partially rehabilitate and salt-sensitive plant species will eventually return if grazing is managed.

Highly saline land is still capable of growing high yields of forages. In highly saline areas agriculture will become increasingly dominated by the production of forages for the use of livestock. In severely salinized regions, vegetables and grain may have to be imported from other regions and farmers may need help in developing new skills in forage conservation and improved livestock management. Farmers vary in their ability to obtain production from saline landscapes. Management practices are important in achieving production from saline land and these can be communicated to other farmers.

Effective solutions to soil salinity require changes to land-use practices and production activities over whole districts. In order to improve farm water productivity under saline agriculture, it will be necessary to address rehabilitation priorities as they relate to soil- and water-salinity problems, create mechanisms for direct farmer participation in the development, evaluation, extension, and monitoring of technologies, and highlight livelihood-enhancing and employment-generating opportunities for farm families. This needs to include planning for livestock production associated with irrigated areas and saline lands. Livestock production can be a major source of income for the poor and thus rehabilitation systems that aim to integrate irrigated cropping and livestock production may have major benefits for disadvantaged people in areas with declining cropping systems.

Addressing River Salinity:

It is critically important to reduce the salinity in the Tigris and Euphrates rivers, especially in the lower reaches. This is critical not only for agriculture but also for the communities that rely on these rivers for their drinking water and other needs. Most of the increase in the salinity of these rivers occurs within Iraq; the salinity of water entering Iraq appears to have been stable since the 1980s. This provides excellent opportunities for the Government of Iraq to invest in measures that will halt and even reverse the salinity trends in these rivers. These actions need to be undertaken soon and within a comprehensive framework that prioritizes those measures that result in the greatest benefit for least cost.

Future Investment:

The Government of Iraq needs to invest in key areas: research, management frameworks, policy development, infrastructure, and education/training and extension. This project will work on developing aspects of these investment requirements in the next 12 months with a view to determining key investment decisions for future effective management of salinity in Iraq.

Future Requirements to Manage Salinity

1. The need for a strategic approach to the rehabilitation and reclamation of saline irrigated areas, based on the recognition that some areas will strongly benefit from investment, benefits will be limited in some areas, and it may not be possible to restore irrigated agriculture in some areas. Farming systems may have to change according to land capability. This approach will help direct funding and human resources to the places where they will deliver the greatest impact.
2. The need for an integrated approach to resolving the salinity problems. This should start with the development of a salinity management framework for the surface waters of the Mesopotamian plain.
3. Surface-water salinity must be controlled by tackling the major sources of surface-water salinization within Iraq.
4. Irrigation and drainage systems should be rehabilitated concurrently. The work should be conducted within the salinity management framework, and based on analyses of upstream/downstream impacts, costs and benefits. Funding should be targeted to maximize the return on investment and speed of return on investment.
5. The need for an increased testing of salt-tolerant crops (for mildly to moderately saline areas) and forages (for moderately to highly saline areas). The nutritive value of forages and their fit within existing, new, and evolving feeding systems should be considered when introducing new species.
6. An integrated and multidisciplinary approach to the salinity problem is required. Tackling the problem from one approach, one scale, or one area alone will not result in a sustainable solution.
7. There needs to be strong co-ordination between the Ministry of Water Resources, the Ministry of Agriculture, and other ministries to tackle the salinity problems within an integrated catchment approach. A multidisciplinary approach is essential.
8. Managing the salinity problem in Iraq requires a cyclical process ((plan–act–review–plan) at all levels. Actions must be strongly driven by the need to achieve rapid improvements on the ground and should be evaluated continuously for improvements.

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